

THE FACE OF THE EARTH

(DAS ANTLITZ DER ERDE)

BY
EDUARD SUESS

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PREFACE TO VOL. III

As an indication of the esteem felt for the veteran author of the 'Antlitz der Erde,' the revision of the translator's rendering of this third volume has been undertaken by a number of geologists representative of all parts of the English-speaking world.

England is represented by Sir Archibald Geikie, the Rev. Prof. T. G. Bonney, Dr. J. J. H. Teall, Prof. Charles Lapworth, and Prof. W. W. Watts; North America by Prof. T. C. Chamberlin; India by Mr. R. D. Oldham; South Africa by Dr. A. W. Rogers; and Australia by Prof. T. W. Edgeworth David. If it should seem that England itself plays too great a part in this list, a sufficient explanation will be found in the exigencies of time and space.

Notwithstanding the assistance I have thus received, I have not relaxed my own efforts as editor, and I have found it necessary to make frequent re-revisions in order to preserve some continuity and uniformity of style. Thus my responsibility remains unimpaired, and whatever improvement may be discerned in the translation of this volume must be attributed to the revisers; any defect, on the other hand, to me. The task of turning German into English is a peculiarly difficult one, owing to a natural tendency of the English to revert to a Teutonic form.

The reverence due to a great classic has restrained us in this, as in previous volumes, from taking any liberties with the text, whether by comment or emendation. Our sole aim has been a faithful rendering. The extraneous matter of this preface would not have been inserted had it been possible otherwise to make known the tribute which the work of the revisers is intended to convey.

W. J. S.

OXFORD,

August, 1908

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PART IV

THE FACE OF THE EARTH

CHAPTER I¹

INTRODUCTION

Analysis of the subject. Attempt to determine a plan of the trend-lines. General folding of the oldest rocks.

WE began our study of the face of the earth by imagining an observer to approach our planet from outer space and, pushing aside the clouds of the atmosphere, to contemplate the surface of the globe rotating beneath him. We then supposed that this observer, as he had previously pushed aside the clouds, was now able to remove the sea, so that he could gaze directly on the bare rocky crust and on the great abysses of the Ocean.

Let our observer now turn aside his glance. Another globe, the moon, shines beside him, illuminated on one side only. In its case no clouds need to be displaced, no ocean removed, and although one half is averted and invisible, yet there is no movement of rotation to disturb the tranquil scene. Sharp shadows reveal the presence of gigantic walls of scoria on the borders of so-called 'seas'; he perceives vast circular areas, such as the Mare Crisium, and lofty ring-like forms, such as Aristotle, Copernicus, and a crowd of others which recall in some respects the terrestrial volcanos of Hawaii; and on the greater circles there are seated, like parasites, smaller circles, evidently of later origin. Finally, our observer succeeds in discovering signs of the progressive solidification of the scoriaceous crust—fissures of contraction, crater rills—and he recognizes an increasing resemblance to the eruptive volcanos of the earth.

At the same time he cannot fail to be impressed with the points of difference which distinguish the face of the moon from that of the earth.

Not only are there no clouds or seas on the moon, but its surface, covered with glassy débris, reveals none of those changes which result from the action of an atmosphere and water. Of stratified deposits there is no sign.

Again, the moon is without those long, continuous systems of folds which form the mountain chains of the earth. There is nothing, for example,

¹ Revised by Sir Archibald Geikie, K.C.B., D.C.L., Pres. G. S., Sec. R. S.

which could be compared to the marginal arcs of Eurasia; and those lunar features which have been named after the Alps, the Apennines, and the Caucasus are ramparts of scoria, having nothing in common with their terrestrial namesakes, save the name.

So great is the part played by stratified deposits in the structure of the earth's crust that we might be tempted to speak of the *stratosphere* of the earth in contradistinction to the *scoriosphere* of the moon. Yet on our planet also we see extensive regions covered by recent rocks, directly consolidated from molten material, as well as analogous rocks of greater age, such as granite, exposed over wide areas by denudation of the stratosphere, and the mutual relations between the molten rocks and the stratosphere present one of the most important problems connected with the structure of our mountains.

The distribution of existing volcanos is alone sufficient to show this. It is obvious that the volcanos of the Aleutian islands, the Kuriles, Java and Sumatra, the Lesser Antilles, and others, are situated on circular arcs which are in a manner indicated by the course of folded mountain-chains. It is equally clear that the volcanic line of Mexico, the volcanic lines of Central America, and those of the Ethiopian fault-troughs, cut the folds of the adjacent ranges at all angles and maintain an absolutely independent course.

We are thus led to recognize a distinction between *longitudinal volcanic lines* and *independent volcanic lines*, and so discover at the very outset the impossibility of considering folds and volcanos apart from one another.

Nevertheless so great is the variety of the phenomena presented by the face of the earth that any endeavour to arrive at a general view of the whole necessarily involves some kind of classification. In a preceding chapter we arranged the dislocations of the crust in two classes, one containing those due to folding, the other those due to subsidence. Adhering to this classification, we shall treat in the following chapters chiefly but not exclusively of folding, while the closer consideration of fracture, shearing, and subsidence, as well as the relations of the molten rocks to the stratosphere, will be reserved for a later part of this work.

The study of folded ranges by means of transverse sections has recently been marked by great progress, and attempts have even been made, with more or less success, to reproduce by experiment the conditions as they are presented in nature. The object of these experiments has always been to obtain sections similar to those which have been observed in the field. Yet at the same time the investigation of nature itself has shown that even the boldest hypotheses, advanced only a few years ago, as to the extent of horizontal movement, stop far short of the reality. Reyer has represented folding as a flowing of the rocks. When geologists in France and Switzerland, with Marcel Bertrand at their head, had proved the existence of isolated fragments of recumbent folds, or 'lambeaux de

recouvrement,' the word 'écoulement' came into use to designate the kind of folding which has produced these structures. Finally, cases have been discovered in which the folding has become only a secondary phenomenon, the tangential movement having taken place along one or more extensive thrust-planes.

A study of the mountain chains in transverse section is, however, only one part of our task: we must also investigate them in horizontal projection, i.e. in plan. There was a time when every single anticline of the Jura was regarded as an independent axis of elevation; then it became clear that such a collection of parallel anticlines must have a common origin; next it was seen that there is a certain dependence between the Alps and the Jura; finally, the influence of the obstacle presented by the Black Forest was recognized, and it became evident that the Alps and the Jura were only parts of the southernmost, innermost, and most recent of three crescentic systems of folds which have arisen one after the other across Central Europe since the close of the Silurian epoch. Thus with our increasing knowledge we are led to the conception of units of a continually ascending order, and the several anticlines of the Jura now appear to us as parts of an organic whole.

To continue this method of synthesis, to group the folded ranges together in natural units of a still more comprehensive character, and to explain by means of a single simple expression as large a part as possible of the terrestrial folding—such is the task which now awaits the geologist. The *plan of the trend-lines*, written by nature on the face of the earth—this it is which he has to determine.

In the southern hemisphere the space covered by the sea is so great, and our knowledge so incomplete, that we can scarcely expect to arrive at any important conclusions. The present investigation is therefore almost exclusively confined to the northern hemisphere, and more especially to that region which lies north of the southern boundary of Eurasia and of the Caribbean sea.

Even in this case the task is difficult enough!

Such simple conceptions as those of tableland and chain, the contrast between which forms the basis of many an excellent description of a country as regards its external aspect, certainly possess some morphological value; but this contrast loses its sharpness when we proceed to a closer examination of tectonic characters. Great tablelands no doubt exist, such for instance as those formed of Cretaceous limestone or Karoo sandstone, but beneath these tablelands are to be found, always and everywhere, folded rocks. The folding may only occur at a great depth, but that it is nowhere absent appears from the fact *that all the Archaean rocks of the earth have suffered folding or an equivalent compression.*

As examples of this fundamental and well-known fact we may mention

the Baltic buckler and the Canadian shield, and the discordance to be seen in so many places of Cambrian sediments lying horizontally on previously folded rocks, as well as the unconformities which occur between the several members of the pre-Cambrian series.

If folding involves compression, we might from this fact alone conclude that the planetary surface had suffered diminution. But it is not this circumstance which now claims our attention, but rather the fact that folded ranges had been already levelled down in times preceding the Cambrian. When these worn-down ranges are covered by undisturbed Cambrian strata as in the vicinity of St. Petersburg, we are compelled to conclude that the ancient folding has not been continued or renewed since an extremely remote period. In these regions, as compared with those where recent sediments are involved in the folding, it would seem that the earth is slumbering or as if the folding force had become extinct.

From this we perceive too *that the folding force was once active over the whole globe, but is restricted at present to particular regions.* The plan we are seeking will therefore embrace fragments of different age, and it is even possible that we may encounter fragments of several dissimilar plans.

In the preceding chapters we have only examined isolated portions of a plan of the trend-lines without bringing them into connexion, and it is their isolation which renders these fragmentary results so enigmatical. Of the results so far ascertained I will recall first, on account of its geographical importance, the contrast between the Pacific and Atlantic types of coast (II, p. 201). We ask by what strange peculiarity in the structure of the earth's crust can we account for the fact that from cape Horn and Staaten island to Greenland, to the cape of Good Hope, and again to cape Comorin and the mouths of the Ganges, the coast of the mainland is nowhere accompanied by trend-lines of folding, while from the mouths of the Ganges eastwards to cape Horn such trend-lines follow the coasts or determine their outline. We perceive plainly that the east coast of Australia exhibits the Pacific type of structure, the west coast the Atlantic type; similarly, the east coast of South America belongs to the Atlantic type and the west coast to the Pacific. But this is not all: the arc of the Lesser Antilles and the arc of Gibraltar, lying almost symmetrically, are bent completely round as they approach the Atlantic region, as though some unknown and mysterious force prevented their entry into this domain.

The basin of Asturias shows us indeed that before the formation of the arc of Gibraltar a similar recurvature occurred eight degrees further north (II, p. 128), and that the existing course of the arc of Gibraltar is a repetition of that of the older arc of Asturias. But it is hard to conceive how such a curve could be formed a second time, unless we assume the existence of some kind of wave propagating itself freely through the crust of the earth.

More to the north the state of things is altogether different. Folded chains advance to the Atlantic coast, but sink beneath the sea. This is the case in Brittany and the south-west of Ireland; and, on the other side of the Ocean, in Newfoundland and New Brunswick. The rias coasts of these regions afford a contrasting element to the recurved arcs of the south.

These relations indicate a certain symmetry between the east and west of the Atlantic Ocean, though it is disturbed in a very remarkable manner, for two elements appear twice over on the European side, which are only represented once in America; these are the rias coast of Brittany and that of the Pyrenees, and next the arc of Asturias and that of Gibraltar (II, p. 141).

When we leave the coast for the interior of Europe we are first impressed by the repeated reconstruction of this extremely complicated part of the world. The gneisses of the Hebrides were folded and levelled down before the Torridon sandstone was deposited upon their remains. Over this sandstone the Caledonian mountain-flakes were thrust from the south-east in pre-Devonian times. Towards the close of the Carboniferous epoch the folding of the Armorican and Variscan arcs took place. When these arcs had been broken up into horsts there occurred still further to the south, and hemmed in by these horsts, the formation of the Alps. In this way the structure of Central Europe has been renewed again and again, and at the same time its mountain border has receded further towards the south (II, p. 130).

While, however, this repeated reconstruction, from the Caledonian up to the most recent folding, has always been produced in an almost similar manner by means of a movement to the north, and the old plan has been constantly maintained and renewed, yet in the Caucasus this is no longer the case, but something quite opposed. The direction of this range is almost perpendicular to that of the Ural mountains, and towards the south it also diverges decidedly both from the trend of the Tauric and that of the Iranian arc. It runs obliquely past the syntaxis of these two great arcs (I, p. 495) with unchanged direction. In this case we can hardly speak of unity of plan, and yet it is precisely the Caucasus which unites the branches of the Thian-shan with the more recent trend-lines of Central Europe.

The scene changes when we pass to the sharp boundary which runs from the Wady Draa on the Atlantic coast to beyond Java, and separates Eurasia from the districts to the south. The arcs which form this limit, all bent towards the south, again indicate the connexion of the different parts of this vast region: if we cast a glance over the east coast of Asia, over the successive island festoons and the archipelagos, more numerous on this coast than any other in the world, then the conclusion is inevitably forced upon us that this engirdling of Asia must have been produced by some common cause.

These examples and questions must suffice. They show that of the facts we have been able to discover regarding the lie of the trend-lines, the greater part and the more important refers to Europe and the periphery of Eurasia. A combination of our fragmentary knowledge, however, or any kind of synthesis, was still impossible when the second volume of this work appeared, because those central parts of Asia where the junction of the arcs must be sought, namely Siberia and Mongolia, were almost completely unknown. It is only the latest discoveries of Russian investigators which have now made such an attempt possible. Even to-day, and notwithstanding the assistance of many eminent geologists, this attempt is made only with the express reservation that it will be subjected later to much correction.

The nature of the task which now lies before us renders it inevitable, however, that the descriptions which follow should be very unequal. It will be necessary to treat less-known regions, especially such as have as yet received no general description, in some detail, while in other cases it will be sufficient to refer to documents which have already been published.

CHAPTER II¹

THE NORTH OF SIBERIA

Asia. The Amphitheatre of Irkutsk. The West Siberian plain. Transgressions of Turgai. Succession of rocks in the East Siberian tableland. The river Angara. Gondwana-land, the Tethys, and Angara-land. Marginal folds. Granite of Nishni-Udinsk. Stony Tunguska. Lower Tunguska. North Yenisei. The table-mountains of the watershed. Vilyui and Lena. Summary.

THE uniform structure of the Asiatic mountains has been recognized by all the most eminent authorities on this part of the world, and has been variously described according to the point of view of each observer. In Siberia, Semenow speaks of a succession of terraces; the Gobi together with the Khingan forms the highest step, the country of the Amur with Sikhota-Alin the second, the sea with its island-arcs the third. In China, Richthofen was impressed with the idea that the whole country sinks in great flexures to the Pacific Ocean. In Japan, Naumann compares Asia to an elevated dome-like protuberance surrounded by peripheral fractures. As one stands in front of the overfolded chains of the Himálaya, says Griesbach, there seems to have been a movement of the whole mass of Asia towards the south.

Let us now unroll the map of Asia.

Fragments of arcs are visible in the east, both on the coast and in the festoon of islands; other fragments appear in the south; and again on the Ganges, on the Indus, and further towards the interior, in Persia and in the western Kuen-luen; then follow the divergent branches of the Thian-shan. These arcs are of various degrees of curvature; in some places they mutually interfere, and in others they are turned aside by intervening masses, but they are obviously harmonious, that is, arranged according to a uniform plan which rules the whole and leads us to suspect the presence of a common vertex in the interior of the entire structure.

This common vertex is situated close to a crescentic fracture which surrounds the region of Irkutsk like an amphitheatre. Near the eastern border of this amphitheatre lies lake Baikal.

Let us once more attempt to obtain a general impression of the whole on the map.

Proceeding from the folded arc of the periphery towards the amphitheatre of Irkutsk we perceive that the typical forms of the mountains change as they advance towards the interior. In such infinite and

¹ Revised by Arthur W. Rogers, Sc.D., F.G.S., Director of the Geological Survey of Cape Colony, South Africa.

marvellous variety has nature placed these peaks and chains, that, just as no human eye can see them in their entirety, so no pen can adequately describe them. Yet we may distinguish on the outer border of the great structure, in the neighbourhood of the Ocean, a large number of volcanos, the mighty Kliutshev, the slender Fusi-Yama, the funnel of Krakatoa, the double cone of Barren island, and further away Koh-i-Taftan and the other great cones of southern Baluchistan. Nearer the centre follow the dazzling white glacier-draped giants of the great ranges, Gaurisankar, Mustagh-Ata, and the chains of Thibet. Then come the long bare cliffs of the Gobi,



FIG. 1. *Goletz, on the Chon-Choldoi-daban (Tunkin Alps).*
(After a photograph by Herr Jatschewski.)

rising above the Bel, i.e. a horizontally stratified foundation, which surrounds these cliffs and is sharply contrasted with them in contour. When we reach northern Mongolia we enter regions which age has deprived of their charm. From the highest crests of the Altai to the south of lake Baikal and as far as the upper Amur and the shores of the sea of Okhotsk, we see old mountain land which has either been completely worn down or broken up into horsts of low relief, or which presents characteristic 'monomorphous forms,' as Radde calls them. These are blunt rounded cones, more or less isolated or disposed in groups which, rising from a

broad plain, reach high above the limit of forest growth. Débris and boulders, with streaks and patches of snow between, cover the slopes. In Siberia they are called 'goletz,' i. e. bald heads. The peaks of the Bjelucha in the Altai mountains, Munku Sardyk on lake Kossogol, Sokhondo, and many of the loftier summits of this ancient range, assume this form to a greater or less extent. Then, beyond the sources of the Vilyui, far out in the northern desert, we meet with extensive table-mountains, the foot and slopes of which are formed of horizontally stratified early Palaeozoic sediments, while the summits are formed of sheets of basic lava. Sometimes these summits are as smooth as a table, sometimes they are broken up along joints and by erosion into a crown of wild fantastic crags around which the Tunguses weave their superstitions. Finally we reach the tundra with its flat Mesozoic transgressions, and the shores of the Arctic Ocean.

In such ways does the landscape change its form; only if it were possible to colour in the outlines and compare the sunny gardens of Buitenzorg with the yellow and terraced landscape of the Chinese loess, or with the clouds of mist which cover the frozen graves of so many noble explorers at the mouths of the Lena, only then should we gain a somewhat clearer idea of the grandeur, the diversity, and the beauty of the subject to which this and the following chapters are devoted.

The contrasts in the structure of the lands and the mountains are not less striking than those of the outward form. At the southern foot of the Himálaya lie overfolded late Tertiary beds; north of lake Baikal we meet with undisturbed Cambrian sediments which extend as far as the Arctic Ocean. Lake Baikal indeed is situated near an important boundary; south of it extend curved chains, of which the arcuate form would appear still more clearly if we were not accustomed to unite fragments of different ranges under certain traditional names, as, for instance, Stanovoi, Sayan, and Kuen-luen. North and west of the lake lies the region of but slightly disturbed beds and isolated table-mountains. Still further north, however, mountain arcs again make their appearance. There are only two of these, the arc of Verkhoiansk and the very little known and doubtful arc on the Taimar.

Thus we obtain a preliminary division of eastern Eurasia into the following regions; 1. the two boreal arcs; 2. the Siberian plain; 3. the great outer region folded in circular arcs.

The boreal arcs are sharply defined towards the plain; a part of the boundary of the arc of Verkhoiansk marks out, under peculiar circumstances, the lower course of the Lena. The Siberian plain is divided, as we shall see directly, into two distinct parts; the western moiety, the low region of the Obi, is covered by recent sediments. It is far more difficult to describe the southern boundary of the plain, on account of its diversified character.

It will facilitate subsequent descriptions if we insert here a brief

Angara : these may be traced southwards in isolated patches south of the Angara ; further by the long folded range (II, II), the greater part of which is called the east Sayan or Ergik-targak on the map, and which is continued near Krasnoiarsk for some distance beyond the Yenisei. The Munku Sardyk (*M S*) on lake Kossogol, the Alps on the Kitoia and the Tunka (III, III), form part of this range. The entire eastern part of the border is formed by the trans-Baikal mountains, which extend from the highlands on the Patom in the north (V) across the high plateau of the Vitim and its continuation in the south (IV, IV), and far to the east across the oft mentioned slope of the Yablonoi on the Ingoda and Tshita (VI, VI).

To the west of lake Baikal there lies another narrow mountain belt (*P_r*) which is closely connected in structure with the trans-Baikal mountains. It terminates against a fracture a little west of the west shore of the lake (*b, b*). This is the Khrebet Primorskii, or the Lake Chain.

All the rocks forming the border of the amphitheatre of Irkutsk are of pre-Cambrian age. All are folded. It is these mountain fragments which form the southern border of the east Siberian plain. The southern border of the western plain is of an essentially different character. There the long branches of the virgation of the Thian-shan make their advance ; the outlying parts of the plain extend between them on the Ili, the Ishu, and the Syr Darya. They may be regarded as a southern girdle without drainage surrounding the great river system of the Obi.

In front of the virgation of the Thian-shan a peculiar and independent folded range comes in, well marked west of the Irtish, and it increases in orographic importance in the Kirghiz steppes.

Having made these prefatory remarks, I will now attempt to describe the plain from the accounts at my disposal, and I shall first deal with the western part of it. The eastern plain or, more correctly, the eastern tableland, is relegated to the second place because its structure is more closely connected with the mountainous country to be discussed in the next chapter.

The boreal arc will be discussed much later, when we have explained the connexion between Alaska and the mountains of Verkhoiansk.

The West Siberian Plain. This plain is open towards the Arctic Ocean, and in the south-west lies the passage through which there was, at least for a time, a connexion between that Ocean, the sea of Aral, and the Mediterranean region of Europe. The study of this vast region is thus particularly instructive in regard to the nature of the great transgressions.

On our map the eastern Kirghiz steppe extends west of Semipalatinsk on the Irtish to Akmolinsk and far beyond. But it is too often forgotten that in Siberia the term 'steppe' as opposed to 'taiga,' primeval forest, is used, regardless of the form of the ground, for any region which is poor in rainfall and vegetation, especially forest growth.

The eastern Kirghiz steppe is a wide mountain land which rises in a few ridges to over 4,000 feet. Its western part nearly shuts off the Siberian plain on the south-west, so that towards the southern Urals only a comparatively narrow passage is left over the watershed between the Tobol and the Irgis: this is the *strait of Turgai*.

This strait has rendered possible temporary connexions between the waters of Turania and the Mediterranean.

The western limit of the plain is formed by the Ural mountains: the eastern limit must be sought near the Yenisei. Jatschewski has shown that the Archaean rocks extend from the east as far as the Yenisei and disappear close to this river along a continuous fault which runs with a downthrow to the west from the mouth of the Angara nearly as far as the mouth of the Stony Tunguska (Podkammenaja Tunguska) (*a*, *a* fig. 2) ¹.

The right bank of the river is steep and rocky; it cuts off the ancient rocks, which strike to the north-west, at an acute angle. The left bank is flat, the ancient rocks have disappeared, and over the vast region which stretches as far as the Obi we see only isolated remains of a covering of friable Tertiary sandstone, now nearly completely destroyed, standing out from under the recent alluvial deposits.

Just above its confluence with the Stony Tunguska the Yenisei becomes broader. Reefs of rock known as the 'Seventy Islands' rise above its waters. Near the village of Ossinovoi the ancient rocks reach the left bank, whence they strike away to the sources of the Taz. At this spot the downthrow terminates.

Let us now turn our attention to the sediments which fill the basin of the Obi.

Passing over Karpinski's important work on the relations of the Ural mountains to the Caucasus to be discussed later, we must now mention some results bearing on the origin of the transgressions which we owe to the labours of Russian geologists.

The middle Jurassic transgression extends from the Arctic regions across the Petchora into central Russia, and has been recognized at Cracow and as far as the most easterly part of Bavaria; it stretches southwards from Russia through the Turanian depression to Baluchistan, and surrounds the

¹ L. Jatschewski, Short account of the mining district north of the Yenisei; Gornoi Journ. 1894, a, p. 127 et seq. The titles of works which have appeared in Russian are given here in English. In the case of independent works this is indicated by the addition of the letter 'r,' in the case of periodicals this indication has been regarded as superfluous. The abbreviation 'Djel. Dor.' refers to the accounts of geological observations made along the Siberian railway. The transcription of place-names has given rise to much difficulty; for *ж*, *дж* has been chosen. Where round numbers are given in feet the English foot is meant (=0.3048 meter). The verst (=1066.79 meters) is frequently employed.

shores of the Indian Ocean. This transgression is up to the present unknown in western Siberia.

Nikitin has given a connected account of the facts and has shown conclusively that the sea of the Volga stage came from the north, while the transgression of the middle and upper Cretaceous came from the south and west, across the plains of European Russia¹.

Sokolow has shown that during the close of the Eocene period, and at all events during lower Oligocene times, there existed in southern Russia a wide sea which communicated freely with the lower Oligocene sea of north Germany. This sea retired before the epoch of the Poltava stage, i.e. before the time of the amber forests².

The last transgression of the Arctic Ocean which left traces in the most northerly parts of Russia was certainly of northern origin. It is more recent than a considerable part of the glacial period.

The present course of the Tobol marks the direction of the ancient connexion of the waters through the strait of Turgai. The rivers flowing from the left to join its upper course show that the rocks of the Ural mountains still occur at a trifling depth far to the east of the mountain border and maintain their usual strike. At a considerable distance above Kustanai, and above the confluence of the Ajat, Krasnopol'ski observed porphyry, porphyrite, and Devonian rocks on the Tobol; and on the Ajat, between Nikolaievsk and its mouth, porphyry, diabase, traces of Carboniferous rocks, Mesozoic plant-bearing deposits, and upper Cretaceous marine beds³.

On the Ajat the Cretaceous rests horizontally on upturned Palaeozoic beds. It contains *Ostrea vesicularis*, *Ostrea acutirostris*, *Belemnitella lanceolata*, and other fossils. Its characters are completely European. But according to existing observations, it does not extend further than the Ajat, and in complete contrast to what occurs in central Europe, no certain trace of the upper Cretaceous transgression is so far known in any part of the Siberian plain, unless, and this is very unlikely, it should prove to be represented by an extremely remote outlier, of entirely divergent character, which is situated on the Sosva in the north-eastern Urals. We shall recur to this outlier directly.

After the Cretaceous epoch the Tertiary seas advanced through the strait of Turgai. Wissotzki has given an instructive account of the

¹ S. Nikitin, Traces of the Cretaceous period in central Russia; Mém. Com. géol. Russie, 1888, V, no. 2, maps.

² N. Sokolow, Die untertären Ablagerungen Südrusslands; Mém. Com. géol. Russie, 1893, IX, no. 2, maps.

³ Krasnopol'ski, Account of the mining section in west Siberia in 1893; Bull. Com. géol. Saint-Petersb., 1894, XIII, p. 181; and Geological observations in the basin of the Tobol; Djel. Dor., 1899, XX, 50 pp. and map. The dip of the Devonian is 60° directed SW. (255°), corresponding to a strike of NNW. (345°).

The sediments of the lower Oligocene are chiefly argillaceous and have a wide distribution. They lie in isolated patches on the northern slopes of the heights of the Kirghiz steppe, and in the valley of the Irtish they even extend as far as Semipalatinsk. They appear there as a laminated gypsiferous clay, violet-grey or variegated in colour, and contain *Cyprina*, *Fusus gracilis*, *Fusus multisulcatus*, and other species. But they also extend far to the north. Federow has found them on the Sosva beyond lat. 63° N., and they are visible east of this locality near Sureisk on the Obi, on the same parallel of latitude. It cannot be doubted that the lower Oligocene sea of Germany extended through the strait of Turgai east of the Urals, into the region of the existing Arctic Ocean.

Towards the middle or end of the Oligocene period all connexion between the seas through the strait of Turgai came to an end. The marine clays begin to alternate with beds of lignite; amber is found and white sands occur. Just as in south Russia, so here, the growth of the amber forests followed the retreat of the sea; and from that time the European seas ceased to communicate with the Arctic Ocean through the strait of Turgai.

The next horizon in western Siberia, perhaps already belonging to the Miocene, consists of thinly stratified gypsiferous clay of a brownish grey colour; it contains salt water in some places, and even gives rise to bitter lakes. This deposit is only visible in the river valleys, but in these it extends, like the above-mentioned Oligocene beds, to beyond lat. 62°N.

Then follow extensive freshwater beds of middle and late Tertiary age. The most widely distributed of these are flat-lying friable sandstones with brown coal; their flora was described by Heer as Miocene¹. These freshwater beds already make their appearance in the strait of Turgai itself, and they form a very broad border in front of the slopes of the Kirghiz steppe, extending northwards to Yalutorovsk on the Tobol, then to Kainsk, and much further still into eastern Siberia. This may well include various Tertiary stages. On the Irtish a tooth of *Mastodon tapiroides* was found, 60 versts below Omsk. The sculptured Unios which Tscherski and Martens have described as occurring near Omsk belong to the Levantine facies of southern Europe².

The glacial deposits and the beds with *Elephas primigenius* need not detain us.

The stratigraphical series in the south-west of the plain thus consists of marine beds which range from the Senonian to the middle Oligocene: they are the relics of the seas which occupied the strait of Turgai. Then follow

¹ O. Heer, *Flora arctica*, V, Mém. Acad. Imp. Sci. Saint-Pétersb., 1877, 7^e sér. XXV, no. 6.

² E. v. Martens, *Fossile Süßwasser-Conchylien aus Sibirien*, Zeitschr. deutsch. geol. Ges. 1874, XXVI, pp. 741-751; F. v. Tscherski, *Zur Frage über das Alter der in der Umgegend von Omsk vorkommenden Schichten*; op. cit. 1876, XXVIII, pp. 217-224.

freshwater beds which range from the horizon of the amber forests as far probably as the Levantine stage.

In the north the case is quite different; the most detailed accounts of this region we owe to Federow¹. From lat. 62° N., to nearly 64°, and probably still further north, green clay with geodes is exposed at the bottom of the river valleys, but seldom visible much above low water. Nikitin distinguishes two horizons in this clay according to the fossils which occur in them, namely, the upper Volga stage with *Olcostephanus Okensis* and, above it, the Neocomian. At one place on the Sosva Federow found dark argillaceous shales, or plastic clay, with numerous remains of *Baculites*. This is the outlier which was referred to above as the only indication yet known in the north of Siberia of a deposit which can be assigned to the upper Cretaceous. It is hardly possible in the present state of our knowledge to compare it more closely with the southern Cretaceous of European type (II, p. 291).

Freshwater sediments appear to be absent in this part of the northern region, which is covered far and wide by still more recent formations.

The deposits of the last Arctic transgression are known as far as Obdorsk.

Let us now briefly sum up all that is known as to the distribution of the seas. The Volga stage and the Neocomian are found only in the north. The upper Cretaceous of European type is only visible in the extreme south-west near the strait of Turgai; and adjacent to it are the doubtful *Baculites* beds of the Sosva. The upper Eocene appears in the south-west. The lower Oligocene sea united the strait of Turgai with the region of the existing Arctic Ocean. The last Arctic transgression, like those of the Volga stage and the Neocomian, is recognizable only in the north.

In the whole of this region there are no traces of a recent folding. The completely denuded folds of the Ural mountains descend on the west under the mantle of younger sediments, and extend beneath them for an unknown distance towards the east.

Succession of rocks in the east Siberian tableland. The tableland of east Siberia differs completely from the broad basin of the Obi, which is uniformly filled with recent sediments. Travelling eastwards from this basin, we meet

¹ E. S. Federow, Note on the existence of Cretaceous sediments and deposits of erratic blocks in that part of north Siberia adjoining the Ural; Bull. Com. géol. Russie, 1887, VI, pp. 439-450; Fresh observations on the geology of the north Ural; op. cit., 1889, VIII, pp. 7-17: for traces of the Jurassic, Gorn. Journ., 1897, II, p. 384. We may mention here that F. Schmidt quotes the isolated occurrence of a specimen of *Micrabacia coronula* Goldf. in diluvial clay from the Korepovskoje Simorje on the lower Yenisei, and concludes that the Cenomanian possessed a greater distribution in the north; Mém. Acad. Imp. Sci. Saint-Petersb., 1872, XVIII, no. 1, pp. 2, 3, 25, 162, pl. 11, fig. 10. But I do not know of any other indication of this kind within the whole Arctic region.

with Archaean rocks on the Yenisei which belong to the border of the amphitheatre of Irkutsk (Fig. 2); and within this the eastern tableland commences. It is bounded by the walls of the amphitheatre on the south-west, south, and south-east, and by the arc of Verkhoiansk on the north-east. From the north-west the Taimyr range encroaches on it, and to the west and east of this range it reaches the Arctic Ocean in comparatively narrow strips.

In the south of this region rise broad unbroken ridges, often completely covered by gloomy primeval forest and marsh; then come, particularly on the watershed between the Yenisei and the Lena, table-mountains with steep slopes, reaching as a rule a height of 600 to 700 meters above the sea. Still further north lies the limit of forest growth and the frozen tundra.

Great rivers, heavily laden with ice, traverse this region, flowing westwards to the Yenisei, eastwards to the Lena, and northwards to the Arctic Ocean. Probably the greater part of the basin of the Aldan must be regarded as an extension of this tableland. The valley of the Lena, excavated more than 300 meters deep over long distances, belongs to the tableland, with the exception of its lowest part, which is imprisoned, so to speak, in the folds of Verkhoiansk. The same is the case with the Olenek. The Anabar and Chatanga reach the Arctic Ocean direct from the tableland. The three Tunguskas represent the drainage of the west, and the Vilyui that of the east.

From the border of the mountains south of Irkutsk (lat. 52° N.) to the mouth of the Anabar (beyond lat. 73° N.) this tableland includes more than 21 degrees of latitude.

Four elements take part in its structure.

The first is a broad *Palaeozoic platform* which in all probability underlies the whole region from the extreme south to the Arctic Ocean. It forms the lower part or even the whole mass of the mountains, and indications of it may be seen in most of the river valleys. It begins with the equivalents of the lower Cambrian or *Olenellus* beds; limestone plays a prominent part, but a series of red sandstones and variegated marls, with gypsum and salt, may also be observed, which, according to Von Toll's investigations¹, must be assigned to the lower Silurian; they are thus distinct from the gypsiferous and salt-bearing beds which are exposed near Minusinsk outside this region, these latter being Devonian in age.

The great platform is to some extent formed of absolutely horizontal beds. But near the border of the amphitheatre true folding appears, and

¹ Baron Eduard von Toll, On the distribution of the lower Silurian and Cambrian in Siberia, Verh. russ. k. min. Ges., 1895, XXXIII, pp. 273-281, and N. J. f. Min. 1895, II, pp. 157-166; Beiträge zur Kenntniss des sibirischen Cambrium, Mém. Acad. Imp. Sci. Saint-Pétersb., 1899, 8^e sér., VIII, no. 10.

it increases in intensity as the border is approached. Towards the middle of the amphitheatre the folding becomes very weak, and throughout the rest of the platform the beds are scarcely disturbed at all. According to existing observations the foundation underlying the Cambrian sediments is nowhere visible, except where it is exposed as a patch of altered clay slates, which Tschekanowski found beneath the Cambrian beds at Djedaïsk in the eroded channel of the Lena above the confluence of the Patom.

On this platform of Cambrian and Silurian sediments, especially over its southern half, rest several larger and smaller patches of *plant-bearing beds*, which are the second element in its structure. They show that the greater part of the platform has not been covered by the sea for a very long period. They consist of sandstone and conglomerate, more rarely of shales, and are frequently accompanied by workable 'coal measures. *Asplenium Whitbyense* is met with in very many localities, but it is by no means clear that all these outliers are contemporaneous. Oswald Heer assigned them to the middle Jurassic. Since then many opinions have been expressed as to their age; the patches representing their prolongation to the south, which lie within the Altai mountains, reveal many points of resemblance to the floras of the Indian Gondwana-land, and in this region Zeiller has assigned them, in part, to the Permian¹.

Patches of these beds appear not only on the east Siberian tableland as far as the foot of the arc of Verkhoiansk, but also extend far into the interior of Asia. We shall be able to trace their various floras through Mongolia and over great parts of China and Japan. In the south of China the 'red beds'

¹ The literature is very extensive; I will only mention: O. Heer, Beiträge zur Juraflora Ostsibiriens und des Amurlandes, Mém. Acad. Imp. Sci. Saint-Petersb., 7^e sér., XXII, no. 12, and Nachträge zur Juraflora Sibiriens, gegründet auf die von Herrn Richard Maak in Ust-Balei gesammelten Pflanzen, op. cit., 7^e sér., XXVII, no. 10; Schmalhausen, Beiträge zur Juraflora Russlands, Mém. Acad. Imp. Sci. Saint-Petersb. 1879, 7^e sér., XXVII, no. 4; O. Feistmantel, Further Notes on the Correlation of the Gondwana-Flora with other Floras, Rec. Geol. Surv. India, 1880, XIII, pp. 190-193; C. Kosmovski, Bull. Soc. Nat. Moscou, 1891, nouv. sér., V, pp. 170-177; R. Zeiller, Remarques sur la flore fossile de l'Altaï, Bull. soc. géol. de Fr., 1896, 3^e sér., XXIV, pp. 471, 487.—*Rhipidopsis ginkgoïdes* appears here, also on the Petshora, in the Barakar beds of India, and in the province of St. Luis of the Argentine Republic; Zeiller, Bull. soc. géol. de Fr., séance du 15 juin 1896, p. cix. Opinions as to animal remains are no less divergent; Brauer, Redtenbacher, and Ganglbauer, Fossile Insecten aus der Juraformation Ostsibiriens, Mém. Acad. Imp. Sci. Saint-Petersb., 1889, 7^e sér., XXXVI, no. 15. These authors find that the insects occurring at Ust-Balei on the Angara, and associated with the plants described by Heer, show the greatest resemblance to those of the Lias; one species is identified with a species from the Stonesfield slates. Rohon, Fossile Fische vom oberen Jenissei, Mém. Acad. Imp. Sci. Saint-Petersb., 1889, 7^e sér., XXXVI, no. 13, places fishes from Medwjesko, near Atshin, in the Devonian; A. Smith Woodward, On a new Palaeoniscid fish from Siberia, Ann. Mag. Nat. Hist., 1893, 6th ser., XII, p. 286, has examined the same specimens and assigns them to the Permian or Trias; cf. also, Rohon, Ostsibirische Fische, Mém. Acad. Imp. Sci. Saint-Petersb., 1890, 7^e sér., XXXVIII, no. 1; Becker, Ostsibirische Jura-fische, is inclined to place Ust-Balei in the Lias.

of the Red basin, and in the north of China the 'supra-Carboniferous sandstone' of Richthofen, must be assigned to them. The latter extends above the snow-line in the Nan-shan, for the boundary of these continental sediments does not coincide with the boundary of the great mountain chains. They also reappear on an extensive scale in the west, as in Persia and on the east border of the Ural mountains, and they penetrate into Europe.

This is not the place to discuss the question of the age of the several floras. Most of them probably belong to the Jurassic formation; some are of Rhaetic, others probably of Permian age. In Japan they extend into the Cretaceous formation. Generally speaking, our knowledge of these floras is now in much the same state as that of the various floras of Gondwana-land once was, before their classification had been seriously attempted.

Gondwana-land is bounded on the north by a broad zone of marine deposits of Mesozoic age. This zone extends from Sumatra and Timor through Tongking and Yunnan to the Himálaya and the Pamir, Hindu Kush, and Asia Minor. It must be regarded in its entirety as the relic of a sea which once extended across the existing continent of Asia. It was termed by Neumayr the 'central Mediterranean,' and we shall speak of it in the following pages as the *Tethys*. The existing Mediterranean of Europe is a remnant of the *Tethys*¹.

The plant-bearing beds of China, Mongolia, and Siberia of which we have just spoken bear witness to the existence during Mesozoic times of a second great continent lying to the north of the *Tethys*. This ancient continent we may name *Angara-land*, after the important river which runs near its centre. And since very large areas of the plant-bearing beds occur on the margin of the river Angara and to the south of it, they will be termed the *Angara series*. This is not intended as a new and final designation, but rather as a provisional and neutral term, without prejudice to the definite determination of the age of its various members. It comprehends the whole assemblage of the Permian and Mesozoic floras of this continent in just the same way as the Gondwana series includes the floras in the south. The classification of the Angara series and a chronological comparison with the floras of Gondwana land must be left for future investigation.

After the disappearance of the *Tethys* a considerable area of *Angara-land*, and in particular the whole southern portion of the east Siberian tableland, was never again covered by the sea. This is shown by many outliers of beds containing brown coal, which are accompanied by Tertiary

¹ Nat. Sci., 13 March, 1893, vol. II, no. 13; E. von Mojsisovics, Beiträge zur Kenntniss der obertriadischen Cephalopodenfaunen des Himalaja, Denkschr. K. Akad. Wiss. Wien, 1896, LXIII, pp. 686-700; also Palaeontologica Indica, ser. XV, Himalayan Fossils, III, pt. 1, pp. 139-157 et passim. As regards the spelling of the name I follow a suggestion in Bittner, Bemerkungen zur neuesten Nomenclatur der alpinen Trias, 8vo, Wien, 1896, p. 18.

floras. To these must be referred the flora of Simonovo on the Tshulym described by Oswald Heer. Such Tertiary deposits extend far into the valleys of the southern mountains, and even if they are not all of the same age, yet their wide distribution proves the absence of the sea. They are the prolongation of similar deposits which occur in the region of the Obi¹.

The disappearance of the Tethys and the union of the ancient continent of Angara with the Indian fragment of Gondwana-land gave rise to the existing continent of Asia.

Standing in peculiar contrast to all the inland deposits which characterize Angara-land is the third element, namely that resulting from the *transgressions* of the Mesozoic seas, which at different times advanced from the north over the ancient platform. They contribute as little to the configuration of the east Siberian tableland as the Angara series, but they are not less interesting. According to our present knowledge, they reach their southern boundary on the middle Vilyui near lat. 62° N. Since, however, plant-bearing beds of the Angara series are known on the Lena in more northerly latitudes, we must suppose that some fluctuations occurred in the outlines of the continent during the Mesozoic period².

Toll has done much to increase our knowledge of these transgressions by repeated journeys in the Arctic Tundras. On the lower Anabara, north of latitude 72° N. and as far as the Arctic Ocean, he recognized the zone of *Amaltheus margaritatus* of the Lias, the zone of *Cardioceras cordatum* of the Upper Jurassic, the Volga stage, and the Neocomian³.

The Trias deposits, which are greatly developed in the Verkhoiansk mountains, and crop out, as we shall see later, even as far as the mouth of the Olenek, have not hitherto been met with in the region of the Palaeozoic platform. Traces of the Arctic post-glacial transgression are scattered over the whole of the most northerly part of Asia (II, p. 486).

Finally, the fourth element in the structure of this tableland consists of very extensive *outflows of basic lavas*. Sometimes they hem in the rivers between high cliffs, at others they form long watersheds, or present themselves as the scarped caps of table-mountains. They frequently

¹ Oswald Heer, Mém. Acad. Imp. Sci. Saint-Petersb., 1878, XXV, no. 6; on the difficulty of an exact determination of age see e.g. Schmalhausen, Bemerkungen über die Flora des Buchtarma-Thales im Altai, Palaeontographica, XXXVIII, p. 281.

² There is doubtful evidence as to the occurrence of Ammonites further south, on the Tshedobetz, which is a tributary of the right bank of the Angara (about long. 98° and 99° E.) and has its confluence in lat. 58° 40' N.; the specimens were destroyed when the museum at Irkutsk was burnt down; Jatschewski, Gorn. Journ., 1894, II, p. 305.

³ Baron E. von Toll, Izvestija Imp. ross. Geogr. Obsch., 1894, XXX, p. 446; Geological Sketch of the islands of New Siberia and the most important problems of Polar Exploration, Mém. Acad. Imp. Sci. Saint-Petersb., 1899, 8^e sér., IX, no. 1, pp. 10, 11. Nordenskiöld brought back a great Belemnite, probably of Jurassic age, from the island of Preobraschenski; B. Lundgren, Om en Belemnit från Preobraschenski-ön, Öfv. K. Vet-Akad. Förh. Stockholm. 1881, no. 7.

exhibit columnar jointing. The term 'Siberian Trap' is often applied to them collectively, but they are as often spoken of simply as basalt. Tschekanowski, who studied these basic flows on many long and arduous journeys, maintained their contemporaneity, chiefly on the ground of the uniform height reached by the table-mountains over great distances. Jatschewski has recently investigated the question and has also pronounced in favour of placing all these rocks, or at least a very great part of them, in a single system¹.

Correspondence in character and contemporaneity are, however, two different things, and the periods of time with which the sedimentary series make us acquainted are not defined by the same factors as those which determine the progress of great eruptive processes. Sometimes a certain chronological correspondence may be admitted, as for instance in the middle Tertiary of Hungary, where different stages are characterized by different eruptive rocks. Sometimes, however, this is not the case, but rather the contrary. The basalts of western Greenland include representatives of floras which range from the Cretaceous to Tertiary times. The basalts of Vicenza were poured out at intervals through the protracted period which extends from the lower Eocene to the later part of the upper Oligocene. The basic rocks of the east Siberian tableland extend to the mouth of the Yenisei, and it is not at all improbable that they are related to quite similar basic rocks which play an important part in Franz Josef's Land and still further north in the Arctic regions. But it will be shown later that in Franz Josef's Land, King Charles's Land, &c., and elsewhere in the north, these rocks are most probably of Jurassic age.

These mighty Siberian flows have in all likelihood a common origin. In some places at least their extrusion has persisted up to very recent times, but the date of their first appearance is unknown.

Nowhere is a volcano of any importance to be seen. The presence of small ash-cones tends rather to confirm than to refute the view put forward in recent times, especially by Michel-Levy and Archibald Geikie, that these great flows do not take place from isolated throats but from a network of fissures.

In describing parts of the tableland we shall first deal briefly with its border in the south, and then pass on to the right tributaries of the Yenisei, the left tributaries of the Lena, the Lena itself, and finally the Arctic region.

The Valley of the Angara. The border of the amphitheatre south of Irkutsk and all along the west side of the Primorskii Khrebet is no doubt

¹ Diary of the Expedition of A. L. Tschekanowski to the rivers Lower Tunguska, Olenek, and Lena in the years 1873-1875, published by the Russian Geographical Society (by F. Schmidt), 1896, pp. 171 et seq.; L. Jatschewski, Nord-Jenisseisk, Gorn. Journ., 1894, I, p. 136.

formed by a fracture. The Archaean rocks, as Tscherski recognized, are cut off across their strike; and, as Tscherski also perceived, the Palaeozoic beds of the platform lose their horizontality as they approach this fracture; they are thrown into folds which run more or less parallel with it and in its immediate vicinity these folds are sometimes very strongly marked.

In front of the Archaean mass of the Elovskii Khrebet, south of Irkutsk, the Palaeozoic beds form a syncline striking east-north-east, and are inclined at angles up to 70°.

North of the point where the Angara issues from lake Baikal the folding appears to be still more strongly marked. Near Kadilnaia (30 versts north of the Angara) the beds rise to a height of 711 meters above lake Baikal; they descend so steeply to the lake that at a distance of 1,000 meters from its shore they are still 1,100 meters above it. These Palaeozoic folds bend from east-north-east to north and then to west-north-west, as though they would follow closely the western fracture of the Archaean mass of Primorskii Khrebet. North of this region, which lies north of the bay of Uluntui, there begins an overfolding of the Palaeozoic beds in a direction pointing away from the lake. On the upper Goloustna, which separates the Onot range (*On*, Fig. 2, p. 10) from the Archaean mass of Primorskii Khrebet, overfolding also occurs, and the folding appears to extend over the whole breadth of the Onot range¹.

In the valley of the Lena also, half-way between Vitimsk and Kirensk, Obrutschew found the Palaeozoic sediments slightly folded with a north-east strike².

On the other side of the amphitheatre, west of the town of Nishni Udinsk (407 meters), an isolated mountain of hornblende granite rises from the Palaeozoic region and forms a landmark visible from far and wide. Its summit, Kruglaia, reaches a height of about 4,200 feet (1,280 meters). Idjitzki has observed contact phenomena, and has shown that the granite is more recent than the surrounding Palaeozoic rocks; he has also found another granite mass with its contact zone at a second locality about 100 versts to the north-west, in the region of Tumanshet (a tributary

¹ J. D. Tscherski, Report of the Geological Investigations on the shores of Lake Baikal, part I, *Izvestija Imp. Sibirsk. Otd. Imp. ross. Geogr. Obsch.*, 1886, XX, pp. 1-405; further, *Material for the Geology of Russia*, 1889, XIII, pp. 1-48, map, and in other works to be quoted later. Ritter, *Asia*, Geographical survey of Russia, published by the Russian Geographical Society (edited by Semenow, Tscherski, and Petz, I, 1894, II, 1895, r), gives a number of data collected from monographs on the structure of the shores of Lake Baikal; in particular, I, p. 153; II, pp. 94, 168, 176, 185, 588.

² W. Obrutschew, *Die altpalaeozoischen klastischen Gesteine des Lenathales zwischen Katschug und Witimsk*, published by the *Izvestija Sibirsk. Otd. Imp. ross. Geogr. Obsch.*, Irkutsk, 1892, 8vo, 212 pp., map; Erman had already observed these remarkable sections on the banks of the Lena in 1829; *Reise um die Erde*; Berlin, 1838, II, pp. 206, 216, 242 et passim.

on the left of the Birjussa)¹. We learn from the observations of Bogdanowitsch that the north-east boundary of the granite of Nishni Udinsk resembles a flexure, that the Palaeozoic sediments along this boundary dip towards the granite, that a patch of these sediments rests high up near the summit of Kruglaia itself, and that in the interval between the granite mountain and the Archaean border the sediments are thrown into folds².

The folds, however, are not restricted to the border of the amphitheatre.

According to Bogdanowitsch, the flexure of Nishni Udinsk is followed towards the north by faults with a west-north-west trend and then by slight undulations which extend into the plant-bearing Angara series. These, however, do not retain the original west-north-west direction, but on approaching the river Angara gradually turn round and finally assume a north-east to north-north-east strike, so that they become parallel with the trend of the Onot range, on the other side of the amphitheatre; the course of these younger folds is thus in the form of a horse-shoe, which roughly corresponds with the outline of the amphitheatre. Bogdanowitsch regards them as the result of a recent movement in an ancient direction, and thinks that a compressive force has acted from the sides towards the middle of the amphitheatre, i. e. in a general sense towards the Angara³.

The folds bordering the amphitheatre we shall in future term *marginal folds*. They are characterized by a decrease in the intensity of the folding as we proceed from the concave edge of the amphitheatre towards the interior. In contrast to the folds of the great Asiatic chains, they are *directed towards the north*. Strange to say, although overfolding occurs among them they do not form an independent chain.

The patches of Tertiary beds containing lignite always lie horizontally.

A broad region occupied by the Angara beds extends to within a short distance of the border. Stretching eastwards from Nishni Udinsk, it occurs along the Oka as far as the trans-Siberian railway line, and it is traversed by the river Angara for a considerable distance near Irkutsk. In this neighbourhood it extends along the shore of lake Baikal for a short distance, and dies away northwards in isolated outliers on the Silurian platform. Patches of basalt and Tertiary beds rest upon the Angara beds. Bogdanowitsch rightly supposes that a great inland lake existed within the amphitheatre during the Angara epoch of the Mesozoic aera.

In the west the basic flows become more continuous. They extend, for example, in a long and narrow band north-westwards from Nishni Udinsk;

¹ N. Idjitzki, Geological Exploration along the Siberian Railway in 1894, Djel. Dor., 1896, III, pp. 65-104, map; in particular p. 89.

² K. Bogdanowitsch, Material for the Geology of the Government of Irkutsk, Djel. Dor., 1896, II, pp. 1-284, maps; in particular pp. 24-30 and section fig. 4.

³ K. Bogdanowitsch, loc. cit., p. 255.

this is cut through by the Birjussa and is continued to Ransk under the name of the Kamennii Khrebet, i. e. the 'Stony Ridge.' It has been described by Idjitzki¹. A second and much broader band stretches, according to Jatschewski's survey, from Nishni Udinsk in a north-north-west direction. It keeps to the country about the rivers Tshuna and Birjussa up to their confluence, which forms the Tassejev². This broad band is probably continued beyond the Tshuna and Angara to the great basaltic region of the Stony and Lower Tunguska.

On the Yenisei, west of the lower Tassejev, between lat. 56° 30' and 58° N., we meet with lignitiferous Tertiary beds only, which there cover wide areas. The border of the amphitheatre dwindles down to a few fragments along the Yenisei, but since in the neighbourhood of the village of Kergyn, south of the confluence of the Angara, we still see the Palaeozoic limestone resting unconformably on mica-schist, there may be an underground continuation of the boundary towards western Siberia in this locality³.

The sections afforded by *the river Angara* are among the most instructive of all that are known in the east Siberian platform.

At Irkutsk the Angara traverses the plant-bearing series and then cuts its bed through horizontal Palaeozoic deposits, of which the lower member is limestone and the upper a great succession of sediments, of a prevalent red colour.

This red series consists of sandstone associated with variegated marl, and sometimes with gypsum containing isolated beds of limestone. In these *Lingula* and *Eophyton* have been found; at a lower horizon *Obolus Apollinis* has been met with. We agree with Toll in assigning the whole series to the Cambrian and lower Silurian. It forms the banks of the Angara for an extremely long distance from the neighbourhood of Balagansk (about lat. 53° 45' N., long. 103° 20' E.) to Kamenka (lat. 58° 45' N., long. 96° E.). From this we must except the region comprised in the bend of the Angara. Here, from lat. 58° 30' N. downwards, as far as the rapids of Aplin in long. 101° 40' E., there extends a more recent area of plant-bearing beds, and a similar area reappears south of the Angara on the river Mura (long. 99° E.).

Jaworowski has travelled over the whole region from Bratzkii Ostrog (lat. 56° 12' N., long. 102° E.) downwards, and I follow his description, leaving on one side for the present the more recent plant-bearing beds⁴.

Over the whole of the upper and middle course of the Angara the

¹ N. Idjitzki, Geological Exploration along the Siberian Railway in 1894, Djel. Dor., 1896, III, p. 86.

² L. Jatschewski, Geological Exploration in the north part of the district of Kansk and along the Railway between Nishni-Udinsk and Kimilteisk, Djel. Dor., 1896, III, map, p. 10.

³ L. Jatschewski, Gorn. Journ., 1894, II, p. 312.

⁴ P. K. Jaworowski; Geological Observations made along the river Angara in 1895, Djel. Dor., 1898, VII, pp. 99-112, map.

Palaeozoic sediments lie very flat and are not much affected by faults. But as we approach the confluence of the Angara with the Yenisei, folding sets in and becomes more and more intense down stream; at the same time the rocks show signs of increasing dynamic action, and are finally traversed by so many surfaces of dislocation in the form of reversed faults or thrust-planes that the folding is of comparatively small importance. We thus reach the zone of the marginal folds on the west side of the amphitheatre.

Although Bogdanowitsch mentions no volcanic rocks from the upper course of the Angara, they occur in great force, according to Jaworowski, below Bratzkii Ostrog and as far as the mouth of the river. Wherever it is possible to observe them closely they are found not to be dykes but sills intruded into the red Palaeozoic beds, which they alter above and more rarely below. They attain a thickness of over 200 meters, and may sometimes be traced for a distance of ten versts. They are dark in colour, and stand out in strong relief from the less resistant red beds of the lower Silurian. Where the river crosses them they give rise to the numerous rapids for which the Angara is notorious. They consist of diabase and also of gabbro and porphyrite.

Within the marginal folds from long. 96° E. to the mouth of the river the conditions become very complex. Dark slates take the place of the red rocks of the lower Silurian, then the more usual type of lower Silurian appears, containing masses of highly altered micaceous and garnetiferous limestones; again normal trap comes in, and finally, quite close to the Yenisei, dykes of granite in limestone. Jatschewski has described and figured the granite intrusions: they belong to a larger granite mass which forms the rapids of Strjelka immediately at the confluence. This recent granite mass in the region of the marginal folds may thus be compared with that of Nishni Udinsk ¹.

The continuation of the Archaean amphitheatre in this neighbourhood must lie west of the Yenisei, as the evidence at Kargyn also proves; we shall soon meet with it again north of the Angara, east of the Yenisei.

Let us now turn to the superimposed Angara series.

Kositzki, who sixty years ago published a geological map of the remote region between the Angara and the Stony Tunguska, mentions that the island of Tshernaia in the Angara (lat. 58° 35' N.) is formed of volcanic ash, with crystals of augite. The ash is widely distributed as a tuff further down stream; it contains fragments of amber, and is associated with very thick conglomerates ².

¹ Jatschewski, Gorn. Journ., 1894, II, p. 315.

² M. Kositzki, Geognostische Beobachtungen im Nord-Oestlichen Sibirien während der Jahre 1834 und 1845, Verh. russ. k. min. Ges., 1848 (for 1847), pp. 23-63, map. On this map we must probably read gabbro or porphyrite instead of granite; Kositzki rightly recognized the intrusive nature of these rocks.

According to Jaworowski, the facts are as follows:—The series, which is fairly thick, begins here as a coarse conglomerate with pebbles of coarse-grained trap and Archaean rocks. The conglomerate becomes finer upwards; then follow layers of sand, and finally beds of a dark colour, resembling volcanic tuff, with white zeolites in nests and cracks. The lower and middle parts of the series are traversed by steeply ascending dykes of a rock identical with that of the sills in the lower Silurian, especially with the porphyritic variety. Thus the outflows of lava actually took place during the deposition of these lower and middle beds.

In the upper horizons are coal-seams and plant-remains. *Neuropteris* and *Sphenopteris* occur, also a *Lepidodendron* and *Rhyptozamites Goeperti*, Schmalhausen, which was formerly believed to belong to the northern development of the Jurassic, but has subsequently been found in the stage of Artinsk¹.

This flora is identical with that which presents itself to the north on the Lower Tunguska, and on the south in the coal-field of Kusnetsk, in the Altai mountains. Some of the basic flows of the east Siberian tableland date from the period of this flora. It probably represents the oldest colonization of the tableland under continental conditions; and may possibly correspond with the oldest flora of Gondwana land.

The *Stony Tunguska*. North of the mouth of the Angara, the Archaean hills appear and continue nearly as far as the mouth of the Stony Tunguska. On the east side of these hills there lies, according to Jatschewski's observations, an intensely folded zone of greywacke, quartzite, and clay slate, which corresponds with the continuation of the marginal folds. This zone crosses the Pit and probably extends over the whole region. Here, however, an unconformity has been described in connexion with the transgressive red sandstone and conglomerate, which are themselves dislocated; above them are limestones with Palaeozoic fossils. The highest point of this region is the *Enashimskii Palkan*, which reaches 4,000 feet; it is a stratified table-mountain and belongs to the interior of the amphitheatre².

Silurian beds are exposed over a very large part of the lower course of the Stony Tunguska. Schmidt and Toll, on the evidence of Lopatin's collections, record lower Silurian trilobites from its banks in long. 92° E. Toll believes he has recognized Cambrian sediments in an oolitic limestone even as far east as long. 98° 30' E.³

¹ Jaworowski, Geological investigations on the Angara in 1895, Djel. Dor., 1898, VII, pp. 105-106. Seward suggests the possibility that certain *Lepidodendron*-like forms found in South Africa associated with *Glossopteris* may be identical with *Sigillaria Brardi*, a species characteristic of the beds of Ottweiler. A. C. Seward, On the Association of *Sigillaria* and *Glossopteris* in South Africa, Quart. Journ. Geol. Soc., 1897, LIII, pp. 330, 335.

² Jatschewski, Gorn. Journ., 1894, I, p. 133.

³ F. Schmidt, Ueber einige neue ostsibirische Trilobiten, Bull. Acad. Imp. Sci. Saint-

The upper course of the river, on the other hand, lies entirely in the basic eruptive rocks. Kositzki states that the tuffs, forming a band of great breadth, cross the watershed from the bend of the Angara to the Stony Tunguska; he also mentions hard clay slates with trunks of *Psaronius* from the confluence of the Yuchtugun I with the Stony Tunguska (almost in lat. 60° N.), that is, in the midst of this volcanic region¹.

Further down also, on the middle course of the Stony Tunguska and as far as its confluence with the Yenisei, Lopatin found the basic eruptive rocks largely developed. They penetrate the Silurian, alter it, and form table-mountains upon it. Chrustschow has described hundreds of specimens from the neighbourhood of the confluence of the Tshuna (long. 98° 30' E.) and of the Velme (long. 92° E.) with the Stony Tunguska, as well as from other localities; he regards them all as plagioclase-pyroxene-olivine rocks, which have been evolved from one and the same magma, the glassy residuum of which possesses a uniform chemical composition. On the one hand they are crystalline, gabbro-like, or ophitic; on the other, they contain residual glass which may sometimes form as much as two-thirds of their bulk².

The heights, which form the watershed between the upper course of the Angara and the Lena and come to an end in the region of the head waters of the Stony and Lower Tunguska, enclose the valley of the Ilim: their names, proceeding from south to north, are the Khrebet Beresovii, the Khrebet Ilimskii, and the Tunguse mountains. They have been described by Idjitzki. Their outlines are broad and rounded, and they all owe their form to the erosion of the Palaeozoic platform. From about lat. 57° N. onwards we meet with isolated domes of superposed basaltic flows. The most northerly part, the Tunguse range, which is covered with dense taiga and bordered by marshy valleys, attains a height of 3,500 feet. North of lat. 58° N., Idjitzki found the tuffs mentioned above³.

Lower Tunguska. The whole course of this river has been explored by Tschekanowski in two laborious journeys⁴.

Pétersb., 1886, XXX, p. 501; von Toll, N. J. F. Min., 1895, II, p. 160, 164; Lindström correlates the corals with the Trenton and Hudson limestone of North America; Bihang Handl. K. Svensk. Vet.-Akad. Stockholm, 1882, VI, pp. 10-19.

¹ M. Kositzki, Verh. russ. k. min. Ges., 1848 (for 1847), p. 52.

² K. von Chrustschow, Vorläufige Mittheilung über die von Herrn Lopatin aus der Steinigen (Podkammenaja) Tunguska gesammelten Gesteine, Bull. Acad. Imp. Sci. Saint-Pétersb., 1892, nouv. sér., II (XXXIV), pp. 193-224. At one locality (61-62 versts above the 5th rapid of the river Velme) a leucitic rock appears; Chrustschow, tom. cit., pp. 225-229.

³ N. Idjitzki, Geological investigations in the government of Irkutsk in 1895, Djel. Dor., 1898, VII, pp. 113-153, map.

⁴ Journal of the Expedition of A. L. Tschekanowski along the rivers Lower Tunguska, Olenek, and Lena, &c.; also Tschekanowski in Röttger's Revue, 1877, X, pp. 170 and 173-190, and Uebersicht der geologischen Verhältnisse an der unteren Tunguska in Ferdinand Müller, Unter Tungusen und Jakuten; 8vo, Leipzig, 1882, pp. 301-311. (Müller was Tschekanowski's companion on this second journey.)

In lat. 58° N. its upper course approaches extremely close to that of the Lena, but although the watershed is very narrow the surface of the Tunguska lies 249 feet higher than that of the Lena. Its bed is here excavated in red lower Silurian beds. Ever and again the 'Krasnie jary,' i. e. red banks, make their appearance; fossils are not infrequent; the bedding is horizontal or gently undulating. In lat. 59° N. salt crops out, as it does also further north, in the valley of the Nepa; and here too trap is met with for the first time. The red lower Silurian strata with gypsum and salt continue to border the river; in places they are seen to be bent; in lat. $60^{\circ} 15' \text{ N.}$ an extensive area of basic eruptive rocks is met with for the first time, and extends without interruption nearly to the mouth of the river, i. e. from lat. $60^{\circ} 15' \text{ N.}$, long. $107^{\circ} 50' \text{ E.}$, to about lat. 66° N. and long. 88° E. Following the windings of the river, Tschekanowski travelled 1,800 versts amongst these basic rocks until he reached their termination near the mouth. From the table-mountain of Longashin (1,900 feet) on the upper course of the river, to the table-mountain of Kutinga (2,000 feet), the distance is 600 versts in a straight line ¹.

In certain cases we undoubtedly have to do here with true lava-flows in the form of covering sheets; but Tschekanowski's description shows that very large masses of sedimentary rocks, which may even be 200 meters in length, are found floating, as it were, in the lava. Although steeply ascending dykes are by no means wanting, it yet appears as though what had happened here was a general and powerful swelling up of sheet-like bodies of intrusive rocks or sills like those on the Angara mentioned above; the stratified rocks have been completely dismembered, broken up, and carried away in fragments by the lava, like the little Tithonian fragment of Fontana Fredda in the Euganean mountains (I, p. 147).

Some of these blocks belong to the Silurian, as for instance the mass of garnet-bearing limestone near the Anakit (long. 91° E.); much more frequent are small and large fragments of the Angara series. They are met with from the upper course of the river down nearly to its confluence with the Yenisei. When lignite has been caught up with them it is often converted into graphite. The flora has been described by Schmalhausen; it is the same as that which we met with in the tuffs at the bend of the Angara ². Laurski has described the lavas as plagioclase-augite rocks, in part containing olivine, and he lays stress, as Chrustschow does, on their wide distribution ³.

It is only when we reach the lower course of the river, from about long.

¹ Müller, *Unter Tungusen und Jakuten*, p. 301.

² J. Schmalhausen, *Jura-Flora der Unteren Tunguska*, *Mém. Acad. Imp. Sci. Saint-Pétersb.*, 1880, XXVII, pp. 55-92.

³ A. W. Laurski, *Ueber die Diabase des Beckens der Unteren Tunguska*, *Sitzungs-Protokoll der Naturforscher-Gesellschaft der Universität Kasan*, 1892-1893, XXIV, pp. 9, 10.

89° E. onwards that Silurian limestone crops out over a considerable area. Folds soon appear which belong, no doubt, to the western system of marginal folds; below the limestone, quartzite is visible and then metamorphic schists. Limestone again follows, at first horizontal, then forming an anticline which strikes north-west; a limestone with *Stromatopora* appears at the mouth of the river.

Thus the Lower Tunguska succeeds just as little as the Stony Tunguska in reaching the Archaean border of the great tableland. The region between the confluences of these two rivers with the Yenisei is little known. F. Schmidt mentions that the *Stromatopora* limestones alternating with argillaceous beds predominate along the Yenisei for about 100 versts above the confluence of the Lower Tunguska, and that, judging from pebbles, they must be exposed on the tributaries as far up as the Bakta, the confluence of which is near lat. 62° 30' N. Thus all this part of the Yenisei must belong to the ancient tableland¹.

North of Turukhansk all traces of Archaean formations disappear, and we perceive that the districts east of the Yenisei, as well as the course of the river itself, belong to the tableland.

It is obvious that the outcrops on the Kureika (the mouth of which is in lat. 66° 30' N.) precisely resemble those of the Lower Tunguska. Lopatin travelled 160 versts up this river. He met with Silurian limestone containing *Orthoceras* and *Pentamerus*, and olivine-diabase. In the now abandoned graphite mine of Pomonarevskaja in Sidorovo there are found, beneath the graphite, graphitic schists with traces of plant-remains, quartzite, and, judging from the lie of the beds in the banks, crystalline limestone; beneath these beds, again, fine-grained diabase occurs².

At Igark (lat. 67° 20' N.) Silurian limestones crop out on the Yenisei and are traversed by dykes of porphyrite.

On the Khantaika (confluence with the Yenisei in lat. 68° 15' N.) Lopatin found Silurian corals and an *Orthoceras* with a cochleate siphuncle. Schmidt mentions the occurrence of salt on this river.

The sources of the Khantaika lie in the Siverma mountains to the east. According to Middendorff, this range runs from south-south-east to north-north-west and terminates on lake Paisino (lat. 69° 30' N., long. 88° 20' E., east of Dudinskoie). The Tunguses described it to him as wild and rocky, and he conjectured, probably with justice, that it joined the mountains on the Lower Tunguska. That part of the range lying near lake Paisino is called the *Noril Mountains*. The foot-hills of these mountains have been visited from Dudinskoie by F. Schmidt. He found that they were tabular,

¹ F. Schmidt, *Mammuth-Expedition*, Bull. Acad. Imp. Sci. Saint-Petersb., 1872, XVIII, p. 16 (also XIII, p. 97).

² Lopatin's *Diary of the Expedition to Thuruchansk in 1866*, published by M. N. Miklucho-Maklai, *Zapiski, russ. geogr. Ges.*, 1897, XVIII, no. 2, pp. 161 et seq.

with an almost uniform height of 500 feet, flat-topped, with precipitous sides, made of bedded rocks, and covered with a sheet of weathered trap. Little fragments of graphite were also found. The distant view presents far and wide the same mountain forms¹. According to Nordenskiöld coal has been discovered in this region².

The numerous islands of the Brechov group are formed of sediments left by the post-glacial transgression. After finding a few pebbles of Mesozoic rocks on the Irgak and the Khantaika, Lopatin met with the *Inoceramus* beds of the Volga stage lying flat between lats. $71^{\circ} 30'$ and 72° N., on the right bank of the Yenisei. Still further north follow hills of melaphyre; this rock reaches the bank of the river at Krestovskoie in lat. $72^{\circ} 15'$ N.³ According to Bodkin, the rocky islands of Korsakov lying close to the coast are formed of trap⁴. Yefremov Kamen, on the Arctic Ocean, is also formed of a basic eruptive rock. Here we are in the immediate neighbourhood of port Dickson, where the fine-grained diabase was found, which Törnebohm recognized amongst Nordenskiöld's collections⁵.

Thus the various basic rocks on the right bank of the Yenisei reach the Arctic Ocean. Their relation to the basic rocks of Franz Josef's Land, King Charles's Land, and elsewhere, do not at present concern us. It can hardly be doubted that the great east Siberian tableland also extends to the shores of the Arctic Ocean. We see, then, that in many places, and often for long distances, the right bank of the Yenisei is bordered by rocks, while on the left bank lies the boundless tundra. We have mentioned the occurrence of rock salt on the Khantaika; from this river, lower Silurian

¹ F. Schmidt, *Vorläufige Mittheilungen, &c.*, *Mém. Acad. Imp. Sci. Saint-Pétersb.*, 1869, XIII, p. 120. F. Müller points out that among worn pebbles brought back by Middendorff from the Paisino and the Boganida, basalts also occur, and he concludes that the covering of trap must have possessed a wide extension, *Unter Tungusen und Jakuten*, p. 305. Also K. Chrutschow, *Ueber eine Gruppe eigentümlicher Gesteine vom Taimyr-Lande aus der Middendorff'schen Sammlung*, *Bull. Acad. Imp. Sci. Saint-Pétersb.*, 1894, new ser., III (XXXV), pp. 421-431.

² A. E. Nordenskiöld, *Redorgerölse for en Expedition till Mynningen af Jenissei och Sibirien*, *Bihang Handl. K. Svensk. Vet.-Akad. Stockholm*, 1877, IV, no. 1, p. 80.

³ See the description of the Kairskii Gori near the Krestovskoje Simovje in Lopatin's *Journal*, p. 11, 72 et passim. Polenow describes the specimens brought back as melaphyre; cf. also F. Schmidt, *Wissenschaftliche Resultate der Mammuth-Expedition*; *Mém. Acad. Imp. Sci. Saint-Pétersb.*, 1872, 7^e sér., XVIII, no. 1, p. 9.—Kjellman, on an excursion from the mouth of the Yenisei to Dudinskoie, encountered only blocks of basalt and beds with Arctic Mollusca, and concluded that the foundation must resemble that of Iceland or the north and west part of Greenland; Kjellman in Nordenskiöld's *Redorgerölse*, *Bihang. Handl. K. Vet. Svensk. Vet. Ak. Stockholm*, 1877, IV, no. 1, p. 70.—*Op. cit.*, p. 62, a description of the yefremov Kamen.

⁴ Compare the new and much modified map of the mouths of the Obi and Yenisei by Wilkitzky; *Izvestija Imp. ross. Geogr. Obsch.*, 1896, XXXII, p. 180.

⁵ A. E. Törnebohm, *Under Vega-Expedition insamlade bergarter*, in Nordenskiöld, *Vega-Expedition vetenskapliga Iakttagelser*, 8vo, Stockholm, 1887, IV, p. 115.

fossils also are known. The Solenaia, which rises in about lat. $68^{\circ} 30' N.$, west of the Yenisei, and joins that river in lat. $69^{\circ} 30' N.$, owes its name to the saltiness of its water. Whether these beds of salt correspond to those in the far south, on the upper Tunguska, can hardly be decided from existing data.

Close above the confluence of the Stony Tunguska the Yenisei enters the region of the ancient tableland, through which it flows to the Arctic Ocean, i. e. through twelve degrees of latitude. The fact that gold is searched for on the upper Taz, between lats. 62° and $63^{\circ} N.$, renders it very probable that Archaean rock prevails here, but it may be conjectured that in the north the Silurian platform is continued beneath the plain west of the Yenisei, in the direction of Yalmal.

The watershed between the Yenisei and the Lena. Numerous table-mountains rise between lats. 65° and $67^{\circ} N.$, on the watershed between the Lower Tunguska and the sources of the Vilyui, and between the latter river and the Moneiro and Olenek. Their height here is also about 2,000 feet above the sea, and this remarkable correspondence with the height of the hills on the Lower Tunguska seemed to Tschekanowski an indication of contemporaneous origin. They consist of a cap of basic rock resting on horizontal Silurian beds. The Silurian beds are red, with intercalations of clay and gypsum, exactly as in the upper region of the Lower Tunguska, which lies 8 or 9 degrees further south.

Tschekanowski, coming from the south, first met with the steep table-mountain *Anaon* on the south side of lake Sjurugna (622 meters high, north of lat. $65^{\circ} N.$). Up to this point his route from the Lower Tunguska had taken him across trap; the Silurian, which lies beneath, being seldom visible¹. The Anaon is joined on the west and north-north-west by the table-mountains *Yang-bur*, which enclose the sources of the Moneiro. The red Silurian beds spread out to the east of these hills and lake Yakogna, and on the south side of the upper Olenek we reach the long table-mountain *Ljutscha Ongoktom*. Travelling over the region formed by the extension of this mountain and of the *Kemnatik* ridge to the east, between the affluents of the Olenek and those of the Vilyui, Maak crossed the remarkable *Tungus Yangy* (mountain of the Tunguses), with its capping of basic eruptive rock, broken up into fantastically shaped needles and peaks, which the Tunguses believe to be the petrified remains of their giant ancestors².

It is to this assemblage of table-mountains that Maak has given the name of the *Vilyui*. They all seem to have the same character. A cap of basic rock forms their summits, the Silurian beds occur below and occupy

¹ Tschekanowski, Journal, p. 129 et seq.

² R. Maak, The circle of Vilyui in the province of Yakutsk, 4to, Saint-Petersb., II, 1886, maps, p. 124. The surface rock is described by Polenow as olivine-diabase and placed in the Permian or Trias period; op. cit., p. 347, r.

the low ground in their vicinity. The Silurian beds belong in part to the upper Silurian.

Near long. 104° E., the basic rocks of this region are probably connected with similar rocks which, according to Toll's observations, separate the rivers Khatanga and Anabara; near the forest limit, which is in lat. 71° N., they should reach the transgressive Mesozoic of the north¹.

Cambrian and lower Silurian beds also border the Olenek. Among the specimens collected by Tschekanowski, Toll recognized *Bathyriscus Howelli*, Walc., of the middle Cambrian, from a locality north of lat. 68° N.; and in a loose fragment from lat. 70° 30' N., F. Schmidt found a species of *Agnostus*. Tschekanowski met with the basic rocks again on the Tolobka (lat. 71° 30' N.)². No doubt these lavas, as well as the undisturbed red lower Silurian beds, extend quite close to the sandstone with *Inoceramus*, which accompanies the outer border of the Verkhoiansk mountains³.

Lena and Vilyui. As far as the confluence of the *Vilyui* and *Chona* (long. 111° 30' E.), the beds of these two rivers are excavated in the basic eruptive rocks. On the Chona, about ten versts above the confluence, stands a hill, the *Toi Chaiu*, which Pawlowski and Maydell regard as an extinct volcano. It presents two summits of no great height, formed of basalt or trap which rests on a base of sandstone traversed by dykes; successive streams of a dark vesicular lava which issued from this hill are clearly visible. Altered limestone also occurs, and in other places there is coal, with associated plant-remains⁴.

The uppermost part of the Vilyui shows similar signs of volcanic action. South of the table-mountains of the watershed, on the II and III Velyukan (about lat. 66° N., long. 108° E.), Maak observed conical summits, and thought he must be near a great centre of volcanic eruption⁵.

Further east we reach the limit of the basic rocks. By uniting the observations of Maak and Pawlowski we arrive at results somewhat as follows.

On the Olenek, at the confluence of the Tyraktach (lat. 67° 40' N., long. 111° E.), the eruptive rocks again make their appearance, but from this point onwards to the south-east nearly as far as the Taz (lat. 66° N., and long. 115° 30' to 116° 30' E.), only flat-bedded Silurian is to be seen. Here,

¹ Baron E. von Toll, Expedition of the königlichen Akademie der Wissenschaften to the Siberian islands and the coasts of the Arctic Ocean, *Izviestija Imp. ross. Geogr. Obsch.*, 1894, XXX, p. 446.

² Tschekanowski, *Journal*, p. 164. This author mentions isolated folds in the midst of horizontal beds on the Olenek, pp. 156, 160 et seq. They are probably local disturbances.

³ Tschekanowski, *Journal*, pp. 253, 263.

⁴ Maak, *Vilyui*, p. 45; Pawlowski, *Izviestija of the Siberian Branch of the Imperial Russian Geographical Society*, 1873, IV, p. 39.

⁵ Maak, loc. cit., p. 130.

once more, we meet with diabase, but towards the south the Silurian sets in again. The Chainga and Markha flow between imposing table-mountains of Silurian beds, and it is not till we reach the watershed between the Markha and Ygetta (lat. $63^{\circ} 45' N.$, long. $116^{\circ} E.$), that the region of basic rocks reappears¹.

This important boundary runs for the most part west of long. $116^{\circ} E.$, so that on the east, towards the Lena, a wide area of tableland remains which is not covered by these basic rocks.

The boundary extends even into the valley of the Vilyui. At the confluence of the little Botubuia (tributary on the right bank, long. $113^{\circ} 30' E.$), Cambrian beds appear². Below the bend of the Vilyui in long. $116^{\circ} 30' E.$, the red lower Silurian, accompanied by beds of rock-salt and gypsum, is exposed over a large area. On the river Djeli lie the already mentioned most southerly representatives of the Mesozoic transgressions of the north, with Belemnites and Tancredia (lat. $66^{\circ} N.$, about). Somewhat lower down, on the tributary river Kjampendsjaia, are the important salt springs of the Tunguses. At the mouth of this tributary there is an outcrop of brown coal³.

The eruptive rocks on the Ygetta are described by Polenow as plagioclase-dolerite. They rest upon white clay, and come to an end below the confluence of this river with the Vilyui. Extending towards the town of Vilyuisk lies an expanse of loam with mammoth remains.

Still further east, near the Lena, plant-bearing beds of the Angara series crop out; Tschekanowski met with them on the river Nashim (lat. $66^{\circ} 15' N.$, a tributary on the left bank of the Lena) and still further north; Maak found them on the island of Socho Chaia, in the region about the mouth of the Vilyui. They belong to the zone which borders the arc of Verkhoiansk.

It is a remarkable fact that, with the single exception already mentioned as occurring near Djedaïsk, the deeply eroded valley of the Lena nowhere, so far as we know, exposes pre-Cambrian formations, and it is nowhere reached by the sheets of basic rock.

Obrutschew has published some observations on the lie of the beds along the upper course of the Lena to beyond lat. $59^{\circ} N.$ Even near its source, close to lake Baikal, the river bed is excavated in the Palaeozoic platform. The height of the land is here from 650 to 700 meters; in lat. $58^{\circ} N.$ it has fallen to between 450 and 500 meters; further on the river has hollowed out its bed 300 meters deep in the platform. Disturbances of the beds are

¹ R. Maak, tom. cit., p. 108 et passim; Pawlowski in Maak, pp. 89, 98 et passim.

² F. Schmidt, Ostsibirische Trilobiten, Bull. Acad. Imp. Sci. Saint-Petersb., 1886, XXX, p. 501; E. von Toll, Beiträge zur Kenntniss des sibirischen Cambrium, I, Mém. Acad. Imp. Sci. Saint-Petersb., 1889, 8^e sér., VIII, p. 32.

³ R. Maak, tom. cit., p. 319 et seq., p. 335 et passim.

sometimes visible; at Kirensk (lat. 58° N.), they strike north-east, and may perhaps be assigned to the marginal folds of the amphitheatre. The red lower Silurian beds cover a large area in this region ¹.

Lower Silurian fossils have been found at Krivoluzk, a short distance above Kirensk. But a little distance further on peculiar oolitic limestones, which Toll regards as certainly Cambrian, make their appearance beneath the red beds. The beds lie quite flat for a great distance; but fossils are not found again till much lower down in the series, as at several places below Olekminsk. The fossils of this horizon include *Ptychoparia*, *Microdiscus*, *Agnostus*, and *Kutorgina*. Toll places the beds in the *Olenellus* zone or lower Cambrian. According to Tschekanowski these beds are continued, remaining almost horizontal, over the whole distance from the last-named locality down to Tabaginskaia, thirty versts above Yakutsk. Soon afterwards the Lena enters the plant-bearing beds of the Angara series ².

Summary. The most remarkable tectonic phenomenon in the region we have just described is the marginal folding of the amphitheatre of Irkutsk. We have seen traces of the folds in the valley bottom of the Lena; they appear conspicuously on the west border of the Primorskii Khrebet and south of Irkutsk, as well as south of Nishni-Udinsk; they are then, as will be shown in greater detail presently, interrupted in a peculiar manner as they proceed towards Krasnoiarsk, but wherever the inner border has been closely studied they are found to reappear in the west, as at the confluences of the Angara, the Stony and the Lower Tunguska. The folding decreases in intensity towards the inner side of the arc. Still nearer the interior, north of Nishni-Udinsk, come the horseshoe-like folds of the Angara series, faintly expressed, but still concentric with the stronger folds. These marginal folds are distinguished from the folds of the mountain chains by the fact that they are not accompanied by a parallel band of older Archaean rocks, but follow the edge of a very extensive Archaean highland.

In contrast to the great ranges of the south, the movement of the marginal folds is directed not to the south but to the north, or rather towards the interior, and this suggests the idea that the amphitheatre has been subjected to compression and constriction.

In some places intrusive granite masses appear within the marginal folds; the most conspicuous is the Kruglaia, near Nishni-Udinsk.

Strictly speaking, we should restrict the term tableland to the country

¹ W. Obrutschew, *Die altpalaeozoischen klastischen Gesteine des Lenathales zwischen Katschug und Witimsk in Ost-Sibirien*, published by the East Siberian Branch of the Imperial Russian Geographical Society, Irkutsk, 1892, 8vo, 212 pages, maps.

² E. von Toll, *Ueber die Verbreitung des Untersilur und Cambrium in Sibirien*, N. J. f. Min., 1895, II, pp. 161, 162; also *Beiträge zur Kenntniss des sibirischen Cambrium*, 1889, I, p. 21 et seq.

beyond the marginal folds and the folds of the Angara series; but there is no definite limit.

The Archaean hills on the east side of the Yenisei, between the lower course of the Angara and the Stony Tunguska, do not form a main watershed, but are part of the western border of the tableland and of the natural boundary between the tableland in the east and the recent plain in the west.

The tableland consists for the most part of horizontal beds which extend from the Olenellus zone or the lower Cambrian through the red salt-bearing series of the lower Silurian into the upper Silurian¹. In the extreme south-west there is Devonian also. From this period onwards only plant-bearing beds of various age occur in the south, while in the north the Arctic transgressions of the sea have left their trace.

The Palaeozoic platform extends from the south of lake Baikal to the Arctic Ocean, and from the Yenisei to the Lena. It is probable, as will appear directly, that it also extends eastwards across the Lena into the basin of the Aldan. In the west the confluences of the Stony and Lower Tunguska still belong to the region of the marginal folds. On the north-west, towards the lower Obi and the peninsula of Yalmal, its boundary is still undefined.

The western moiety of the platform is covered in many places with basic eruptive rocks. On the north outliers of these rocks extend along the Yenisei to the Arctic Ocean, which they reach near port Dickson, and they are also found on the lower course of the Olenek. In the east they extend to the meridian of 116° in the basin of the Vilyui, but stop short of the Lena; in the west they do not appear to cross the Yenisei. These basic rocks are sometimes olivine-diabase, sometimes plagioclase-basalts, and often again, especially in dykes, gabbro-like; they are always of a somewhat varied character. Throughout the greater part of the basin of the Lower Tunguska, from lat. 60° 15' N. to its confluence, the intrusion of the principal mass was accompanied by a swelling up of the injected strata, including both the Palaeozoic and certain plant-bearing beds; or the phenomenon might be described as a mighty intumescence produced by the intrusion of sills. True flows occur as well, and perhaps traces of volcanos also, i. e. definite centres of eruption. But the latter, like a large part of the flows, may be of more recent origin.

The oldest of these basic masses cannot be younger than the terrestrial flora of the beds which overlies the conglomerate containing basic pebbles at

¹ The conjecture that Devonian occurs in the midst of this region is only supported by badly preserved specimens which Tschekanowski found in red sandstone near Padun, on the Angara, and in which F. Schmidt believed he recognized remains of Eurypterus. Schmidt, however, himself admits that the determination of the specimens is doubtful owing to their imperfect state of preservation; Schmidt in Maak, The circle of Vilyui, II, pp. 365, 366.

the bend of the Angara. This flora corresponds completely with that of the graphite-bearing beds enveloped by the basic rocks on the Lower Tunguska. It is also identical, as Schmalhausen discovered many years ago, with that of the coal-field of Kusnetz, in the Altai.

The earliest flora of the Angara series, the *Tungusian*, is characterized by a peculiar mixture of older types, such as *Lepidodendron*, and younger ones, such as have hitherto been regarded as exclusively Mesozoic; a similar mixture characterizes the flora on the Petchora, and in certain horizons of the lower Gondwana, as well as at Bajo de Velis in the Argentine Republic. We may place it provisionally in the Permian period, in accordance with Zeiller's views¹.

Thus it seems probable that the plant-bearing beds of Ust-Balei and the whole border of the amphitheatre of Irkutsk, belong to the more recent divisions of the Angara series, and the same is true of those which accompany the arc of Verkhoiansk on the lower Lena.

As regards the character of the Permian plants and reptiles discovered by Amalitzky in northern Russia, we may fairly suppose that, notwithstanding the existence of the intervening Tethys, there was a very similar development of organic life on the Gondwana continent in the south and the Angara continent in the north.

After all that has preceded we are now prepared to recognize the difference which exists between eastern and western Siberia. It depends chiefly on the absence of basic eruptive rocks in the west and on the presence of a widespread covering of more recent sediments.

The marine transgressions which made their entrance by the strait of Turgai are strangers to the east. First of all, the upper Cretaceous of Europe passed into the strait, but it seems to have covered only a small part of the south-west. Then followed, by the same road, the marine transgressions of the upper Eocene and Oligocene, part of which, extending along the east side of the Urals, reached the existing Arctic Ocean. During the age of the amber forests the strait of Turgai was closed up, and from that time onwards no sea ever again entered Siberia through that portal.

The transgressions of the Arctic region belong to other periods of the Mesozoic aera; of Tertiary transgressions, only one can be recognized, that of the Oligocene epoch, and this was merely an extension of the strait of Turgai; on the other hand this region was affected by the quite recent Arctic transgression.

¹ R. Zeiller, Remarques sur la flore foss. de l'Altai à propos des dernières découvertes paléobotan. de MM. les Dr. Bodenbender et Kurtz dans la Républ. Argentine, Bull. soc. géol., 1896, 3^e sér., XXIV, pp. 466-487; especially p. 471 et seq.: Examen de la flore de l'Altai et de la Tougouska inf. It is striking that Polenow, relying principally on the nature of the basic rocks, ascribes these to the Permian period or to the Trias; comp. Maak, Vilyui, Appendix to Vol. II.

In respect to the transgressions, the contrast is not so much between east and west Siberia as between Turgai and the north.

Out of these various circumstances arises the peculiar arrangement of the river systems of north Siberia. All the drainage flows to the north, and it is not only the tableland of the east and the plain of the west that contribute to the large volume of fresh water which the Arctic Ocean receives, but a considerable part of the rainfall of the great southern ranges also enters that ocean, chiefly by the Yenisei.

As regards the three most important river courses, the Obi, the Yenisei, and the Lena, we may note the following differences:—

The western plain, covered by recent sediments, forms, apart from the smaller rivers of the north-eastern Arctic tundra, a single great catchment area for the waters which reach the sea by the Obi. On the other hand, the middle of the tableland in the east is a watershed, and its drainage flows either directly to the sea or to the east and west, so that the Yenisei and the Lena assume the character of marginal rivers in relation to the tableland.

The great prairie of North America is formed by Cretaceous deposits which have spread over the depression from the south. Later on, the area within which the Tertiary sediments were deposited north of the gulf of Mexico became uniformly constricted around the same point in the south, and in this very place, whence also the transgressions from the south proceeded, now lies the mouth of the Mississippi (I, p. 284, Fig. 37). Thus a certain continuity of events becomes apparent, and the delta appears as a sequel to earlier formations.

In the Sahara the case is similar. Although the position of the mouth of the Nile is completely eccentric, yet it is obviously determined by the progressive narrowing of the curves which bound the distribution of the Cretaceous and Tertiary deposits (I, p. 360, Fig. 41).

None of the great Siberian rivers present similar phenomena. The Arctic transgressions have left their sediments over the whole breadth of the northern coast of Asia.

The Obi, which in its regular course most closely resembles the Mississippi or the Nile, presents, in contrast to these rivers, deposits of transgression not only at its mouth, but also at the headwaters of its basin. In the south the transgressions proceeded from the strait of Turgai, following the existing slope of the Tobol.

The Yenisei is a mountain river of composite character. At first, under the names Khua-kem and Ula-kem, it flows through the longitudinal valley along the northern foot of the Tannu-ola, then it cuts through the western Sayan and passes through portions of successive transverse valleys to Krasnoiarsk and its confluence with the Angara, which discharges the drainage of the Khangai; it then proceeds along the western foot of the

Archaean range and finally enters the most north-westerly part of the Palaeozoic plateau, the western drainage of which it receives as far as Turukhansk.

The eastern part of the tableland drains into the Lena. This river flows in a true valley of erosion which is doubtless of very great age. It is not confined by mountain folds except in the lowest part of its course, where the Khara-ulach hems it in, and in this region it is deflected together with the lower Olenek. It exhibits in a marked degree the characters of a marginal river but, from facts which will be adduced later, it would seem probable that the basin of the Aldan is a continuation of the tableland lying beyond the Lena.

CHAPTER III

THE ANCIENT VERTEX¹

Introduction. Patomske Nagorie. Trans-Baikalia. Lake Baikal. Western shore of lake Baikal. Mountains south of lake Baikal. East Sayan. The Horst on the Yenisei. Summary. Minusinsk. West Sayan. Tannu-ola-Khangai. The Valley of the Lakes. Gobi-Altai. East Gobi. Conclusion.

THE extensive region we are about to discuss forms, by virtue of its position and structure, *the most ancient vertex of the Eurasian folds*. Its western limit is marked by the Yenisei below Krasnoïarsk; in the east it is bounded near long. 120° E. by the continuation of the Great Khingan running to the north-north-west, the western border of which is crossed by the Argun at Nertchinskii-Samod and further north by the lower Shilka. In the amphitheatre of Irkutsk the vertex is surrounded by the marginal folds of the Palaeozoic tableland.

The rocks and the folds of the vertex are extremely old. Granite, frequently containing hornblende; gneiss and hornblendic gneiss; and in certain localities a series, regarded as unconformable, consisting of mica-schist, chlorite schist, ancient quartzites, and crystalline limestones with flakes of graphite, form the greater part of its long ridges and its lofty hills or 'goltzi.' Associated with these are more recent granites, diabase, porphyry, porphyrite, and finally basic lavas, some of which are of comparatively recent date. Here and there in the valleys are found freshwater Tertiary deposits with brown coal.

The folds of the vertex are doubtless anterior to the Cambrian sediments of the Lena. Along the fracture west of lake Baikal (*b, b*. Fig. 2) regions occur in which these folds strike at right angles to the fracture and to the marginal folds. It is doubtful whether the inner parts of the vertex were ever covered by the Palaeozoic seas, though indications of such a submergence are supposed to be afforded by certain widely scattered outliers consisting for the most part of schists and quartzite. In vain do we seek here that variety of fossiliferous marine deposits which distinguishes so many other mountain regions; but towards the outer periphery, especially in the south-east and south, these ancient folds merge into more recent folded ranges, and we encounter fossils of Devonian age. The marginal fracture of the amphitheatre is of great antiquity.

As early as 1855 Meglitzki published a sketch map of lake Baikal showing that for long distances the lake cuts obliquely across the strike of

¹ Revised by J. J. H. Teall, Esq., Sc. D., F.R.S. Director of the Geological Survey of Great Britain.

the rocks which form its mountainous shores¹. Later on, Tschekanowski, Kropotkin, and, above all, the indefatigable and acute observer Tscherski, added considerably to our knowledge of the mountains about lake Baikal; and recently the works preparatory to the construction of the Siberian railway have opened a new aera in the geological study of these regions.

Tscherski was aware that a narrow band of mountainous country lying west of lake Baikal represents the continuation of the trans-Baikal highland. He also recognized that the folds of the ancient mountains to the east and west of lake Baikal strike in opposite directions and converge towards the south. The north-easterly or east-north-easterly strike which exists east of lake Baikal he terms the *Baikal direction*, and that to the north-west or west-north-west, which prevails west of the lake, the *Sayan direction*².

Both in the west and in the east this twofold direction of the pre-Cambrian folds appears to reveal itself in the courses taken by many of the rivers and in the superficial form of the ground. A closer examination of the facts shows, however, that this is not the case, and that the existing configuration is determined by structural features of a totally different kind.

Far away in the west, in the region of the upper or Black Irtysh, Bogdanowitch long ago arrived at the conclusion that we must assign to subsidences and long fractures a far greater influence on the structure of the Asiatic mountains than had hitherto been supposed. Klemenetz formed the same opinion from his studies of the Valley of the Lakes, in Mongolia. But it is the particular merit of Obrutschew to have shown that all the mountainous country of the trans-Baikal region is traversed by long fractures which sometimes form continuous troughs and give to a great number of the long mountain ridges the character of so many horsts³.

These long fractures sometimes coincide for a considerable distance with the strike of the folds; in other places they intersect the strike; but on the whole, as we have observed above, they give rise to a configuration which recalls the course of the ancient folds. A deviation from this course

¹ N. G. Meglitzki, *Geognostische Skizzen aus Ost-Sibirien*, Verh. russ. k. min. Ges. 1855-1856, pp. 109-171, map.

² J. D. Tscherski, The structure of the mountains of east Siberia considered as part of the north-west border of Central Asia, *Travaux Soc. Nat. Saint-Pétersb.*, 1886, XVII, 2, Report, pp. 52-58; Report on the geological investigation of the shores of lake Baikal, part I, *Izviestija Sibirsk Otd. Imp. ross. Geogr. Obsch.*, 1886, XII, pp. 1-405; Geological investigation of the great highroad of Siberia from lake Baikal to the east border of the Ural, *Mém. Acad. Imp. Sci. Saint-Pétersb.*, 1888, LIX, supplement 2 (published under the editorship of J. W. Muschketow); *Mater. Geol. Russ.*, 1889, XIII, pp. 1-48 and geological map of lake Baikal in two sheets, &c.

³ In particular, Obrutschew, *Geological observations in Transbaikalia in 1896*; *Djel. Dor.*, 1898, X, p. 43, and *Geological observations in south-west trans-Baikalia in 1897*, op. cit., 1899, XVIII, p. 25 et passim.

would not afford conclusive proof of the presence of fractures, for in mountains of such great age erosion may be influenced in many ways. This is shown by the eroded transverse valleys of trans-Baikalia, and when we study the Alps of the Tunka and the Kitoi, west of lake Baikal, we shall see that special circumstances have rendered the valleys in that region independent of the structure of the mountains.

Of still greater importance is the fact that the long fractures mentioned above are frequently accompanied by extrusions of eruptive rocks, such as porphyry and porphyrite with tuff and breccias, melaphyre, basalt, and sometimes also trachyte and rhyolite.

Finally, in the best-known parts of the mountainous region, and particularly across the lower Selenga, we see undoubted subsidence troughs. Our Russian colleagues describe them by the very expressive term '*disjunctive dislocations*.' Indeed it would be impossible to explain the formation of a series of sub-parallel fractures and troughs, the course of which corresponds for long distances with the strike of the ancient folds, without assuming a certain amount of tension, acting approximately in the direction of the ancient folding. This tension may result in disjunction, i.e. may give rise to fissures and also to the subsidence of long strips of land between these fissures. Eruptive rocks of different ages may then accompany the disjunction. In closely compressed folded mountains of comparatively recent date, such as the Himálaya or the Alps, such disjunction is not known.

Patomske Nagorie. Along the fractures and flexures which surround the inner border of the amphitheatre of Irkutsk a very considerable part of the western half of the vertex has subsided, and its place is taken by the Palaeozoic tableland of the Lena, the Angara, and the Oka. To the east, on the other hand, in trans-Baikalia, and to the south of lake Baikal, the features of its structure are clearly displayed, and there our study of the vertex may begin.

We know that the Cambrian tableland is visible in the bed of the Lena nearly as far as Yakutsk. At Yakutsk the red sandstone, the latest deposit here of Palaeozoic age, is covered by plant-bearing beds belonging either to the Angara series or to the Tertiary group.

When Middendorff made his arduous journey to the south-east from Yakutsk to Udskii Ostrog, he observed in the region between the river Aldan and the little Aim (a tributary on the left bank of the Maia, about lat. 58° N.) horizontal sandstone with conglomerate and thin seams of coal. Lying beneath these, exposed in the deeper ravines, are flat-lying limestones and dolomite, which Middendorff correlated with the deposits in the bed of the Lena. It is not till we have passed beyond this locality more than four degrees of latitude south of Yakutsk, that the treeless range of *Kochkat* appears, with its rounded summits of diorite and granite; but even

these summits seem to be covered by red sandstone. Beyond the Koch-kat the horizontally stratified limestone again becomes visible, and above it the sandstone; these extend from the river Utshur, up the river Uyan to the western foot of the rocky chain of the Aldan mountains¹.

Meglitzki travelled up the river Maia and reached the western foot of the Aldan mountains at a point situated about 230 versts north of Middendorff's route. He too encountered only horizontally stratified beds, limestone below, sandstone above, sometimes containing plant remains. At Nelkan we are still on the sandstone. The land certainly rises from the Lena towards the upper course of the Aldan, but the rise is not considerable, and where the flat-bedded sediments abut against the rocky foot-hills of the Aldan mountains, their tabular surface, although deeply cut up by river channels, clearly reveals by its uniform height the boundary between these sediments and the ancient rocks of the range².

The contrast presented by the landscape on the two sides of the Aldan mountains has been described by Bogdanowitsch. Coming from Uaskii Ostrog, i.e. from the south-east and following the river Nemerikan, he ascended the mountains under great difficulties. Looking down from a height of 4,000 feet in the direction of the sea, long parallel chains present themselves to the eye, while towards the interior a boundless primeval forest extends over the gently sloping sides of the range, and the water-courses bury themselves in deep channels³.

If now we take Yakutsk as a centre, then proceeding for a distance of 500 versts up the Lena towards Olekminsk, for about 700 versts on Middendorff's route to the upper Utshur, and for more than 600 versts on Meglitzki's route to Nelkan, we meet everywhere, the ancient ridge of the Koch-kat alone excepted, with horizontally stratified sediments. Thus the basin of the Aldan may be regarded with great probability as an easterly extension of the great plateau of east Siberia, which inserts itself between

¹ A. Th. von Middendorff, *Reise in den äussersten Norden und Osten Sibiriens* während der Jahre 1843 und 1844, 1848, I, 1, p. 216; 1867, IV, 2, pp. 230, 327; Atlas, pl. X-XII.

² N. G. Meglitzki, *Account of the expedition to the Province of Yakutsk in 1851*: edited according to the manuscripts, diaries, and collections of N. G. Meglitzki by M. P. Melnikow, *Gorn. Journ.*, 1893, III, pp. 111 et seq. The leader of this expedition was General Agte. Meglitzki prepared the account in 1853, and died at Weimar in 1857 at the early age of 32, in consequence of the hardships he had undergone. It was not until long after his death that the report was published, and it has not yet, to my knowledge, been superseded by later works.

³ Bogdanowitsch, *Some information on the progress of the work of the mining expedition to the shores of the Sea of Okhotsk and to Kamtchatka* (communicated by L. A. Jatschewski), reprinted from the *Izviestija of the Society of Mining Engineers*, St. Petersburg; meeting of the 9 Dec., 1896, pp. 5 et seq. The point at which Bogdanowitsch ascended the Diugdiur does not appear to be very far distant from the route by which Meglitzki crossed it. The latter also started from Aian.

the arc of Verkhoiansk and the but little known border of the mountainous region of trans-Baikalia; it is separated from the sea on the east by the Aldan mountains.

In order to reach the north border of trans-Baikalia let us turn our steps towards the west. Below its junction with the Vitim the Lena makes a bend towards the north beyond lat. 60°, and again returns to the south of this latitude. This bend is caused by an outcrop of Archaean rocks within it. The structure of this region was admirably described some years ago by P. Kropotkin¹.

Here the Lena has excavated its valley to a depth sometimes of almost 1,000 feet, and its banks are extremely steep. High above the river lies a platform of red sandstone of lower Silurian age, the mean level of which is something under 1,400 feet above the sea, thus corresponding in height to the horizontal red sandstone encountered far from here, in the Kutshug mountains between Atchinsk and Krasnoiarsk. Beneath the sandstone lies the Cambrian limestone. The bend of the river, however, coincides with the margin of the platform.

If we now leave the Lena, about fifty versts below the mouth of the Vitim, and proceed in a south-easterly direction for some distance, we reach steeply upturned beds of quartzose sandstone, schists, and ancient limestone. They probably represent a continuation of the marginal folds of the amphitheatre. About fifty versts from the Lena, we find ourselves at a height of 900 meters on a range of grey gneiss running to the north-east. Further to the east, beyond the great Patom, a still higher range appears, which Kropotkin has named *Patomske Nagorie*, i.e. the highland of the Patom. This also consists of Archaean rock. Its highest part, the granite and gneiss mass of the *Teptoró*, also called 'Napoleon's hat,' reaches a height of 1,794 meters. It rises, covered with snow, above the surrounding country, which stretches far and wide in rounded bosses, striated and polished by glacial erosion.

These rocks do not reach the Lena in the north-east; on the other hand, they cross the Vitim in the south-west. An extremely long band of clay slate borders the south-east side of the highlands and separates them from the mountains of the Olekma. It has been traced for a distance of 200 versts, and its northern end nearly reaches the confluence of the Patom. Its strike is NE. (40° to 50°)².

Subsequently to Kropotkin's investigations the lower Vitim was again studied by Obrutschew, who has kindly placed at my disposal a geological map of the *Patomske Nagorie*. Obrutschew discovered the surprising fact that there exists on the north shore of the Vitim, south-east of the ancient

¹ P. Kropotkin and J. Poljakow, Report on the Expedition from the Olekma and the Vitim, *Zapiski, Imp. ross. Geogr. Obsch.*, 1873, III; in particular, pp. 191 et seq.

² P. Kropotkin and J. Poljakow, *tom. cit.*, p. 214.

mass of the Patomske Nagorie, an extensive tract of clay slate, probably of pre-Cambrian age, associated with quartzite and altered limestone, and traversed in places by more recent granite; it is affected by numerous long, broad folds, which follow an east to west direction, with a slight divergence to the east-south-east; that is in a direction not in accordance with the general strike of the Archaean highlands. These folds are abraded. Obrutschew has named the highest of them *Khrebet Kropotkina*; it reaches an altitude of 1,100 meters and forms for more than 100 versts the watershed between the tributaries of the Vitim, which here flows from east to west, and those of the great Patom and the Vatcha ¹.

From the foregoing facts we conclude that the Patomske Nagorie represents a continuation of the trans-Baikal mountains lying beyond the Vitim, and that it possesses the normal Baikal strike (as defined by Tscherski). A solution to the problem presented by the divergent strike of the apparently younger folds of the Kropotkin mountains must be left to future observers.

Vitim and trans-Baikalia. Kropotkin's travels, so fruitful in scientific results, were made in 1866. The route followed ran southwards from the Patom between long. 113° and 115° E., through the inhospitable region which extends to the southern slope of the Yablonoi. In the preceding year Lopatin had traversed the vast tract lying to the east of the northern half of lake Baikal. His collections were described by Polenow ².

The eastern half of the vertex, which has been preserved for our examination, coincides substantially with trans-Baikalia. The works of Kropotkin and Lopatin referred to above are our most important sources of information as regards the north; for the southern part, the investigations made in connexion with the construction of the Siberian railway. The region extending from the Selenga to the confluence of the Shilka and Argon has been studied by Obrutschew and his fellow workers, Gerasimow

¹ W. A. Obrutschew, *Geologische Untersuchung des Gebirgslandes von Olekma-Witim und seiner Goldlagerstätten im Jahre 1890*, Vorläufiger Bericht, *Izvestija Sibirsk, Otd. Imp. ross. Geogr. Obsch.*, 1891, XXII, pp. 1-71, maps; report by the same for 1891, *op. cit.*, 1892, XXIII, pp. 1-28.

² J. A. Lopatin, *Diary of the Expedition to the Vitim in 1865*, edited by W. K. Polenow; *Zapiski, Imp. ross. Geogr. Obsch.*, 1895, 283 pp. and map; Polenow, *Die massigen Gesteine vom nördlichen Theile des Witim-Plateau, Ostsibirien*, *Travaux Soc. Nat. Saint-Petersb.*, 1899, XVII, pp. 89-482; Kropotkin's collections were unfortunately burnt in a conflagration at the museum of Irkutsk.—It is very much to be regretted that little has been published concerning J. Martin's arduous journey on the line between Olekma and Vitim. All the specimens collected have been lost; we only know that he encountered granite in the north, and from lake Amadiess onward schists and stratified formations. South of lake Netchatka a height of 2500-3000 meters is assigned to the watershed; I have not been able to ascertain any further details concerning this lofty range. Accounts also exist of an important chain on the Kalar, but these are also unconfirmed; *Voyage de M. Joseph Martin dans la Sibirie Orientale*, *Compte rendu Soc. Géogr. de Fr.*, Paris, 1887, pp. 219-236, map; in particular, p. 258.

and Prince Gedroitz; the works of Obrutschew refer to the region from the Selenga to Tchita, those of Gerasimow to the middle part as far as the Onon, and those of Gedroitz to the east¹.

I take this opportunity of expressing my grateful acknowledgements to M. Obrutschew, not only for much information communicated in manuscript, but also for personal assistance in the composition of the following pages, rendered to me during lengthy and repeated visits; all that is of value in the following account of the structure of trans-Baikalia must be ascribed to him.

The Palaeozoic border which in the north and west separates the highland of the Patom from the Lena also appears on the lower Vitim, where it attains a breadth of forty versts. East of the border, as we have mentioned above, the Vitim cuts through the continuation of the highland that extends to the south-west. Somewhat further east, the folded ranges of the Kropotkin mountains make their appearance north of the Vitim; their relation to the Archaean regions has not been clearly ascertained, but it is evident that they form the boundary of the highland.

In the wild country to the south, which lies to the east and north-east of lake Baikal, Kropotkin recognized three independent tectonic elements; namely the two ranges, north Mujskii and south Mujskii, separated by the broad valley of the Maia and the vast plateau of the Vitim, which extends on the south-east of south Mujskii.

We will now attempt an analysis based in the case of the northern region on the works of Lopatin, and on those of more recent authors in that of the southern region.

1. The *range of north Mujskii* consists of two parts: the *Deliun-Uran mountains*, formed to a large extent of syenitic granite, in the north, and the north Mujskii range, using this term in a restricted sense, in the south. The north Mujskii range is an anticline of gneiss striking to the south-west, with an axis of granite and great dykes of diorite: according to Kropotkin, it is directly continued to the south-south-west by the *Bargusin* range. This forms the north-east shore of lake Baikal, and its southern extremity is known as the *Tshivyrskvinskii*. It is connected, as Kropotkin also perceived, with the promontory of Swjatoi Noss, and is continued still further, crossing lake Baikal obliquely and reaching its western shore through the island of *Olkhon*.

The south-east side of the Bargusin range, north of lat. 54° N., descends

¹ The accounts in question by Obrutschew, Gerasimow, and Gedroitz form pamphlets, VI. 1897, X, 1898, XVIII, 1899, and XIX, 1899, in Djel. Dor. The last part contains a geological map of the whole region. Obrutschew gave a brief description, with the sketch of a tectonic map, before the geographical congress in Berlin, 1899; Verh. des siebenten Internat. Geographen-Kongresses, II, 1899, pp. 8-11, map. Also in Aperçu des explorations géologiques et minières le long du Transsibérien, publ. par le Comité géologique de Russie (Exposition Universelle de 1900 à Paris), 8vo, with map. In this work fractures in the east have been assigned independent names (p. 142 et seq.).

precipitously in a mighty cliff to the river valley of the same name; it is formed for the most part, especially towards the south-west, of a porphyritic granite, and to the presence of this rock we must doubtless ascribe the unusually jagged form of the summit. To the south, towards the town of Bargusin, there are foot-hills which present a greater variety of rocks, such for instance as syenite, augitic syenite, and crystalline limestone containing flakes of mica².

The broad valley of Bargusin is partly filled with freshwater Tertiary deposits. The depression is continued far to the north-east in the valley of a tributary river, the Djirga, and *represents the north-easterly continuation of the southern half of lake Baikal*. The watershed between the Djirga and the upper Zipa, as well as the upper course of the Zipa, were visited by Lopatin at a time when there was snow on the ground, and are little known. The valley of the Zipa, however, follows closely the north-east direction of the Bargusin valley, broadens out, includes the great lake of Bauntov, and finally becomes a broad, marshy depression in which the Zipa, accompanied by many small lakes, continues its course. This depression of lake Bauntov and the Zipa forms the boundary between the south Mujskii range and the Vitim plateau.

If we accept this view, and regard the valley of the Zipa as the continuation of the valley of the Bargusin, then both the Mujskii ranges lie to the north of the boundary line thus formed. According to Kropotkin, on the other hand, the *south Mujskii* range is continued through the watershed between the Djirga and Zipa, mentioned above, into the lofty mountains of *Argoda* and *Ikat*, lying east of the Bargusina. These mountains, which descend precipitously to the valley of Bargusin, are very different from the Bargusin range lying opposite to them: they are higher (2,000 meters), and well-rounded domes of gneiss form their summits.

2. *The plateau of the Vitim* is bounded on the north by a long scarp which runs from the region between the Vitimkan and the Vitim-her towards the north-east, and represents the southern border of the depression occupied by lake Bauntov and the middle Zipa. A broad and continuous zone of crystalline schists forms the connexion with the mountains of Argoda and the Ikat. On the inner side of this zone, the plateau consists of granite and syenite covered in places by freshwater Tertiary deposits or by sheets of basalt.

The region lying to the west of the Vitim is traversed by ranges of low hills which run in a north-easterly direction parallel to the great mountains on the Ikat; within the bend of the Vitim, however, and further to the

¹ W. K. Polenow, *Die massigen Gesteine vom nördlichen Theile des Vitim-Plateau*, p. 100; Schwarz had expressed a similar opinion as regards the north-east part of lake Baikal; cf. Kropotkin, *Report on the Expedition to the Olekma and the Vitim*, 1873, p. 345 (r).

east, the surface extends without any considerable elevations at a mean height of 3,000 feet: it was within the bend that Lopatin discovered a vast tract of basalt, which he crossed for a distance of 400 versts. The surface is a dead flat, except where deep and extremely steep-sided ravines have been excavated in it by the Djilinda and the upper Amalat. Lopatin encountered small cones of scoria with circular orifices filled with water, which Polenow regards as the remains of solfataras¹.

The mountains lying east of the valley of Bargusin, on the Ikat and the Argoda, as well as a large part of the plateau of the Vitim, extend still further to the south-west, and unite with the range of *Ulan Burgassai*. We thus reach the south-east shore of lake Baikal, a region which has been studied by Obrutschew and his companions. The spurs of Ulan-Burgassai or the Kurbin mountains are cut through by the Selenga near Verkne-Udinsk, and are continued under the name of Khrebet *Khamar-Daban*; these are joined by the short range of *Khambinskii*, the direction of which diverges to the south-south-west.

The latter chains all consist of gneiss and ancient schists with isolated outcrops of granite. In the Kurbin mountains the strike is east to west and west-north-west, in places north-north-west and north-north-east; masses of limestone run to the east-north-east. In the Khamar-Daban, on the left bank of the Selenga, the ancient rocks strike east-north-east and north-east; thus the Baikal strike probably prevails, but there are already indications of a strike in the Sayan direction. The outline of the mountainous area is not determined by the strike of the rocks, however, but by a long zone of fracture which runs along its southern margin.

The zone of fracture is not quite rectilinear. It begins with the trough at the south foot of the Khambin range, in which lies the *Geese lake*. The inbreak is accompanied by various eruptive rocks, and the Tertiary beds containing brown coal which occur in it are themselves dislocated.

Before reaching the Selenga the lines of fracture on both sides of the Geese lake, which there run to the north-north-east, turn to the north-east and east-north-east; they cross the Selenga at Verkne-Udinsk, and then form, on the north of the Uda, the southern border of the Khamar-Daban and the Kurbin mountains; they are accompanied by numerous outcrops of basalt. The Uda flows here in a long subsidence trough. Even as far as 300 versts east-north-east of Verkne-Udinsk outcrops of basalt are still visible on the north side of this trough. Following the direction of the trough we reach the great lakes which mark the watershed between the Uda and the Vitim. A river channel, the Choloi, and afterwards the middle Vitim itself, continue this long straight depression still further, even beyond lat. 54° N. In this part of its course, according to Gerasimow, the

¹ W. K. Polenow, Die massigen Gesteine vom nördlichen Theile des Vitim-Plateau, p. 348.

Vitim flows in a narrow valley of Archaean rocks. Here and there freshwater Tertiary beds containing fossil fish occur in the valley; they are covered by a sheet of basalt 15–30 meters thick. Further on, along the Ingur and Olnau, this horizontal sheet of basalt broadens out, and is doubtless connected towards the west with the great tracts of basalt on the upper Amalat. It is precisely in this locality, north of the Konda, a tributary of the right bank, that Gerasimow has discovered two volcanic cones. One of these, 5 to 6 versts distant from the Vitim, and situated on the rivulet Kakirtai, consists of loose scoriae and lava; it rises to a height of 200 meters above the surrounding country, and has been named by its discoverer the *volcano of Obrutschew*. The second, named the *volcano of Muschketow*, lies 7 versts from the Vitim, near the little river Ingur, and rises from a platform of basalt to a height of 140 meters; its crater encloses a little lake. The basalt contains fragments of granite¹.

Thus we may regard the long line which extends through the trough of the Geese lake, Verkne-Udinsk, along the course of the Uda, the lakes of the watershed, the Choloi, and the middle Vitim, as a disjunctive line, possibly interrupted by Archaean rocks on the watershed, but continuous in position and direction: it reproduces the features of the nearly parallel line of Bargusin-Zipa.

In its south-westerly part this line, as we have seen, is diverted to the south-south-west in the trough of the Geese lake. The distance from the Geese lake to the Selenga amounts to 120 versts, and from there to the volcanos on the Vitim to about 450 versts, but even beyond this point the Vitim continues to follow the same direction for a great distance.

3. To the east of the trough of the Geese lake rises the short range of the Monostoi mountains, which, contrary to the general rule, trends to the north-north-east: towards the east it joins the granitic range of the *Zagan-Daban*, which extends in breadth from Verkne-Udinsk to Selenginsk, and is continued to the east-north-east by the range of Chudun.

Another trough borders the south side of this range. The whole course of the Tugnui, which enters the Khilok south of Selenginsk, lies within the trough or zone of subsidence. It is accompanied by many eruptive rocks, and the granite horst of the Tugnui mountains rises out of it.

The *trough of the Tugnui* is united west of Selenginsk with that of the Geese lake. A band of basalt 100 versts in length borders its northern edge, forming at the same time the southern edge of the *Zagan-Daban*; then towards the east-north-east the trough becomes constricted, and only small traces of basalt indicate its continuation into the valley of the Kitshenga.

¹ The gold prospector Buiwid appears to have drawn attention to these volcanos and especially to the volcano of Muschketow, *Izviestija Imp. ross. Geogr. Obsch.*, 1898, XXXIV, p. 222.

4. The horst next in succession takes its name from the *Saganskii range*, which is formed of gneiss and ancient schists. It embraces in the south-west the mountains on the Djida and those which extend between this river and the Selenga, as well as the range which crosses from Mongolia and enters Siberia between Ust-Kiakhta and Troitskozavodsk. This last range, however, appears to be only a continuation of the southern moiety of the horst, the northern moiety having disappeared beneath a vast mass of basalt, the *Khrebet asaltovii*, 60 versts in length. This basaltic mass is of great breadth; it is cut through by the river Tshikoi, and right down to the river only basalt is to be seen. To the east-north-east the Archaean range of Saganskii emerges from the basalt; it is continued further to the east-north-east as the Zagan Khunti.

The south border of the Saganskii range also is accompanied by a fracture, the *subsidence trough of the Khilok*, which repeats in all its characters the troughs of the Geese lake and the Tugnui, and like them is constricted towards the east-north-east. Basalts border it on both sides. It seems to die out to the east-north-east, but Gerasimow has shown that this is not the case, and has traced its prolongation first as represented by certain basalts, and then by a very long band of porphyry. The latter turns gradually from east-north-east to north-east, and accompanies the chain of lakes which extends along the west side of the Yablonoi mountains; it passes these and, as Gerasimow has shown, continues even as far as the sources of the Yumargon (tributary of the right bank of the Vitim, lat. 53°N.). The two horsts mentioned above as the Zagan-Daban and the Saganskii, lose their importance towards the north-east, at about 50 versts south-south-east of the volcanos on the Vitim.

5. The most important part of the next horst is formed by the *Malkan mountains*. This range rises in the vicinity of Kiakhta from a veritable flood of eruptive rocks; it increases in breadth to the east-north-east, describes a gentle curve as it passes into a north-easterly direction, and then becomes much narrower again. It is this narrower part of the horst of Malkan, directed to the north-east or north-north-east, which forms, as it descends on the east to the valleys of the Ingoda and the Tchita, the oft-mentioned range of *Yablonoi*: this, according to Gerasimow, proceeds further in the same direction, following the left bank of the Karanga.

The descent of the Yablonoi mountains to the trough of the Ingoda amounts to 800 or 1,000 feet; it presents itself sometimes as a dark cliff scattered over with broken patches of forest, at others as a slope of rocky débris. The Archaean rocks strike to the east-north-east and are cut across by the scarp which runs to the north-north-east¹.

The reason that the scarp of the Yablonoi has hitherto been regarded as

¹ A. P. Gerasimow, Djel. Dor., 1899, XIX, p. 15; W. Obrutschew, tom. cit., p. 108; also Djel. Dor., 1897, VI, p. 26 et passim.

one of the principal step-faults of Inner Asia is probably to be found in the fact that all the horsts and ridges lying to the east of it are cut through by the Ingoda and then by the Shilka. The result is that a traveller coming from the west remains on high ground until he reaches the steep slope of the Yablonoi; thence onwards, however, he crosses no further height, but continues his journey in a long river valley which through the whole of its course to the Khingan flows across the grain of the country.

Space does not suffice for a detailed discussion of the succeeding horsts, all of which trend to the east-north-east. The first of these are: 6. the *Tsherski* range, and 7. the *Daurian* range; a broad band of metamorphic schists is continued from Mongolia into their south-western part. The *Borshtshevoshnii* range is remarkable for its great length; it is cut through by the lower Ingoda and upper Shilka; and beyond Nertchinsk and Strietensk the *Shilka* range inserts itself on the east. Metamorphic schists and greywackes play a considerable part in the formation of the Borshtshevoshnii mountains; lofty ridges and 'goltzi' of granite rise from them. Gedroitz traced a long narrow band of granitic outcrops in the Shilka mountains as far as Uriumskii (lat. 53° 45' N.), a point on the watershed to the Polar sea. To the Borshtshevoshnii range belongs the highest summit of trans-Baikalia, the porphyry mountain *Sokhondo* (2,516 meters), situated at the south-west extremity of the range¹.

A broad band of low country with freshwater Tertiary deposits containing fish remains, and associated with basalts, extends from the south-west into the region of the Tarei lakes and thence into the valley of the Onon-Borsa². Further to the east, as far as the Argun, comparatively recent volcanic rocks extend from Mongolia across the south-west extremity of the following bands: 9. The *Gasimur-Onon*; 10. the *Nertchinskii*; 11. the *Klitchk*; and 12. the *Argun* range, which occupies the south-east part of trans-Baikalia. I use the term bands because in the majority of cases simple lines of dislocation appear to take the place of troughs. Their direction is the same as that of the horsts mentioned above, but they are shorter. In this eastern part of the vertex the ranges are accompanied by marine deposits of Devonian age and thus one of the most striking

¹ Radde has already described it in his *Berichte über Reisen im Süden von Ost-Sibirien*, ausgeführt in den Jahren 1855 bis incl. 1859; Baer und Helmersen, *Beiträge zur Kenntniss des russischen Reiches*, 1861, XXIII, p. 456. Of the mountains at Akcha on the Onon a description has been given by Makerow: *Geological sketch of the gold-bearing beds of the basin of the Amur*, *Izviestija Sibirsk. Otd. Imp. ross. Geogr. Obsch.*, Irkutsk, 1899, XX, no. 3, pp. 45 and 55.

² These fossil fish (*Lycopera Middendorffi*, Müll.) were discovered by Middendorff; the deposits have also been described by Sergijew, *Gorn. Journ.*, 1897, I, p. 71. Details are given by Gerasimow, *Djel. Dor.*, 1899, XVIII, p. 88. Terraces occur on the border of the valley of the Lakes; here there rises the granite ridge of Adon-tchilon, known for its mineral veins.

characters of the central part is lost. These Palaeozoic sediments extend to the Shilka. Metamorphic schists and greywackes then make their appearance, and from Strietensk and Nertchinsk onwards to the south-west attain a great extension in the region of the river Onon. Carboniferous sediments may also be present, and there are besides some gently folded beds which probably belong to the Angara series.

The volcanic rocks extend from Mongolia along the Argun to the bend of the river near Alt-Tsurukhaita (lat. $50^{\circ} 15' N.$); then they again cross the Argun above Nertchinskii-Savod, and basalt, rhyolite, and trachyte appear over a large area. According to Gedroitz, not only sheets of lava are to be seen, but also isolated domes, volcanic bombs, and all the signs of recent eruptive activity.

South of Nertchinskii-Savod the ancient rocks strike N. by E. (10° – 20°), while north of this locality and particularly *north of lat. $52^{\circ} N.$, the strike of the rocks is entirely different and is directed to the north-north-west.* We have now reached the Great Khingan, and with it the eastern boundary of the vertex.

Among the most important results obtained by Gedroitz is the proof that the western border of the Great Khingan lies above the confluence of the Argun and the Shilka; it reaches the Argun a little below Nertchinskii-Savod, and the Shilka between Gorbitza and Voskressinsk¹.

In a general way we may sum up the result obtained by Obrutschew and his colleagues as follows:—

In the whole region extending from the mountains north of the Baikal to the Argun, the folding strikes in the Baikal direction (east-north-east to north-east); it is only towards the southern end of the lake that the Sayan direction (west-south-west) makes its appearance in a few isolated localities. In the neighbourhood of the amphitheatre the folding is certainly of pre-Cambrian age; on the other hand, in the south-east of trans-Baikalia, the Devonian, and perhaps even the Angara beds, are involved in it. We agree with Obrutschew that the folding stresses continued to operate in the south-east, though with diminished intensity, up to comparatively recent times².

The fissures or disjunctive lines follow the same general plan. With the exception of some short cross fractures which may be observed in the south-western part of the Zagan-Daban and the Saganskii horst, these long lines also follow on the whole the Baikal direction. If we include the most northerly regions, we see that the line from Olkhon through the valley of the Bargusin runs almost to the north-east; that from the north of the Geese lake, the Uda, and the Vitim, almost to the east-north-east; and all the following lines up to the east side of the Daurian mountains present an

¹ Prince Gedroitz, Djel. Dor., 1897, VI, p. 124; 1899, XVIII, pp. 141 et seq.

² W. Obrutschew, Djel. Dor., 1899, XIX, p. 115.

arcuate course directed to the east-north-east, but with a slight convexity to the south-east, whilst east of this point the direction is rectilinear and almost due east-north-east.

In this way three successive wedge-shaped fields of subsidence originate along the troughs south-east of lake Baikal, namely at the Geese lake, on the Tugnui, and on one part of the Khilok.

These fissures are accompanied for long distances by eruptive rocks. The porphyries and their tuffs appear throughout to be older than the basalts. The fissures themselves are of various age, and the craters on the Vitim indicate a persistence of volcanic action up to a late period.

The disjunctive lines and troughs find their sharpest expression in the western part of the region under discussion, and there folds of recent date do not exist. It seems *as though tensions had arisen subsequently to the folding*, and that these tensions manifested themselves in dislocations following a direction which, if not identical with that of the folds, was at least in the main the same, i.e. to the east-north-east or north-east.

Lake Baikal. This lake is more than 600 versts in length; if it were transferred to Europe it would extend as far as from Trieste to Prague. It attains a breadth of somewhat more than 80 versts.

Its shores are formed in great part of steep cliffs; its depth is very considerable. The works of Dybowski and Godlewski, as well as the more recent soundings of Drischenko, enable us to form an approximate idea of the configuration of this submerged abyss¹.

In the part situated to the south of the mouth of the Selenga, and particularly towards the shore lying north of the Angara, the depth of the lake over a considerable area amounts to more than 700 sagenes (1,493 meters), and the deepest sounding hitherto recorded is 1,610 meters. Taking 512 meters as the height of its surface above the sea, then the bed of lake Baikal descends 1,098 meters below the sea-level. Irregularities, however, occur in the depression. In the first place, the alluvial cone formed by the sediments of the Selenga is so immense that, from off the mouth of the river to beyond the central part of the lake, the depth does not exceed 200 to 300 meters. To the south-west of the delta, between it and the deepest part of the lake, an isolated ridge rises from depths of 500 to 800 meters to within 70 meters of the surface².

North of the delta considerable depths occur between Swjatoi Noss and Olkhon, and around Swjatoi Noss the bottom was frequently not reached at a depth of 1,000 meters. West of Swjatoi Noss, towards the middle of the lake, four little reefs of gneiss, the *Ushkani*, rise high above the water from depths of 600–700 meters. The northern part of the lake, so far as it is

¹ T. K. Drischenko, p. 227, Survey of lake Baikal in 1896, Izviestija Imp. ross. Geogr. Obsch., 1897, XXXIII, pp. 210–241, maps.

² According to Drischenko, p. 227, it is probable that this ridge is at least 23 versts long.

known, is everywhere more than 400 sagues (853 meters) deep, even almost up to its shores.

Kropotkin, as was mentioned above, regarded the promontory of Swjatoi Noss and the island of Olkhon as continuations of the Bargusin range. All subsequent observations tend to confirm this opinion. Thus lake Baikal may be regarded as consisting of two fairly equal parts, joined together obliquely end to end. The south end of the northern basin lies in the Maloe More behind the island of Olkhon. The north end of the southern basin is continued by the valley of Bargusin. Lake Baikal is thus *a twin lake*. While its breadth as a whole amounts to 80 versts, the greatest breadth of each part is only 50–55 versts.

The Selenga, which is by far the most important affluent of the lake, enters it transversely, as it were, through the eastern shore; the Angara, which is the outflowing river, similarly leaves it at right angles, and its course is not in any way indicated by the outline of the lake. The position of the two rivers causes the one to appear as the continuation of the other, as though they had once been parts of a single stream which was cut in two by the formation of the lake.

Violent earthquakes which have visited this region in recent times have certainly been the cause of subsidences in the alluvial land of the delta (I, p. 32), but they have not produced any appreciable tectonic change.

Georgi, who visited lake Baikal in 1772, showed great penetration in calling special attention to the steep shores, 'which reveal a section of the mountains; the fragments of rock in the water; the round, often closely adjacent islands separated by fissures and representing the ruins of ancient mountains; and the appalling depths close to the cliffs.' All this, he thinks, shows that the lake had a violent origin. The space it occupies he regards as the continuation of the valley of the upper Angara, which by some cataclysm of nature, such as a falling in of the crust, has become the bed of the lake¹.

Erman also regards the lake as an inbreak. Tscherski, who has contributed so much to its exploration, conjectured that it was originally part of an extremely ancient valley of erosion, modified later by folding. Obrutschew reverted to Erman's opinion, and thought that the lake had been formed by a disjunctive process; in support of this view he referred to the subsidence troughs of trans-Baikalia².

Lake Baikal is not a valley of erosion; neither is it a trough, like the Rhine valley, let down along rectilinear step faults, nor a rectilinear fissure like lake Rudolf. The gently curving outlines of its two parts are related to the pre-Cambrian folding in such a way that in some places, as in the

¹ J. G. Georgi, *Bemerkungen zu einer Reise im Russischen Reich im Jahre 1772*, 4to, St. Petersburg, 1775, I, p. 150.

² Obrutschew in *Izviestija Sibirsk. Otd. Imp. ross. Geogr. Obsch.*, Irkutsk, 1897, XXVIII, p. 14.

Maloe More, the course of the cliffs almost coincides with the strike of the folds, while elsewhere, as further to the south-west beyond the Buguldejka, the folds are cut by the coast transversely. On the other hand, we must admit that the course of these steep shores closely resembles that of the disjunctive lines of the vertex. The fact that the two moieties of which the lake consists are so very similar to each other and so intimately related in position, is alone sufficient to show that they must have had a common origin; it is probable, then, that the cause which produced them acted over a still more extensive area; and lake Baikal itself, therefore, would appear to be the result of the same tensions as gave rise to the subsidence troughs of the Geese lake, the Tugnui, and the Khilok.

An additional point of resemblance with these disjunctive valleys is furnished by the presence of deposits containing brown coal, probably of Tertiary age, on the east shore of the lake near the Malinovskaia, opposite the Angara. Jatschewski has described them; their bedding is fairly horizontal¹.

On the other hand, there are two fundamental points of difference.

The first of these is the great breadth of the lake. Though the trough of the Ingoda is 10–15 versts broad—a breadth frequently attained by the disjunctive valleys—and though we find even wider troughs in the Selenga, yet none of them approaches that of lake Baikal. The horst of Bargusin is reduced to the breadth of the island of Olkhon, as though large slices of it had subsided and disappeared.

The second point of difference consists in the absence of eruptive rocks. Only in one locality, near Kultuk, at the southern extremity of the lake, does basalt appear. This, however, represents the end of a flow which filled the ancient bed of the Irkuta, and forced this river, as has been shown by Tscherski, to hollow out its existing bed along a course directed towards the Angara. Herr Obrutschew informs me that in the conglomerates of the Angara series above and below Irkutsk pebbles of porphyry and felsite, and of corresponding tuffs and breccias, are found in great abundance, although such rocks are not known in place within a wide radius.

As regards the age of certain parts of the shore of lake Baikal, we possess the following data: the above-mentioned porphyries are possibly posthumous signs of an older disjunctive movement; they are older than the conglomerates with which the Angara series on lake Baikal begins. Near the Angara this plant-bearing series breaks off steeply towards the depths of lake Baikal; this stretch of coast is therefore more recent than the corresponding fragment of the Angara series. The south-east shore

¹ L. Jatschewski, Geological Explorations along the Siberian Railway south of lake Baikal, *Djel. Dor.*, 1898, VII, pp. 20–22. The dip of the beds is 12° NW., and the elevation above the lake is inconsiderable.

near Malinovskaia is older than the brown coal which rests against it. The abandoned valley of the Irkuta, which entered lake Baikal at Kultuk, is older than the stream of basalt which flowed into it.

Hence we may conclude that the southern part of lake Baikal is more recent than the Angara series (apart from the pebbles of porphyry), and older than certain sections of the Tertiary series; probably older also than the basalt of Kultuk.

The fauna of lake Baikal presents a number of interesting features which have a special importance as bearing on the question of the age of the lake.

Alexander von Humboldt called attention to the fact that seals are known not only in the Caspian sea and in lake Baikal, but also far east of lake Baikal; in the little freshwater lake of Oron on the Vitim, and he regarded this as an indication of the original continuity of these waters¹. Oscar Peschel explained lake Baikal as a fjord of the ancient glacial sea of Siberia; the seals having been prevented from returning by an elevation of the land. This hypothesis was opposed by Tscherski. He emphasized the fact that the waters of the Arctic Ocean are not known to have extended further south in post-Tertiary times than lat. $67\frac{1}{2}^{\circ}$ N., while Tertiary and post-Tertiary sediments, not of marine but of freshwater origin, extend far and wide around lake Baikal. The Angara may have extended in recent times into considerable lake-like expansions, and with such a configuration of the surface the seals might easily have wandered in.

The question as to an ancient communication with the sea was again raised when Dybowski showed in 1884 that *Lubomirskia baikalensis*, a sponge of lake Baikal, also lives in Behring sea². It may, however, be pointed out that another sponge, *Spongilla Carteri*, Bow., the original habitat of which is the Indian peninsula between Bombay and Madura, has also been found in great abundance in central Europe at Fured, in lake Balaton³; we will therefore follow Tscherski's suggestion and turn our attention to the freshwater forms.

The investigations of Kessler and others have shown that the Siberian rivers possess in common a number of typical species, such as *Accipenser ruthenus*, which are certainly older than many of the existing watersheds. Herr Steindachner has been kind enough to remind me that not a few typical fishes of European rivers, such as *Lota vulgaris*, *Cyprinus carpio*,

¹ North of lat. 57° N. the Vitim broadens out like a lake; this is connected by a strait towards the east with a second smaller sheet of water: the latter is lake Oron.

² W. Dybowski, Notiz über eine die Entstehung des Baikal-See's betreffende Hypothese, Bull. Soc. Imp. Nat. Moscou, 1884, LIX, pp. 175-181. Here there is a detailed exposition of the views of Humboldt, Peschel, and Tscherski.

³ Resultate der wissenschaftlichen Erforschung des Balatonsee's, herausgegeben von der Ungarischen Geographischen Gesellschaft, 1897, II a, E. Vángel, Coelenterata, pp. 68, 69.

Carassius vulgaris, *Gobio fluviatilis*, *Phoxinus laevis*, *Cobitis taenia*, and others, actually penetrate into the basin of the upper Amur¹. Dybowski's investigations of the gastropods of lake Baikal led, on the other hand, to the instructive result that these do not possess a distribution like that of the freshwater fish mentioned above, but represent, save for a few exceptions, an independent colony in the midst of Siberia².

The observations of Heude on the fluviatile mollusca of Nanking, and the discovery by Anderson of the great keeled Paludinas, which inhabit the lake of Tali, in Yunnan, became known almost simultaneously with the work of Dybowski; and Theodore Fuchs at once recognized the importance of these new facts in relation to the freshwater Tertiary faunas of Europe. He declared that the character of the Levantine Paludina and Unio beds of Europe was Japano-Chinese. At the same time Fuchs observed that the Melanopsides, which play so large a part in the Pontic stage, do not possess corresponding representatives in eastern Asia, but are first met with in New Caledonia. He described lake Baikal as the 'most northerly outpost of a rich fauna of peculiar inland Mollusca, destined to populate the freshwaters of the regions situated to the south and east of it'³.

Shortly afterwards Széchényi and Lóczy brought back a large collection of shells from the lake of Tali, and Neumayr was thus able to confirm the unity of the freshwater Levantine fauna in Europe during late Tertiary times, and the fauna now living in eastern Asia and North America; as well as the different distribution of the two genera Melanopsis and Congeria, which are characteristic of the Pontic stage⁴.

Thus facts began to accumulate, all of which tended to show that the fauna of lake Baikal was derived, in part at least, not from the north, but rather from the south, east, or west⁵.

Finally, shells like those characteristic of lake Baikal were found in the Tertiary deposits of Europe. Bittner was the first to discover them on

¹ B. Dybowski, Vorläufige Mittheilungen über die Fischfauna des Ononflusses und des Ingoda in Transbaikalien, Verh. k. k. zool. bot. Ges. Wien, 1869, XIX, pp. 945-958; Zur Kenntniss der Fischfauna des Amurgebietes, op. cit., 1872, XXII, pp. 209-222; S. Herzenstein and N. Warpakhowski, Note on the fish fauna of the region of the Amur and the adjacent regions, Travaux Soc. zool. Saint-Petersb. 1887, XVIII, p. 58. Nikolski has expressed the view that certain correspondences exist between the fish faunas of lake Balkhash and the Lob Nor; Nikitin has opposed this view for geological reasons; a fresh examination is much to be desired; Travaux Soc. Nat. Saint-Petersb., XVI and XVIII, N. J. f. Min., 1887, pt. I.

² W. Dybowski, Die Gastropoden-Fauna des Baikal-Sees anatomisch und systematisch bearbeitet, Mém. Acad. Imp. Sci. Saint-Petersb., 1875, 7^e sér., XXII, no. 8, 73 pp.

³ T. Fuchs, Ueber die lebenden Analoga der jungtertiären Paludinen-Schichten und der Melanopsiden-Schichten Ost-Europa's, Verh. k. k. geol. Reichs., 1879, pp. 297-300.

⁴ M. Neumayr, Ueber einige Süßwasser-Conchylien aus China, N. J. f. M., 1883, II, pp. 21-26.

⁵ A similar view has also been expressed by R. Credner in 1887, Peterm. Mitth., Ergänzungsheft No. 86, pp. 17, 59; and 1888, Ergänzungsheft No. 89, p. 25.

a fairly low horizon in the lignite deposits of Carinthia; subsequently Brusina described the genus *Baglivia* (which is allied to Dybowski's *Liobaikalia*) from the Pontic beds of Croatia, and afterwards Lörenthey met with the same fossil in the upper Pontic sediments of South Hungary¹.

R. Hoernes has shown that similar shells occur scattered through a fluviatile deposit which is intercalated with beds of Sarmatian age; and remarks on the frequent presence of seals in these deposits. Thus Hoernes is led to conclude that lake Baikal has derived its fauna, not from the Arctic Ocean, but from the late Tertiary inland sea, although there may never have been any direct communication between the two².

The facts so far as they are now known may be summed up as follows:—

Shells of the Levantine stage have been found at Omsk. But the forms resembling those of lake Baikal which occur in the valley of the Danube are found not in Levantine but in Pontic and Sarmatian deposits, and a few with less marked affinities occur at even lower horizons. At the same time lake Baikal contains many peculiar forms, and, among animals of other classes, a few species which indicate a marine origin. Forms obtained by inheritance at second and third hand are united in lake Baikal.

Thus we see that a few species of the Pontic, perhaps also of the Sarmatian epoch, have persisted in this part of Siberia down to the present day, and this in all probability is owing to the fact that the depths of lake Baikal afforded them a necessary refuge. Drischenko's tables show that the temperature at a depth of 25 sagues (53 meters) amounts to about 4° C., but even at 500 sagues (1,066 meters) it does not sink lower than 3·4° C.³

We must therefore suppose that lake Baikal was already in existence in the later part of the Tertiary aera.

These considerations, and in particular the relations between the faunas of Omsk and Tali, suggest a number of questions relating to the more recent history of the continent of Angara.

Ferdinand von Richthofen believed that the site of the existing desert

¹ A. Bittner, Die tertiären Ablagerungen von Trifail und Sagor, Jahrb. k. k. geol. Reichs., 1884, XXXIV, p. 513. *Hydrobia* (*Godlewskia* ?) sp., allied to *Godlewskia turri-formis*, Dyb.; p. 514, *Valvata* (?) *Rothleitneri*, and a species the sculpturing of which remotely resembles that of *Valvata baikalensis*, Gerstf.; Brusina, Spir. Fauna fossile terziaria di Markusavec in Croazia; Glasnik, Soc. hist. nat. Croatica, Agram, 1892, VII, pp. 113–210; E. Loerenthey, Neuere Daten zur Kenntniss der oberpontischen Fauna von Szegzárd, Természetr. Füzet. Budapest, 1895, XVIII, p. 320. Brusina found together with *Baglivia* and the typical representatives of the Pontic stage such as *Melanopsis vindobonensis* and *Congerina subglobosa*, forms of the Caspian sea such as *Caspia* (Mém. cit., p. 119).

² R. Hoernes, Sarmatische Conchylien aus dem Oedenburger Comitatus, Jahrb. k. k. geol. Reichs., 1897, XLVII, pp. 74, 75; and Die Relictennatur der Fauna des Baikal-See's, tom. cit., pp. 89–94. Here Penck's distinction is appropriate between a relict fauna and a relict lake.

³ T. K. Drischenko, Survey of lake Baikal in 1896, p. 241.

of Gobi between long. $75^{\circ} 30'$ and $114^{\circ} 30'$ E. (about) was once covered by a sheet of water, the length of which was approximately equal to that of the Mediterranean of Europe. So great an extension would seem to imply an arm of the sea, and Richthofen connected this hypothesis with the Chinese name 'Han-hai' or dry sea. From the position of the sediments Richthofen was led to suppose that the coast line of this sea lay in the west, i. e. around Kashgar, Yarkand, and Kiria, at a height of about 1,500 meters, and in the east at 1,200 meters¹.

Subsequent observations have shown that the extension of these sediments is even greater than Richthofen supposed, especially towards the upper Hoang-ho, and that they occur at still greater heights in the mountain regions. As a rule they are brownish red fine-grained conglomerates, red and yellow friable sandstone, and red clay, together with gypsum and rock-salt, the presence of which served to support the hypothesis of their marine origin. A well-known example is the *Masar-Tag* on the Khotan-Darya, which rises about 500 feet above the middle of the plain. According to Prjewalski and Dalgleish, it is formed of two ridges. They consist of red clay and alabaster, and are without doubt the remains of sediments which originally possessed a very wide distribution². In the eastern Gobi, the sediments of this group form the sharply defined horizontal sockels or *bjel* above which rise the remains of mountain ranges which must at one time have been surrounded by the waters in which these sediments were deposited.

The deep furrow above Lan-tshou-fu, which the Hoang-ho has cut in these red, horizontal, gypsiferous deposits, sometimes 3,000 feet in thickness, has been described by Prjewalski, Lóczy, and other travellers. Obrutschew has shown that these beds may be traced far up into the valleys of the Nan-shan, that they enter the Tsaidam, and towards the south extend to Min-tshou in south Kansu³.

Organic remains are very rare in these sediments. Lóczy has shown that in the Wei valley near Tsing-tshou (east of lat. 160° E.) they contain *Stegodon insignis*, a species of the Siwalik fauna, and in the ravines of the Hoang-ho, mentioned above, he has found existing species of *Bithynia* and *Lymnaea*, as well as the remains of mammals. For this reason Lóczy, although he found not only gypsum and rock-salt but also kieserite, maintained the view that these deposits are not of marine origin. The whole of the highlands, stretching on the one hand to Ling-tsi-thang, and on the other far south of Yunnan, perhaps as far as Hundes, where the

¹ Baron F. von Richthofen, *China*, I, pp. 24, 25.

² E. D. Morgan, *Orography of Northern Thibet*, Supplementary Papers, R. Geogr. Soc., 1890, III, p. 13; also Sven Hedin, *Durch Asiens Wüsten*, 8vo, Leipzig, 1899, I, p. 328. It was north of these hills that Sven Hedin saw his caravan destroyed and nearly lost his life.

³ Obrutschew, *Izviestija Imp. ross. Geogr. Obsch.*, 1894, XXX, pp. 98, 723, 727 et seq.

high-lying freshwater deposits were described by Griesbach, was covered at the time of the formation of the red sediments on the upper Hoang-ho and the Wei by extensive lakes without outflow. Kuku-nor and the existing salt lakes of Thibet would be the remains of these lakes ¹.

This conclusion has received important confirmation from a discovery made by Obrutschew; on the way from Urga to Kalgan, near the plateau of Khuldyin-gobi and 25 kilometers south-south-east of the salt lake Iren-dabassun-nor (about lat. 43° 30' N., long. 112° E.), he found in deposits of this kind which form the butte Djadjin-Shanda the remains of a rhinoceros or *Aceratherium* of middle or late Tertiary age ².

The freshwater deposits of such wide extension in the region of the Rocky mountains of North America have given occasion to great differences of opinion, to which Davis in particular has given expression. The presence of intercalated beds of gypsum is indeed an indication not of a damp, but of a dry climate, such as exists at present. It is certain that factors of very different kinds, running water, cones of debris, and subaerial influences, must have played their part, especially on the margin of the plain and perhaps on the 'bjels' of the desert mountains ³; this has been pointed out by Penck when proposing the term 'continental formations.'

In Asia not only gypsum and salt, but even kieserite, occur as the extreme products of evaporation. On the other hand, it must be observed that the existence of great terrestrial animals implies vegetation, and consequently a certain amount of moisture.

We are now in a position to conclude with some assurance that the so-called Han-hai or Gobi beds are not marine deposits; that for a considerable period, especially during certain epochs of the Tertiary aera, large parts of Asia were covered by freshwater lakes of vast dimensions, together with numerous smaller ones, some of which were without outflow, and that these sheets of water were subject to fluctuations of level due to climatic changes. The magnificent *Aralia* leaves from the Tertiary beds of Greenland, which Nathorst has deposited in the museum at Stockholm, represent scarcely a greater contrast between past and present than the remains of great herbiferous mammals in the horizontal marl beds of Khuldyin-gobi.

Many problems of great interest arise out of this subject; foremost

¹ L. Lóczy, *Ost-Asien, Reise des Grafen Bela Széchenyi*, I, 1893, pp. 822-827, III, 1899, pp. 212-215; C. L. Griesbach, *Geology of the Central Himalayas*, *Mem. Geol. Surv. India*, 1891, XXIII, pp. 82-87; the mammalian remains of *Hundes* lie about 14,000-15,000 feet above the sea.

² E. Suess, *Ueberreste von Rhinoceros sp. aus der östlichen Mongolei*, *Verh. russ. k. min. Ges.*, 1899, 2. Ser., XXXVI, pp. 171-180; W. Obrutschew, *Central Asia, North China, and Nan-shan*, publ. by the Imp. ross. Geogr. Obsch., 4to, St. Petersburg, 1900, I, pp. 88 et seq.

³ W. M. Davis, *The freshwater tertiary formations of the Rocky Mountain Region*, *Proc. Am. Acad. Arts and Sci.*, Boston, 1900, XXXV, no. 17, pp. 345-373; A. Penck, *Morphologie der Erdoberfläche*, 8vo, 1894, II, pp. 24-36.

among them is the general question as to the origin of red coloration, so especially important in connexion with the formation of the Rothliegende and similar deposits. With regard to the fauna our knowledge has so far advanced that we can now distinguish the following elements:—

(a) The relict forms of lake Baikal, which have survived from Sar-matian, Pontic, or even earlier times; (b) the relict forms in the lake of Tali, which have survived from the Levantine period, as represented by the beds of Omsk; (c) the European forms, which are associated with Chinese forms in the upper Amur; and (d) the fauna of Inner Asia properly so called, with peculiar Cyprinides.

West border of lake Baikal. The narrow belt of ancient rocks bordering lake Baikal on the west, or at least that part of it which lies north of the Angara, is a horst of very peculiar character, for it is bounded by two fractures which differ both in age and origin. The western fracture is a true fault, dating from very remote, perhaps from pre-Cambrian times, which cuts through the pre-Cambrian folds in complete independence of their strike. The eastern fracture forms a part of the western shore, both of the northern and southern half of the lake: it appears rather as if it had been produced by tension and was not so completely independent of the strike of the folds as the western fracture. This narrow horst is the only fragment of the innermost part of the vertex which has remained visible, and at the same time the only spot where there can be any hope of obtaining information as to the mutual relations of the two directions of strike in the pre-Cambrian folds.

Although there are numerous treatises on this region of more recent date, yet the work of Tscherski, in particular his geological map of lake Baikal, still remains our chief source of information¹.

Let us first cast a glance at the structure of the shore.

Near Kultuk, at the extreme south-western end of the lake, the shore is formed by Archaean rocks, except where the basalts previously mentioned occur. These Archaean rocks form the *Elovskii Khrebet*, a continuation of the Tunkin Alps; they are traversed by the somewhat recently eroded valley of the Irkuta; and they form a narrow belt about the outflow of the Angara.

The Angara series, which is directly superposed upon these rocks, now reaches the lake. At its base lies gold-bearing conglomerate with boulders up to half a meter in diameter. The Angara beds rise to a height of 384 meters above the lake, and end in steep cliffs which descend below the water to considerable depths. The dip of the beds is 50° to the south-south-west².

¹ Published under the editorship of Muschketow, *Mater. Geol. Russ.*, 1889, XIII.

² Tscherski, in the Russian edition of K. Ritter, *Geography of Asia, East Siberia, lake Baikal, and trans-Baikalia*, 1895, II, p. 163, r.

Soon Palaeozoic rocks appear, the continuation of the broad and lofty Onot range, and shortly after these give place to the Archaean rocks of the rugged *Primorskii Khrebet*, which now forms the border of the lake. This range forms the western horst mentioned above. It reaches a height of 4,500 feet (1,372 meters) above lake Baikal, or 1,884 meters above the sea; its slopes, descending rapidly below the surface of the lake, reach to the bottom, so that their total height amounts to 2,800 or 2,900 meters. The sources of the Lena lie close to its western edge; the island of Olkhon, which rises to a height of 800 meters above the lake and forms a precipitous mountain range, branches off from it.

Further to the north the breadth of the *Primorskii Khrebet* diminishes. Once more only a narrow belt of Archaean rocks borders the lake; then, at cape *Elochin* (lat. 54° 35' N., about), the Palaeozoic sediments reach the shore for the second time, but soon the Archaean rocks reappear and continue along the lake to its northern end.

The following data as to the strike of the pre-Cambrian rocks are taken from the works of Tscherski, except in those cases where some other source is mentioned.

In the *Elovskii Khrebet*, as in the Alps of Tunkin, the west-north-westerly strike of the Sayan mountains prevails. Even on cape *Baklanii*, not very far south of the Angara, Jatschewski found the direction to be NW. (320°–330°) in the gneiss, with the dip vertical; then variable, sometimes almost due north and south with a dip of 40° E.; then on the Angara the north-westerly strike shows itself again in beds of crystalline limestone¹.

Then follows the region north of the Angara, in which the Archaean rocks are not visible. When they reappear, in the southernmost part of the *Primorskii Khrebet*, the north and south direction becomes more and more marked.

At the mouth of the *Goloustna* (40 versts north of the Angara) the gneiss runs in steep narrow folds with a north-north-west to north strike, and this direction is maintained for a considerable distance. Where the *Primorskii Khrebet* increases in breadth on the *Buguldejka* (100 versts from the Angara) the east-north-east or north-east strike of the Baikal region comes in, and from here onwards dominates the island of Olkhon and the whole of the east.

The Baikal direction, as may be perceived from *Idjitzki's* observations, now appears all along the west side of the *Maloe More*². Much further north, towards the northern end of the lake, Tscherski marks on the map

¹ L. Jatschewski, Geological explorations along trans-Siberia south of lake Baikal, *Djel. Dor.*, 1898, VII, pp. 2–6.

² N. *Idjitzki*, Geological investigations in the government of Irkutsk in 1895, *Djel. Dor.*, 1898, VII, pp. 113–153, map.

two trend lines striking across the lake, but in the region we are describing deviations exist, which are perhaps only local, but sufficient to render it impossible to arrive at any definite plan of the west shore.

If we confine our attention to the more precisely known tract which extends from Kultuk to the northern end of the Maloe More, a distance of about 320 versts (343 kilometers), we shall find that it is divided into two principal regions: one on the west, characterized by the Sayan or west-north-west to north-west strike; and the other on the east, characterized by the Baikal or east-north-east to north-east strike: the first of these includes the Elovskii Khrebet, the second the island of Olkhon, and *between these two principal regions the folds become crowded together and acquire a more or less north to south direction.*

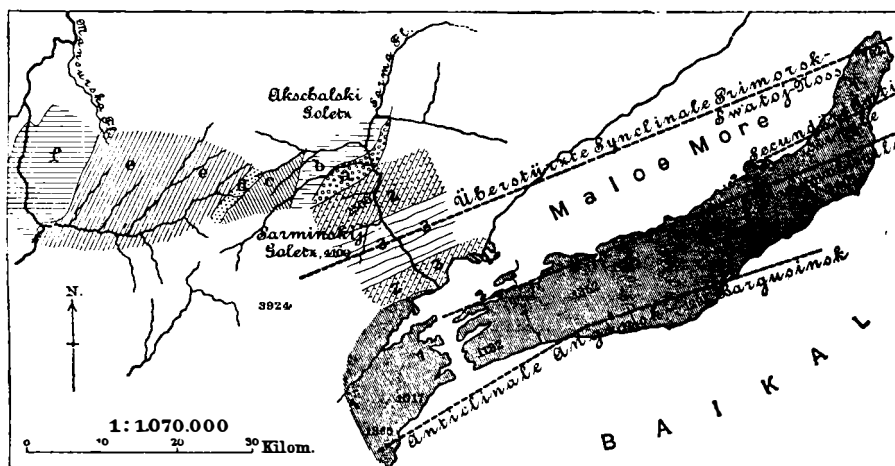


FIG. 4. The Island of Olkhon. (After Obrutschew.)

1, 2, 3. Archaean rocks; a to e, metamorphic schists; f, Cambrian limestone.
(The heights are given in feet above the level of the lake.)

The course of the individual folds in the Primorskii Khrebet shows according to Tscherski's map a very gentle curvature from north-east to east-north-east, so that starting from this middle region a direction is reached which is very nearly that of the island of Olkhon. We possess a recent description of this island by Obrutschew. The bands of gneiss, ancient schist, and crystalline limestone reveal the presence of two long anticlines and two synclines striking obliquely across the lake to the east-north-east. They cross Maloe More and Olkhon at an acute angle, and then reach the east coast and the mountains of Bargusin, south of Swjatoi Noss, as well as the promontory itself, precisely as Kropotkin had supposed.

In Olkhon the folds are steeply upturned, and the syncline which strikes through Maloe More is, as recognized by Tscherski and confirmed

by Obrutschew, *overturned to the north-north-west*; the beds dip to the south-south-east ¹.

The facts furnished by the Primorskii Khrebet are of such importance that we will briefly recapitulate them.

In this narrow horst the pre-Cambrian folds having the Sayan direction approach those having the Baikal direction. The prevailing rock is hornblende gneiss. As the folds converge they assume a more meridional direction, and in all likelihood unite 50 to 100 versts north of the Angara in a common north and south strike. This circumstance indicates compression towards the axis of the vertex.

At the same time a syncline overturned towards the interior may be recognized in the island of Olkhon.

The primitive folds of the vertex are therefore crowded towards the interior. They are cut off on the west border of the Primorskii Khrebet by a fracture running approximately north-north-east, which is completely independent of the strike of the folds of the vertex. This fracture, however, determines the strike of the Cambrian and Silurian marginal folds, which run strictly parallel with it in a north-north-east direction, and it is precisely in this region that they are overturned towards the interior, that is to the north-west.

The marginal folds thus indicate a contraction of the surface, but the axis of this contraction probably lies further west, and corresponds with the axis of the amphitheatre of Irkutsk.

The eastern face of the Primorskii Khrebet, which forms the west shore of lake Baikal, is, like the shores of the island of Olkhon, of much more recent origin, and belongs to the system of tension-fractures or disjunctive-lines of the vertex.

Mountains south of lake Baikal. Between the Selenga and the most southern extremity of lake Baikal, and thence further to the west as far as the great ranges north of lake Kossogol, a phenomenon is observed which is apparently unknown in those easterly parts of the vertex with which we have so far been concerned. This is the occurrence of fragmentary basaltic plateaux on the summits of many of the loftiest 'goltzi.' All the existing data combine to show that these plateaux are older than a considerable part of the existing valleys which have been cut deep into the Archaean

¹ K. Ritter, *Geography of Asia*, II, pp. 149, 232, 456, 464, 480; for the north, II, pp. 514, 589. While restricting the inversion to the syncline in the Maloe More, I follow the detailed description which Obrutschew has given of the folds in Olkhon; Obrutschew, *Oro-geological observations on the island of Olkhon and the west of the Pri-Baikal*, *Gorn. Journ.*, 1890, III, pp. 429-457, maps. For the stratified succession see W. Obrutschew, *Ein Ausflug in das goldführende Gebiet der Flüsse Sarma und Ilikhta im westlichen Baikargebirge*, *Izvestija Sibirsk. Otd. Imp. ross. Geogr. Obsch.*, Irkutsk, 1897, XXVIII, pp. 1-24, map. The author distinguishes a Huronian series between the Laurentian gneiss-granite of Olkhon and the Cambrian-Silurian series.

floor. On the other hand, some observers, and in particular Jatschewski, have shown that in certain localities streams of basalt have flowed down into existing valleys and have even spread over the gold-bearing alluvium of the valley bottom. These observations, apparently contradictory, may doubtless find their explanation in the view already indicated that the period of the basic eruptions in Siberia was of considerable duration. The recent cones of scoria which are met with here and there do not permit us to suppose that this period is even yet concluded.

In this manner the formation of valleys among these mountains has always been liable to disturbance and interruption. The stream of basalt already mentioned as occurring at Kultuk, near the south end of lake Baikal, and the deep and winding ravine which it has compelled the Irkuta to cut through the Elovskii Khrebet, are examples both of such an interruption and of the force of erosion. If we follow the course of the Irkuta and approach the entrance to the ravine from above, we reach a place where the valley broadens out, and towards the east the ancient bed of the Irkuta, now occupied by the Kultushna and interrupted by a low watershed, leads us out to Kultuk. Terraces occur in the broadened part of the valley up to a height of 214 meters above lake Baikal and 99 meters above the Irkuta. Along its margin sandstone is visible probably of Tertiary age and containing trunks of trees and pebbles of basalt; this is capped by streams of basaltic lava which attain a considerable elevation above the lake. It was these lavas which, according to Tscherski, turned aside the Irkuta ¹.

The trans-Siberian railway runs from Irkutsk into the valley of the Irkuta, and, following a ravine, passes through the ridge of Syrkusun, in which the Archaean rocks strike west-north-west and north-west; a sheet of basalt caps the highest dome of this ridge at a height of 1,610 meters (1,098 meters above lake Baikal). The railway then follows the original bed of the Irkuta, now occupied by the Kultushna, and at length reaches the south end of the lake ².

From Jatschewski's description of the valley of the *Djida* we perceive that a fault-trough exists on the north side of the lower course of this river. It forms in all likelihood the continuation of the united troughs of the Geese lake and the Tugnui. The Djida itself intersects a granite ridge 218 meters high, in order to reach the broad valley of the Selenga; but on its north side, above the granite ridge, there is a caldron elongated from east to west, at the bottom of which lie the two lakes

¹ K. Ritter, *Asia*, I, pp. 128, 145; II, 2, 14; also Tscherski, *The spur of Elov*, *Izviestija Sibirsk. Otd. Imp. ross. Geogr. Obsch.*, Irkutsk, 1875, VI, no. 4; Velain marks the lavas of Baikal as augite andesite with Labrador felspar; *Notes géologiques sur la Sibérie orientale d'après les observations faites par M. Martin*, *Bull. Soc. géol. de Fr.*, 1885, 3^e ser., XIV, p. 164.

² L. Jatschewski, *The tunnel of Syrkusun*, *Djel. Dor.*, 1899, XI. pp. 1-11.

Ust-nur and Khoitu-nur. The surface of these lakes lies 40 meters below that of the Djida. Granite forms the south and porphyry the north side of this caldron ; on the boundary between these two rocks a ridge of basalt is visible.

The band of porphyry reappears 75 versts further up stream on the north side of the Djida¹.

A transverse section, made by Jatschewski from the upper Djida to the south shore of lake Baikal, affords the following instructive results.

From the post-station of the Khamnei on the Djida (933 meters) we ascend the Khamnei on basalt. The higher mountains are formed of granite, porphyry, and a sort of wacke, together with limestone (strike NW.; 290°-320°). From the gneissose summit of Ulgyt (strike NNW.; 330°) the country descends to the river Sanginé: in the valley bottom basalt occurs. The next pass, situated in gneiss (1,874 meters), is dominated by rocky 'goltzi' which rise to a height of 200 to 300 meters above it; a wall of gneiss extremely steep, 480 meters in height, leads down to the river Snechnaia, and crossing the upper course of this river we ascend with difficulty the valley of the Shibe to the Shibanskii 'goletz' (2,041 meters). Here, in the valley of the Shibe, almost equally distant from the Djida and the lake, *the strike of the gneiss is no longer in the Sayan, but in the Baikal direction, i. e. to the north-east.*

In the valley of the Shibe basalt is nowhere to be seen, but the summit of the 'goletz' is formed by a sheet of this rock having a thickness, as seen on the north side, of 20-30 meters only. The distant view presents a number of similar isolated tabular summits which all rise to about the same level, and it is only as we look far away to the south-east (110°) that we catch a glimpse of a more elevated angular peak, the exact position of which has not been ascertained, but which is known to the guides as the Khorin-Khoite-dolge, i. e. the ear of the black dog. The outpouring of basalt appears to have taken place chiefly in the southern valleys. Suffice it to say that from the Shibe onwards the Baikal strike is maintained, but that at one locality on the Khonkhobi-Daban gneiss with schistose quartzite, standing on end, strikes east and west. Further on along the river Studianka the strike is invariably north-east.

Jatschewski sums up his observations as follows: the range, descending gently to the south, and very precipitously to the north, consists of two sharply defined regions, *a northern with a strike to the north-east, and a southern with a strike to the north-west*².

¹ L. Jatschewski, Geological explorations along Trans-Siberia south of lake Baikal. Djel. Dor., 1897, VII, pp. 1-29, in particular pp. 6-9. The depression must be very marked, for the Russian 40-verst map designates the east-to-west furrow which leads to these lakes 'Choloi,' a name given, as will be seen later, by the Mongolians to channels of this kind.

² L. Jatschewski, loc. cit., pp. 9-14. According to the Russian 40-verst map the pass

In order to form a correct idea of the remarkable achievements of the Russian geologists, and at the same time not to lose sight of the scale which must be maintained in our comparative studies, it may be pointed out that the length of this section, from the post-house of Khamnei to the south shore of lake Baikal, amounts to 130 kilometers, and is therefore approximately equal to the distance from Pallanza to Lucerne. We must not forget that even further to the north, near the tunnel of Syrkusun, the strike has been shown to follow the Sayan direction. These observations show that there is little prospect of again encountering, south of lake Baikal, that innermost region of the vertex, distinguished by a north and south strike, of which probable traces have been described on the slopes of the Primorskii Khrebet. It is not possible at present to give an exact account of the manner in which the Baikal strike (north-east to east-north-east), which prevails throughout the whole eastern part of the vertex, and the Sayan strike (north-west to west-north-west), which distinguishes the whole of the west, are brought into relation in the region south of lake Baikal. It is clear from Obrutschew's summary that the Baikal strike occurs in the Khamar-Daban on the right bank of the Selenga, and further, that it extends to the left bank of this river, appearing in the Khrebet Borgoiskii, which forms a continuation of the Sagan-Daban horst: it likewise crosses the river in that other continuation of the same horst which is represented by the mountains on the south side of the Djida. But at the same time it appears that deviations in the Sayan direction occur much further to the north-east, particularly in certain parts of the Khamar-Daban¹. The mountains of Shondagar, which lie south-east of lake Baikal, very nearly on the meridian of the supposed region of maximum compression, are, so Herr Obrutschew informs me, dislocated to so high a degree and in such a variety of ways that it is impossible at present to make out any dominant direction of strike.

The observations of Jatschewski cited above have enabled us to distinguish two broad zones of almost equal extent lying between the southern end of lake Baikal and the boundary of Mongolia; the northern zone being characterized by the Baikal, the southern by the Sayan strike. The northern region is difficult to follow towards the west. Tschekanowski nowhere mentions gneiss with an east-north-east strike except on the middle Tibelti (right tributary of the Irkuta); but at Kultuk, as well as towards the north-west in the ravine of the Irkuta and towards the west not far from Tunkinsk, the Sayan strike everywhere prevails².

of Shibetskaia lies 65 versts from the nearest point on the Djida (near the Karaula of Zakirskaia) and 60 versts from the nearest point on the shore of lake Baikal (east of Kultuk).

¹ W. Obrutschew, *Djel. Dor.*, 1899, XVIII, p. 25.

² Tschekanowski, in the Russian edition of K. Ritter's *Asia*, 1894, I, p. 108; further data concerning the ravine of the Irkuta, I, p. 127, for Kultuk, II, p. 13, &c. The statements regarding the valley of the Ospa are very divergent.

The east Sayan range. The *Sayan* mountains are generally represented as a hook-shaped range of which the two branches, the *east Sayan*, or *Ergik-targak-taiga*, and the *west Sayan*, or *Khabin-dabata*, converge towards the north and unite a little to the east of the meridian of 96° . More recent observations do not accord with this view, and we shall treat the two branches as distinct and different ranges. As a matter of fact the east Sayan is continued as an independent range beyond long. 96° E., with a persistent direction to the west-north-west. The pass from the Kana to the little Agul, for example, lies on this continuation, and according to Idjitzki reaches a height of 2,393 meters. Among the snow-covered mountains on the upper Kana it rises into peaks of over 6,000 feet; and then proceeds with a decreasing height, but still with a considerable breadth, in the direction of the river Mana; it is crossed by the Yenisei a little south of the town of Krasnoiarsk, forms the heights of Gremjatschin on the other side of the river, and finally disappears beneath the recent deposits of the plain before reaching the high road near Atchinsk.

Here the line of the east Sayan range, almost a thousand versts long, at last disappears from sight.

In this place we shall not discuss the Kabin-dabata, but confine our attention to the east Sayan range, or the Ergik-targak and its continuation.

The mountains are much higher than those of trans-Baikalia, but the rocks are similar. A lower division includes gneiss, granite, and hornblende rocks; an upper, in addition to gneissose rocks, contains mica-schists, talc schists, and chlorite schists, serpentine, and a granular limestone with pyroxene, known as Baikalite, which is very widely distributed. Intrusions of more recent granite and syenite, dykes of diorite, and in many localities basaltic lavas, also occur.

From the neighbourhood of the goletz of Shibe, of which a description, based on the observations of Jatschewski, has already been given, high mountains forming the watershed between the Selenga and Irkuta extend to the west-north-west, and one of these situated near the northern end of lake Kossogol forms the highest peak of the east Sayan range, the *Munku Sardyk*, 3,405 meters. The Nukhu-Daban, a branch of this range, which separates the Irkuta from the Oka, forms the connexion with the *Tunkin* alps. To the north-north-west the ridge of the Iltei Daban leads to the *Kitoi* alps. To the west-north-west the Ergik-targak is continued as the watershed between the Angara and Ulu-kem, in many places exceeding a height of 7,000 feet.

Munku Sardyk is only accessible from the south; Radde arrived within 60 feet of the summit; Peratoltschin ascended it in 1896. Basaltic lavas enter into the composition of its southern foot-hills. Part of a very extensive flow forms the table-mountain of *Yangit*; strange to say, the

Baikal, or east-north-east, strike occurs here in the ancient rocks. Radde crossed the Yangit and observed limestone and granite; at greater heights granite and syenite¹. Jatschewski points out that the mountains east of lake Kossogol only rise from 200 to 250 meters above the lake, the level of which lies at about 5,300 feet (1,615 meters), while the mountains to the west are considerably higher. The western shore probably corresponds to a fault. The northern part of the lake lies in granite and crystalline schist, the southern in limestone, which, as will be shown later, is continued



FIG. 5. *A goletz cappel with basic lava.*

Right bank of the river Zagan-Chari (left tributary of the Kitoi; eastern group of the goletzi on the Ospa).

(After a photograph by Herr Jatschewski.)

for a long distance towards the Tannu-ola mountains. Basalt and trachyte appear at several localities near the lake².

¹ G. Radde, *Berichte über Reisen im Süden von Ost-Sibirien, ausgeführt in den Jahren 1855 bis inclusive 1859, in Beiträge zur Kenntniss des Russischen Reiches, herausgegeben von Baer und Helmersen*, 1861, XXIII; *Asia*, I, pp. 46, 50. S. P. Peratoltschin, *Ascent of Munku Sardyk in the summer of 1896*, *Izviestija Sibirsk. Otd. Imp. ross. Geogr. Obsch.*, Irkutsk, 1897, XXVIII, pp. 270-279, map.

² L. Jatschewski, *Report on the expedition Prein-Jatschewski*, letter dated from the mission house of Mondin (Changinskaia Karaula) of July 5, 1887, *Izviestija Sibirsk. Otd. Imp. ross. Geogr. Obsch.*, Irkutsk, 1887, XVII, pp. 212-221.

Tscherski long ago perceived that the topographic features of the great ranges lying in front of the Munku Sardy, on the north, do not correspond with their internal structure. The valleys have been formed by erosion, and intersect the strike, which is directed mainly but not exclusively to the west-north-west or north-west. At the same time, however, the high ridges between the valleys are here and there serrated by secondary ridges, which cross them obliquely and correspond in direction with the strike of the rocks. In the Tunkin alps many peaks reach a height of 8,000 feet, and the Kitoi alps are still higher¹.

In the Kitoi, crowning the *Munku-Sagan-Khardyk* (or Ospinskii 'goletz'),

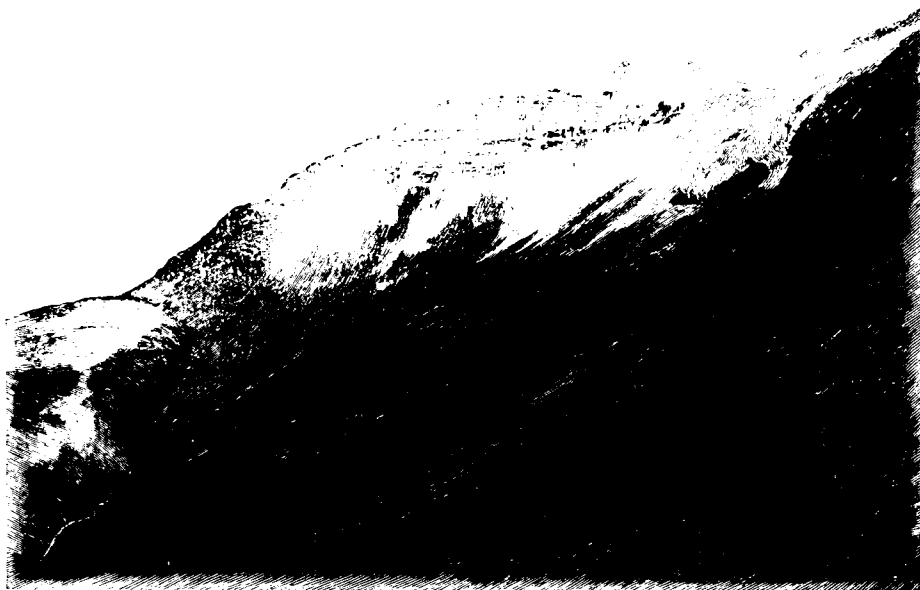


FIG. 6. *High-level basaltic flows near the source of the Ospa (partly covered by snow).*
(After a photograph by Herr Jatschewski.)

Tscherski saw with astonishment for the first time the high-lying lavas of this region. The ascent was attempted in company with Hartung. At a height of 945 meters they crossed the Ospa; at 2,050 meters they reached the summer 'yurtes' of the Soyotes. Passing over chloritic and

¹ So far as I can perceive from the data at my disposal, the presence of the west-north-west to north-west (Sayan) strike has been established in the ridge of Elov and the whole of the adjacent part of the alps of Tunkin as far as the lower course of the Djemtschug, above Tunkinsk on the slopes of the Sayan, and into the valley of the Bogdaschka (north of the Nilan-Saram) on the north slope of the Kitoi alps. But in the valley of the Kitoikin (on the south side of the Nilan-Saram), in the valley of the Khon-goldei in the Tunkin alps, and in the whole transverse section of the Munku-Sagan-Khardyk in the Kitoi alps, there is divergence in the data, and still further west the north-east strike (Baikal) has been observed.

talcoose schists, rocks resembling greenstone and granular limestone, they reached two gullies at a considerable height, leading to a dark peak which they had previously noted from the valley below. Here, at a height of 2,584 meters, a conglomerate of angular blocks, some of them formed of dark lava, rests upon the basett edges of the limestone. Above the conglomerate follows basaltic lava, which forms the whole peak. The horizontal stratification shows traces of at least eight flows.

On a ledge formed by this lava, at a height of 2,640 meters, the travellers looked northwards towards the valley of the Ospa, and amidst the chaos of summits were able to recognize tabular mountains which once formed a common plain of horizontal lavas at a higher level than that at which the observers were standing; now deeply excavated and broken up by the existing valleys.

The height of the dark peaks was estimated at from 9,462 to 9,662 feet (about 2,914 meters). The highest summit of the mountain mass appears from a distance as a snowy dome surrounded by a crown of peaks¹.

It is the same spectacle as that with which we have already made acquaintance to the south of lake Baikal.

North-west of this peak and of the Kitoi alps rises the lofty *goletz of Botugol*, and in its immediate neighbourhood, in the midst of a lonely wilderness, lies the abandoned graphite mine of the enterprising Frenchman M. Alibert. Here there is an intrusion of syenite into limestone, and the graphite is found in the zone of contact².

South of this locality we observe at a great altitude the beginning of a longitudinal channel, traceable for at least 300 versts, in which the waters from the adjacent north slope of the east Sayan are collected; it is crossed by secondary but lofty watersheds, and from the several parts so formed the waters drain into the great transverse valleys of the Oka, the Ya, and the Uda, which run to the north.

Where the Oka forms a bend and passes from the longitudinal into the transverse valley, there lies the post-house of Okin, at a height of 4,300 feet.

¹ Russian Edition of K. Ritter's Asia, I, p. 213 et seq. Although lake Il'tchir, which is situated about 40 versts from here to the west-south-west, in the Kitoi mountains, sends its outflow to the Irkuta, it is also let down beneath these platforms of lava. The surface of contact on the summit of the Munku-Sagan-Khardyk lies, as we have seen, at a height of 2,584 meters, and sinks to 2,266 meters; round about lake Il'tchir, which lies in Archaean rock, 2,180 meters, and on a neighbouring table-mountain known as the 'little table' it is 2,148 meters. Tscherski, in Asia, I, p. 246. With regard to the erosion which has taken place in mica schist to the extent of 300 meters since the Oligocene period, and for high-lying lavas, compare Boule, Bull. Serv. Carte géol. France, Comptes rendus des collaborateurs pour 1899, p. 107.

² J. B. Auerbach, Bull. Soc. Imp. Nat. Moscou, 1856, XXIX, pp. 154-158 (mineralogical description of the graphite); Asia, I, p. 157 et seq.; in particular L. Jatschewski, The bed of graphite described by J. P. Alibert on the Botogolskii 'Goletz,' Djel. Dor., 1899, XI, pp. 19-56.

Here, in the valley of a tributary, the Djambulak, between slopes of granite and limestone, a basaltic lava-stream descends from the mountains into the valley of the Oka, 25 versts from the post-house. At a height of 6,200 feet, near the head waters of the Khikuchka stream, where the cliffs, 7,200 feet in height, are formed of limestone, and the valley bottom of lava, Kropotkin observed a cone of scoriae and porous lava 400 feet in height, with a funnel-shaped hollow at the summit. A neighbouring valley contains a similar cone. Kropotkin regarded them both as centres of eruption¹.

Further to the north-west the structure of the great ranges is little known, but judging from the foot-hills, so far as they have been studied by Hofmann and Idjitzki, in the region of the Uda, it is probable that here also the general strike is north-west or west-north-west². Hofmann, in particular, has met with the west-north-west strike (285°) far in the interior of the mountains, in the valley of the Kamenka, one of the upper branches of the Kula (tributary of the left bank of the Biriussa); this valley is formed of limestone, greenstone, talc schists, porphyry, and porphyritic breccias, and is situated between long. 96° and 97° E., i. e. near the region in which the east Sayan range has been supposed to make a bend to join the west Sayan³.

The south side of the east Sayan is very different from the north. It does not present a Palaeozoic border and even a fairly continuous slope, such as occurs on the north side, is absent. It is true that in this region, east of the Khabin-dabata, three great drainage basins may be distinguished, but they lie so high that they look as though they were depressions lying in a common plateau which unites the east Sayan range with the heights of Mongolia situated further to the south.

The first basin is that of lake *Kossogol*, which we have already described. Its waters lie, as we have said, at a level of 5,300 feet. In the second basin, surrounded by the southern slopes of the east Sayan range, and situated at a height of over 5,000 feet, lies the lake of *Dod-nor* with the smaller lake of *Turgo-nor*, both, according to Potanin, surrounded by basaltic lava, which does not, however, spread over the neighbouring country. Rocks of schist and limestone project from the lava and surround

¹ Asia, I, p. 24 et seq. Tscherski in his time contested this point of view; but since centres of eruption have subsequently been found at several places of inner Siberia I see no real reason for doubt.

² E. Hofmann, *Reise nach den Goldwäschchen Sibiriens, Beiträge zur Kenntniss des Russischen Reiches*, 1847, XII, pp. 108, 117, 119, 123, 131, 140. N. Idjitzki, *Geological explorations along the Siberian railway in 1894*, Djel. Dor., 1896, III, pp. 80, 84, map.

³ E. Hofmann, *mem. cit.*, *Beiträge zur Kenntniss des Russischen Reiches*, 1847, XII, p. 124. On the upper Biriussa a few observations have been made of a strike from east to west, but the predominance of the north-westerly direction has been placed beyond doubt.

it. The Shichkil, i. e. the highest branch of the Yenisei, flows over lava on leaving the Dod-nor¹.

The third basin, the broad expanse of *Uriankhai*, is drained by the tributaries of the Bie-kem, a river which flows through the Ulu-kem to join the Yenisei. This basin, which corresponds to the space between the east and west Sayan of the maps, has been made known by Krylow and Saitzew; we shall return to it when we come to describe the upper course of the Yenisei. The principal range of the east Sayan here rises into the mighty mass of the *Ulu-taiga* with its scarped peaks; Krylow saw it in August covered with snow down to its southern foot-hills. The foot-hills, so far as they are known, consist of gneiss (head waters of the Assas, 2,214 meters) and of granite (peak of Oiba-taiga, near the head waters of the Khamsar, 2,066 meters). On the heights of the Assas melaphyre is also exposed. Gneiss and granite extend far down into the valleys. In the lower parts of the basin (at a height of 1,122 meters) quartz porphyry forms many hills on the Assas; basalt crops out on the river Yissuk (at a height of 1,167 meters). Gneiss is again seen on the lower Assas (at a height of 924 meters)².

The lofty mountains which, proceeding beyond long. 96° E. in the west-north-westerly or Sayan direction, form the true continuation of the east Sayan, and at the same time the watershed between the Tuba and the Kana, have been described in detail by Klemenzen and more especially by Idjitzki. Towards the north, particularly between the rivers Agut and Kungurs, porphyry is somewhat widely distributed; but the lofty ridges and 'goltzi' running to the west-north-west consist chiefly of gneiss and hornblende granite. Quartzose rocks are recorded as occurring on the bare ridges of the Kanskoe *Bielgorie* (2,020 meters) and on the highest point which has been described, that is the pass from the Kana to the little Agut (2,393 meters)³.

The *Odinskoie Bielgorie* and their granitic extensions may be traced into the river basin of the upper Mana. Bogdanowitsch and his colleagues have published a map of this region. This shows that the west-north-west or north-west strike is continued across the Yenisei⁴. In this most

¹ G. N. Potanin, Sketches from the north-west of Mongolia, 1883, III, p. 172, r. All the basalts collected by Potanin on the Dod-nor and in the neighbourhood of lake Kossogol are typical plagioclase basalts; P. Wenjukow, On some basalts of the north of Asia, Travaux Soc. Nat. Saint-Petersb., 1885, XVI, pp. 287-309, in particular p. 299.

² P. N. Krylow, Journey into the region of Uriankhansk in 1892, Izvestija Imp. ross. Geogr. Obsch., 1893, XXIX, pp. 274-291, map; A. Saitzew, Petrographical specimens collected by MM. Krylow and Klemenzen in the Sayan mountains and the region of Uriankhansk, Izvestija Univ. Tomsk, 1896, IX, no. 6, 23 pp.

³ N. Idjitzki, Geological investigations in the districts of Krasnoiarsk and Kansk, government of Yeniseisk, 1893, Gorn. Journ., 1895, II, pp. 53-93.

⁴ C. Bogdanowitsch, On the geological investigations carried out in 1893, along the railway line of west Siberia, Gorn. Journ., 1894, II, nos. 9 and 10, and Bull. Com. géol.

westerly part of the continuation of the east Sayan, granites and porphyries, possibly representing more recent intrusions, become increasingly abundant¹. Beyond the Yenisei the granites are continued to the north-west and are finally concealed by recent sediments².

It is necessary to cast a glance at the marginal folds on the north of the east Sayan.

The marginal folds occurring on the south side of the granite mass of Nishni-Udinsk have already been mentioned³. They are followed by a bordering series of rock salt deposits included in a red rock, which is regarded by several observers as Devonian. Later investigations must decide whether, as appears probable, they are to be classed with the Silurian deposits of other parts of the great plateau, or with the red beds equally salt-bearing which occur west of this locality, in Minuzinsk, and which are undoubtedly of Devonian age. Further on, in the direction of Krasnoiarsk, the border of the amphitheatre presents a slight interruption or indentation; and at the point where the north border of the prolongation of the east Sayan range is cut through by the Yenisei near Krasnoiarsk we come upon Cambrian limestone. It occurs both near this town and outside the otherwise fairly regular contour of the amphitheatre, near the village of *Torgochino*.

According to Bogdanowitsch the limestone of Torgochino belongs to a long band which enters this region from the south-east, and is cut off by a fault on the Yenisei. The limestone, together with the subjacent greywacke, is thrown into folds striking to the north-west; on the Yenisei itself, close above Krasnoiarsk, these folds assume a monoclinical structure with development of the southern limb.

These facts would seem to indicate an imbricate structure with movement to the north-east, that is a continuation of the structure of the marginal folds. But I must repeat that these folds lie outside the boundary of the amphitheatre, and north of Torgochino we again see the Archaean rocks of the middle Yenisei. It may be an ancient fault-trough which gives rise to this interruption in the border of the amphitheatre. Toll has shown that the limestone of Torgochino is of Cambrian age; it contains the genera *Olenoides* and *Archaeocyathus*⁴.

Russie, 1894, pp. 229-280; geological map. The Palaeozoic sediments of this folded range are marked on the map as S₂ and D₁.

¹ The mining district of Irbin belongs to the south slope of this folded range; B. K. Jaworowski, Gorn. Journ. 1894, II, and elsewhere.

² L. Jatschewski, Preliminary report on the geological investigations carried out in 1893 in the government of Yenisei, Gorn. Journ., 1894, II, pp. 305, 315.

³ I am still in doubt whether to regard the granite indicated on the map of Brusyztzin, Djel. Dor., 1899, XIII, on the Tumanschet, as the true border of the east Sayan, or rather as a part of the more recent granite described here by Idjitzki.

⁴ F. Schmidt, Ueber einige neue ostsibirische Trilobiten, Bull. Acad. Imp. Sci. Saint-Petersb., 1886, XXX, p. 501; von Toll, Verh. russ. k. min. Ges., 1892, p. 279, and

From the fact that the Sayan and Baikal directions co-exist in the east Sayan range we may infer that this range is inseparably connected with the trans-Baikal fragment of the vertex. This connexion is also maintained, as regards the orography, by the mountains south of lake Baikal, by those of Elov and the alps of Tunkin and of Kitoi. The east Sayan range also presents Archaean rocks which, as far as our observations extend, are the same as those of trans-Baikalia; broken through in the same way by more recent masses of granite and porphyry and overflowed by basic lavas which appear sometimes on the summits of the mountains and at others in the bottom of the valleys.

One difference, however, there is: in the east the border of the amphitheatre cuts across the folds, while here it coincides with the Sayan strike, and thus the course of the marginal folds, so far as it is known, corresponds with that of the Archaean folds.

The east Sayan range, or Ergik-targak, is a still visible fragment of the south-western part of the vertex, and it joins the Mongolian mountains in the south in the same way as it joins trans-Baikalia. It is only in the western part of its continuation, near Krasnoiarsk, that phenomena occur of which the final interpretation must be left to future observers.

These facts may be explained on the supposition that the amphitheatre of Irkutsk is an ancient inbreak of the vertex, and that the north-to-south axis of this inbreak lies west of the region where the encounter of the Baikal and the Sayan folds takes place.

The importance assigned in our maps to the arc which is formed by the supposed union of the east and west Sayan ranges, probably dates from a period when in these remote countries the lines of the great watersheds were chosen as political boundaries; thus the nomenclature has followed the frontiers.

The horst on the Yenisei. Between Kansk and Krasnoiarsk, on both banks of the Kana, we meet once again with the gneisses, hornblende rocks, and granites of the east. Tscherski was already acquainted with the fact that ancient rocks with a north-westerly strike exist on the Kana. Bogdanowitsch pointed out that their mode of occurrence in broad ridges is different from that of the intrusive granites in the adjacent range south of Krasnoiarsk—here regarded as the western continuation of the east Sayan range—and that it recalls rather that of the high mountains near the head waters of the Mana. These ancient rocks reach at length the Yenisei¹.

N. J. f. Min., 1892, p. 164. T. Tschernyschew, *Materialien zur Kenntniss der devonischen Fauna des Altai*, Verh. russ. k. min. Ges., 1893, p. 38 (Separat-Abdruck), note I. Also Idjitzki, *Djel. Dor.*, III, p. 66; and in particular, von Toll, *Beiträge zur Kenntniss des sibirischen Cambrium*, I, Mém. Acad. Imp. Sci. Saint-Petersb., 1899, 8^e sér., VIII, no. 10, pp. 16–20 and 33–48.

¹ The geological map by Bogdanowitsch, in *Bull. Com. géol. Russie*, 1894, XIII, shows the distribution of these rocks on the lower Kana.

It is to Jatschewski's labours that we owe our knowledge of the remarkable contrast which exists, from Krasnoiarsk downwards, between the opposing banks of this great river. On the left, the Tertiary lignite-bearing beds extend far and wide into the basin of the Obi. On the right, the Archaean mass rises abruptly, and in the south it extends across the Yenisei in detached hills which rise out of the plain. Further north the right bank assumes the characters of a fracture.

North of the Kana the slopes formed by the ancient rocks on the banks of the Yenisei are about 100 meters in height, and above them the Archaean land rises gradually to the east till it reaches about 350 meters above the river, i. e. more than 400 meters above the sea. Granite and gneiss are to be seen, the latter vertical with a north-west strike (320°). The breadth of this ancient mass can scarcely be less than 50 versts. Towards the east Palaeozoic sediments come in contact with it ¹.

Thus the ancient rocks approach the mouth of the Angara but do not reach it. On the right bank of this river, as we have already mentioned, folded limestone appears, striking to the north-west (335°), with dykes of more recent granite ².

It has long been known from Hofmann's investigations that on the Pit, and on the tributaries of the Stony Tunguska lying north of the watershed, gneiss and clay slate occur with a constant strike to the north-west; but it was not until the publication in 1894 of Jatschewski's important account of the mining district of the north Yenisei that the connexion of these exposures and their significance as regards the structure of Siberia became apparent ³.

For a distance of 500 versts, from a point not far below the mouth of the Angara down to the village of Ossinovoï, above the mouth of the Stony Tunguska, all that can be seen on the left side of the Yenisei is recent alluvial land, while the right side is formed by a rocky slope generally about 100 feet in height. From the Yenisei eastwards the land rises in a broad ridge 200 to 250 versts across, which is succeeded still further to the east by a plateau of less height and different character. We have already mentioned the table-mountain *Enachimskii Potkan*: it rises 100 versts east of the Yenisei; its summit is the beginning of the watershed which separates on the one side the Teja and Tchana, flowing northwards to join the Stony Tunguska, from the Pit and the other tributaries of the Yenisei

¹ L. Jatschewski, Geological explorations in the north part of the district of Kansk and along the railway of Siberia between Nishni-Udinsk and Kimilteisk, Djel. Dor. 1896, III, pp. 1-24, map.

² L. Jatschewski, Preliminary report on the geological investigations carried out in the government of Yeniseisk in 1893, Gorn. Journ., 1894, II, p. 315.

³ Hofmann, Reise nach den Goldwäschen Sibiriens, pp. 155-209; L. Jatschewski, Short account of the mining district north of the Yenisei, Gorn. Journ., 1894, I, pp. 125-144, map.

on the other side. West of the Enachimskii Potkan, in the valleys of the Pit, the Kija, and the other tributaries of the Yenisei, we see gneiss, granite, and granular limestone, striking north-west (330° – 340°). It thus appears that in the western part of the vertex the Sayan strike turns from the west-north-west towards the north-west, just as beyond lake Baikal in the eastern part of the vertex the Baikal strike turns from the east-north-east to the north-east.

These rocks, since they possess the north-westerly direction of the Sayan, show in the clearest manner that the east Sayan range belongs to the vertex. They form throughout its length that slope on the right bank of the Yenisei which Jatschewski regards as a fracture. Above Ossinovoi, near the 'seventy islands,' they cross the river and are continued beyond it, as was mentioned above, into the basin of the Taz; here too they strike to the north-west. The Yenisei, however, enters a transverse valley which corresponds in direction with the continuation of the fracture.

The eastern slope of this broad ridge of ancient rocks, which we will call, following Jatschewski, the *horst of the Yenisei*, is bordered by the marginal folds of the amphitheatre. We have already observed them at the mouth of the Angara, the Stony Tunguska, and the Lower Tunguska. To this same group of folds belongs the anticline, described by Meister, which strikes to the north-west near the head waters of the Uderei¹.

Summary. At the risk of considerable repetition, we may select the following points as of special importance.

The visible parts of the ancient vertex which have hitherto been mentioned include the whole of trans-Baikalia as far as the Great Khingan, together with the plateau of the Vitim, the highland of the Patom, and on the west side of the Baikal the Primorskii Khrebet: further, all the mountains on the south of lake Baikal, the mass of the Munku-Sardyk, the whole of east Sayan together with its continuation up to and beyond Krasnoiarsk, the Archaean rocks on the Kana and along the Yenisei, the horst situated north of the Angara on the Yenisei, and the region of the upper Taz.

The highest summits are Munku-Sardyk and Sokhondo.

The whole of this region is formed of Archaean rocks with here and there eruptive rocks and a few patches of more recent freshwater beds; with the exception of the Devonian beds on the extreme south-easterly margin it is devoid of all fossiliferous marine deposits.

The Archaean rocks are folded and the folding is of pre-Cambrian age. In the east the strike is to the south-west or west-south-west, and in the west to south-east or east-south-east; the first direction is called the Baikal strike and the second the Sayan. The two directions are conjoined

¹ A. Meister, Basins of the rivers Uderei and Udoronga, Geological observations in the gold-bearing region of Siberia, gold-bearing region of Yenisei, I, 8vo, 1900, 87 pp., map, r.

towards the centre. The Baikal strike has been recognized on the Lena, up to lat. 60° N., and on the Argun as far as long. 119° or 120° E., and the Sayan strike on the Yenisei up to lat. 66° N. (if we include Lopatin's observations, up to lat. 68° N.) and as far as long. 93° E. Towards the south we have traced them down to lat. 50° N.

On the west side of lake Baikal, in the Primorskii Khrebet, it appears as though the two directions, striking on both sides more and more to the north, would eventually unite in a mean north-to-south axis, and as though compression had occurred acting towards the centre. Consistently with this, the island of Olkhon reveals a syncline overfolded towards the interior. South of the lake, however, it appears rather as though the two directions merged gradually one into the other along a more or less circular arc, but here also the true state of things is by no means clear.

The eastern portion of the vertex is divided by very long fault-troughs into more or less parallel horsts. These troughs sometimes follow the Baikal folds for very long distances, sometimes cut across them. It is as though tension or shearing had succeeded the ancient folding and had followed almost the same direction. Recent lavas and craters indicate that this process of disjunction is not yet terminated. On the Selenga three wedge-shaped fields of subsidence have been formed, namely on the Geese lake, the Tugnui, and the Khilok. The effects of the same process may be traced into the valley of the Djida. Lake Baikal itself consists of two basins which are separated from one another by the prolongation of the Bargusin horst into the Swjatoi Noss and the island of Olkhon. It was probably formed by a similar disjunctive process during middle Tertiary times, indeed before the Sarmatian, or at least before the Pontic phase of central Europe.

The larger part of the western half of the vertex was faulted down at an early period, and thus gave rise to the amphitheatre of Irkutsk. From the structure of the marginal folds of the amphitheatre it may be inferred that a subsequent compression affected this area at a much later date. This view receives important confirmation from the presence in the island of Olkhon of a fold overthrust towards the interior, although this fold belongs to a far earlier period.

High up on the Archaean 'goltzi' lie fragments of basaltic sheets which are older than the valleys. Other basic lavas have poured down into the valleys. The wide extension of these lavas is a phenomenon common to the vertex and the tableland.

Minuzinsk and west Sayan. South-west of the mountainous tract which is here regarded as the continuation of the east Sayan range lies a region presenting a structure both different and peculiar. This region is bounded on the south by the west Sayan range; on the west by the Kusnetzki-Alatau and its foot-hills. Towards the north-west, between

Atchinsk and Mariinsk, it reaches the northern plain, with which it is nowhere else in contact. It is traversed from south to north by the Yenisei, which receives within its boundaries two important tributaries, the Alatau on its left side, and the Tuba on its right. The town of Minuzinsk lies almost in the centre of this region.

Even the configuration of the country is strange. Klemenz gives an excellent description of it as it appears from one of the foot-hills of the west Sayan range situated in about lat. $52^{\circ} 45' N.$, on the right of the Yenisei within its second great bend. Towards the south we see broad ridges traversed by a labyrinth of deep valleys rich in water, covered with thick forest and dominated by the snowy peaks of the west Sayan. Towards the north, on the other hand, there broadens out on the left side of the Yenisei a vast steppe which, regarded from above, looks at first like a plain, and only on closer consideration resolves itself into undulating ridges. In the distance it is bounded by the blueish outlines of the hilly range of Saksar, which strikes obliquely across from the Alatau to the Yenisei. The immediate neighbourhood is clothed with luxuriant forest growth, its verdant foliage contrasting with the uniform yellowish green of the steppe. This is an isolated fragment of 'Mongolian landscape on Siberian ground' ¹.

Numerous lakes, some salt and some bitter, and freshwater lakes also, are scattered both over the steppe and the region to the north of the Saksar.

Such are the characters of the *intermediate region of Minuzinsk*, which separates one from the other two different elements of the mountain framework of Asia; the ancient vertex on the east, and the mountains belonging to the Altai on the west. These characters are determined chiefly by the Devonian transgression. In the stratified series which forms the plain, green shales, according to Klemenz, lie at the base; on these red shales with conglomerate are superposed; then follow calcareous beds, with *Spirifer Anosoffi* and the middle Devonian fauna, the resemblance of which to that of the Ural has been pointed out by Tschernyschew ². These are covered by red sandstone, brown sandstone, and marl and clay with salt and gypsum; the salt and bitter lakes belong to this horizon. The uppermost beds have afforded *Lepidodendron Veltheimianum*, *Bornia*

¹ D. Klemenz, Die Salzseen des Minussinischen und Atschinischen Kreises und die devonischen Ablagerungen am oberen Yenissei, Izviestija Sibirsk. Otd. Imp. ross. Geogr. Obsch., 1892, XXIII, pp. 28-83, in particular p. 49.

² T. Tschernyschew, Die Fauna des mittleren und oberen Devon am West-Abhange des Ural, Mém. Com. géol. Russie, 1887, III, no. 3, p. 194; the Devonian fossils from the Beia (tributary of the right bank of the Abakan) have been described by Stuckenberg, Materialien zur Kenntniss der devonischen Ablagerungen Sibiriens, Mém. Acad. Imp. Sci. Saint-Pétersb., 1886, 7^e sér., XXIV, no. 1. *Osteolepis* and *Coccosteus* (?) from the salt lake of Kisi-kul, 50 versts west of Minuzinsk, have been described by Rohon in Mém. Acad. Imp. Sci. Saint-Pétersb., 1889, 7^e sér., XXX (VI), no. 13.

radiata, and other plants of the European Culm. It is not impossible that the salt deposits may belong to the Culm.

The Devonian strata extend over the plain for a breadth of 100 versts. With the exception of the river terraces no deposits are known of later age than the Culm. Augite porphyrites and diabase porphyrites occur in the Devonian, but they do not extend into the Culm.

The structure of Minuzinsk has been studied for many years by D. Klemenzenz, who has been kind enough to render me very special assistance both by personal instruction and by the communication of extracts from his unpublished diaries relating to the west and south-west of the bordering regions¹. In addition we possess valuable works by Bogdanowitsch and Jaworowski².

The Devonian of the plain is thrown into broad open folds, which group themselves towards the north in arcuate lines having their convexity towards the south. North of the town of Minuzinsk, from the confluence of the Tuba with the Yenisei down to the mouth of the Sissim, i.e. in a distance of about 120 versts, Jaworowski counted seven of these horseshoe-like folds, which are cut through by the Yenisei. The course of the river never coincides with the strike of these folds, except in one instance, where it flows to the east-north-east in the northernmost part of the region.

The arrangement recalls the horseshoe-shaped folds of the Angara series in the middle of the amphitheatre of Irkutsk.

The western border of the country lying in the direction of the Kusnetzki Alatau is traversed by isolated spurs or branches of the main Alatau range.

A long folded band of Devonian, with which granite is associated, runs from the Alatau almost due north into the region south-west of the great salt lake of Chir, that is nearly to the west side of the horseshoe-shaped folds mentioned above.

Still more important is the mountain mass of *Saksar*, which rises according to Klemenzenz between the rivers Kamychta and Uljbat (tributary of the left bank of the lower Abakan, lat. 53° 15' to 53° 30' N.), its sharp

¹ The notes and sketches kindly placed at my disposal embrace the following regions: 1. the upper spring region of the Kemtchik and Alach together with the north-east slopes of the Sailingem (1886, 1887 et seq.); 2. the valley of the Tchuya and a part of the Katunj (1898); 3. the region between the rivers Saksasai and Zagan-gol (uppermost spring region of the river Kobdo) in Mongolia (1896); 4. Ulan-Daban, Barmen-Daban, lakes Uriu-nor and Atchit-nor (1895); 5. pass of Shabin-Daban in the west Sayan; 6. bedding of the Devonian at Beiskoie on the Abakan; 7. mountain bog of Saksar on the lower Abakan.

² K. Bogdanowitsch, and P. Jaworowski, Preliminary report on geological investigations in Siberia in 1892; Gorn. Journ., 1893, II, p. 290; P. Jaworowski, On the geological explorations carried out in 1893 in the north-east of the district of Minuzinsk in the mining district of Irbin; op. cit., 1894, II; K. Bogdanowitsch, Investigations along the line of the Siberian railway in 1893; Bull. Com. géol. Russie, 1894, XIII, pp. 229-280, map; Jaworowski, op. cit., 1895, XIV, pp. 195-228.

outlines contrasting with the gently rounded hills of Devonian sandstone surrounding it; it is described by Klemenzen as a fragment detached from the Alatau. It consists of perpendicular beds of ancient schist striking to the north-north-west, such as we shall also encounter in the Alatau. The Devonian folds of the neighbourhood unite with the outer border of the Alatau ¹.

Salt and gypsum and fossiliferous Devonian beds have long been known at Bejsk, Monok, and Arbat, on the middle and upper Abakan, and Klemenzen even mentions Devonian on the Ada (left tributary of the Little Abakan, lat. 52° 30' N.). Klemenzen has also pushed westwards up the valley of the Tachtyp to the watershed. This consists of the older rocks of the Alatau, but Devonian and Culm are still found fairly far up ².

East of the Abakan the southern border coincides with the slopes of the west Sayan range. A belt of granite and syenite hills of more recent age lies at the foot of the Sayan. On the Tasskyl, between the Abakan and the Yenisei, Bogdanowitsch and Jaworowski found that the whole succession of rocks of the west Sayan is overthrust towards the north, so that on descending from the crest we see the younger rocks beneath the older. They consist of mica schists, chlorite schists, and clay slates, dipping to the south-east (150°–170°). This indicates an east-north-east to easterly strike, in contrast to the almost north and south strike of the Alatau ³.

Further, Klemenzen has also observed an east-north-east strike on the south side of the pass of Shabin-Daban, in the granite-veined schists on the little river Tossna. Here the mountains consist of two ridges, a northerly ridge or the Sayan range proper, which is cut across by the deep ravine of the Khantigyr (left tributary of the Yenisei), and the southern or Soyotes mountains, which form the watershed between the Khantigyr and the upper Ichkem ⁴.

In the whole of this region the sediments everywhere exhibit intense folding. The belt of granite hills at the north foot of the Sayan reaches

¹ Klemenzen, manuscript notes and *Die Salzseen der Minussinischen und Atschinischen Kreises*, pp. 47 and 72. The elongated mountain of Isykh described by Bogdanowitsch, which lies south-west of the town of Minuzinsk and is composed of Devonian and Culm, possibly also exhibits the stage of the Tungusian flora; this is the only trace of more recent formations in the region of Minuzinsk which is known to me. The mountain belongs to the folded ranges of the west. The northerly continuation of the Devonian along the north-east slope of the Alatau to beyond Mariinsk has been described by Saitzew in *Gorn. Journ.*, 1893, pp. 451–464, and *op. cit.*, 1894, pp. 183–195.

² Klemenzen, Sapiski of the west Siberian branch of the *Imp. ross. Geogr. Obsch.*, Omsk, 1885, VII, 2, p. 6 et seq.; reports of the Session, p. 3. The watershed is formed of clay slate, quartz-conglomerate, quartz schist, and diorite. Similar rocks appear in the middle of the Kusnetzki Alatau.

³ Bogdanowitsch and Jaworowski, *Gorn. Journ.*, 1893, II, p. 291.

⁴ Ary-kem, according to the 40-verst map; lake Sut, which is said to lie east of this point, does not exist.

the Yenisei near the towns of Kalskoie and Osnatchennoie, only about 70 versts south of Minuzinsk, and it is here but little developed. The folding is much less marked in the low ground than in the mountains.

Let us cross the Yenisei.

South-east of Minuzinsk, in the direction of the Sayan, we see similar broad folds of Devonian. Their general course is north-east (45° – 80°), that is almost corresponding to the direction of the higher mountains, but with deviations to the north-north-west. 'Their orientation,' says Bogdanowitsch, 'has evidently been determined by pre-existent tectonic lines.'

In regard to the eastern half of the west Sayan two sources of information are at my disposal.

The first is the journey made by the botanist Krylow over this part of the Sayan and into the region of Uriankhai to the south of it; the rocks collected by him have been determined by Saitzew. The facts obtained from this source enable us to construct two transverse sections. The first runs through the whole region from north to south, approximately in long. $92^{\circ} 40'$ E.; the second is directed to the south-east from the middle Tuba up the river Amyl, and then down the south slope of the west Sayan through the valley of the Sistyr-kem to the factory of Skobielev on the bend of the Bie-kem (somewhere about long. $94^{\circ} 6'$ E., lat. $52^{\circ} 40'$ N.)¹.

My second source of information is a personal communication from M. Jatschewski, which contains a list of the rocks collected by Colonel Baranow during his inspection of the Sayan frontier in 1897, with indications of strike and dip, and also a sketch map showing the localities where specimens were obtained. From this it appears that the bend of the Bie-kem extends much further north, and consequently that the Sayan, near the headwaters of the Ussa, is much narrower, than was previously supposed. I am greatly indebted to his excellency General von Stubbendorf, as well as to MM. Jatschewski and Baranow for this communication. It relates to the region lying between the two routes followed by Krylow mentioned above, and supplements and confirms Krylow's statements.

On collating these accounts we obtain the following result :—

About 100 versts south of the town of Minuzinsk, the spurs of the west Sayan are formed of granite. This is the case near the headwaters of the Kebesh, in the Kultui mountains (1,411 meters, syenite and granite), and also further to the north-east at Kuchabar, on the Amyl (muscovite granite, 307 meters); between these two points the granite is probably continued to the upper Ussa. Here the prevailing rock is coarse-grained biotite-granite. Further, amidst the foot-hills on the north an isolated and lofty mountain

¹ P. N. Krylow, Journey into the region of Uriankhaïsk in 1892, p. 274, map; A. Saitzew, Petrographical material collected by P. N. Krylow in the mountainous region of the Sayan, and in the region of Uriankhaïsk, Izviestija Univ. Tomsk, 1896, IX, no. 6, 23 pp.

of hornblende-granitite (1,914 meters) rises on the upper Oja. This granitic belt is the same as that described by Klemenzen west of the Yenisei.

In spite of the wide extension of granitic rocks on the north side of the range they are not mentioned as occurring on the crest. This, together with the greater part of the mountains, generally consists of a rock which is frequently described as chloritic gneiss, and may possibly be identical with that which Jatschewski, perhaps more correctly, terms green schist. In the western part of this region, in the lofty foot-hills north of the Ussa, this green rock forms the upper basin of the Oja (1,555 meters), the valley of Aradan, the peak of Mirski Khrebet (1,926 meters), the valley of the upper Ussa (1,932 meters, on the Buiba; the strike, in this region is NE. 48°), the west end of the Usun Arga mountains (strike ENE. 80°), the neighbourhood of the high boundary mark on the Khrebet Semdjir (strike ENE. 80°, here green aphanite), that of lake Tchernoe (strike ENE. 75°) situated on the watershed, the frontier mountain of Irgak (strike ENE. 72°), and the watershed of the Amyl (1,276 meters).

In almost all these parts of the north slope and along the crest of the west Sayan range the strike is constant to the east-north-east, corresponding with the course of the chain itself. All the more striking, therefore, is the fact that, beyond the crest on the south slope, a completely different strike prevails. The places where it has been determined lie east and north-east of lake Tchernoe, mentioned above, in the higher parts of the mountains¹. It is as though the direction of the east Sayan was already making itself felt in this region.

On the upturned rocks lie patches of red, white, and often dark violet sandstone and conglomerate which are the continuation of the Devonian of Minuzinsk.

The first patch lies north of the principal crest in the valley of the lower Ussa (right tributary of the Yenisei, confluence close to the point where the Yenisei cuts through the Sayan range); it consists of violet conglomerates accompanied by sandstone and porphyry (654 meters, east and west strike).

The two other patches are much larger and belong to the south side.

One of them occupies the middle course of the Odja. The third and largest fills the whole valley of the Sistyr-kem from the summit of the Sayan down to the Bie-kem; it is accompanied by porphyry, and this rock forms the peak of Yuttig-tasskyl (1,746 meters), which rises above the watershed between the Sistyr-kem and Amyl (1,276 meters), near lake Tchernoe on the crest of the Sayan.

¹ Mountain ridges between the little rivers of Kara-kem and Ulun-tashtyk, green schist, strike NW. 320°, dip 80° SW.; summit of the mountain Kynsy-Made; siliceous schists, strike NW. 291°, dip. 66° SW.; rocks at the confluence of the river Tchogom with the Ut; strike NW. 305°, dip. 14° SE. All these remarks are derived from the account of Colonel Baranow.

Let us now turn our attention further west.

The mountain range which we ascend east of the gorge of the Yenisei, after leaving the Devonian patch on the lower Ussa, shows at first chloritic gneiss (green schists), but the highest part of the pass of Kurtchubin, on the Aspanski-Khrebet (2,317 meters), consists of clay slate, mica-schists and hornblende schist. The south slope is formed of clay slate. Far below, at the south foot of the range, the singularly jagged mountain of Khairkhan rises from the valley of the Ulu-kem. It is formed of white granular limestone traversed by dykes of brownish-red porphyry¹.

Further west the strike in the whole of the west Sayan passes from east-north-east to east and west, and this direction prevails in the gorge of the Yenisei. On this river, just below the Mongolian frontier, Klemenetz observed vertical limestone and chloritic gneiss, both striking from east to west. M. Karpinski has drawn my attention to the fact that Schwarz has met with talc schists on the Yenisei in lat. 51° 45' N. (Mongolian boundary), with a strike from west to east and a dip to the north; in lat. 52° N., with an east-north-east strike to almost due east; and in lat. 53°, with a strike from west to east, and a vertical dip².

The chief structural features of Minuzinsk and the west Sayan would thus appear to be as follows:—

The principal strike of the west Sayan is, in the west, east-north-east to east and west; in the gorge of the Yenisei, east and west; and east of the gorge, east-north-east. The chain consists of sharply folded schists with patches of Devonian, similarly folded, resting on them unconformably; the latter are associated in the east with porphyry. Near lake Tchernoe they reach the crest of the Sayan and pass over it to the other side. In the west, on the Tasskyl, the Sayan for a certain distance is overfolded towards the north.

A belt varying in breadth, of granite and syenite bosses of post-Devonian age, borders the north foot of the Sayan both in the west and east, and recalls to some extent the granite masses associated with the marginal folds of the amphitheatre of Irkutsk.

Occupying the plain outside this belt the Devonian and Culm are thrown into broad folds, which bend round in their strike into the form of a horse-shoe concave to the north. To all appearance a posthumous movement has occurred here corresponding to the inversion on the

¹ Potanin has also described the Khairkhan, *Sketches from Mongolia*, III, p. 120.

² The astronomer Schwarz long ago made observations in these regions, as well as throughout Siberia; they have been combined for Minuzinsk by Grewingk in the first sketch of a geological map; *Otsch. Imp. ross. Geogr. Obsch.*, 1864, and elsewhere. Adrianow encountered talc schists directed 60° NE. at the confluence of the Abdyra with the Yenisei (lat. 52° 42' N.). *Adrianow, Sap. Imp. ross. Geogr. Obsch.*, 1888, XI, p. 278. It is below this point that the most dangerous of the rapids, called Barka, occurs. It is formed of granite.

Tasskyl and directed northwards and inwards; whence there results a certain resemblance to the movements of the Angara beds in the amphitheatre.

From the west, i.e. from the Kusnetzki Alatau, spurs and foot-hills advance obliquely towards the valley plain.

The distinction between the west and the east Sayan is very marked. In the west Sayan we see nothing of the great development of the Archaean gneisses and hornblende rocks; nor have the basalts of the east Sayan as yet been observed; the Cambrian marginal folds are also unknown. On the other hand, the Devonian transgression reaches to the tops of the mountains. The strike is east-north-east and east to west, while in the east Sayan it is west-north-west.

Wherever the Sayan strike—as understood by Tscherski—is mentioned, the reference can only apply to the east Sayan.

The east Sayan and the west Sayan are two absolutely distinct and different mountains; the former extends to Krasnoiarsk and beyond. They should be designated by independent names.

Tannu-ola. A study of the boundary region of Russia and Mongolia shows that between lats. $49^{\circ} 30'$ and $52^{\circ} 30' N.$, east and west of the meridian of $90^{\circ} E.$, the chains of the west Sayan, striking almost east and west, and of the parallel range of Tannu-ola, encounter the ranges of the Sailyugem, which run almost due north and south. The zone where they actually meet forms one of the most remote and inaccessible portions of the mountain boundary, and even the topographical maps are not always exact.

Here also we begin by taking Klemenz as our guide.

The Yenisei just before entering the transverse portion of its valley receives on its left side the river Kemtchik, which derives its tributaries, on the left from the Sailyugem, on the right from the Tannu-ola. Klemenz has visited all the upper tributaries on the left, and following one of them—the Alach—to the west, has crossed the watershed in the direction of the Tchultcha, i.e. the watershed between the Yenisei and the Obi¹.

In the valleys on the right descending from the Tannu-ola green schists and limestone, probably Palaeozoic, striking east and west, occur, but just at the entrance to the valley of the Alach clay slate makes its appearance striking from north to south, and dipping 62° to the west; dykes of porphyrite have been intruded into it along the strike; then comes red limestone with corals and shells, and still further west conspicuous sheets of green aphanite. Then for a short distance in the valley of the Alach the strike is east-north-east and east to west, and further up this valley, as well as in all the other valleys on the left side, there is a general strike to

¹ D. Klemenz, *Journal*; in part also, *Voyage en Mongolie occidentale*, Bull. Soc. Géogr. Paris, 1899, 7^e sér., XX, pp. 308-314.

the north-east in schists. Not until Klemenzen had travelled 70–80 versts up the Alach towards the high mountains did he observe the strike N. 20° E., in folded green schists beyond lake Karagol, while on the other side of the watershed above the lake of Tchultcha, as well as at the sources of the little Abakan, he observed talc schists with a north and south strike.

Here we are on the meridional strike of the southern continuation of the Kusnetzki Alatau, and only 60 versts east of the south end of the great lake of Teletzki. Generally speaking, we may, I think, infer that the heights lying east of the Kemtchik belong to the Tannu-ola; that west of this river there is a broader zone of foot-hills, with a strike to the north-east, and belonging probably to the spurs of the Sailyugem like the little chains of west Minuzinsk; and finally that near the crest the general meridional strike of this part of the Alatau is reached.

The prevailing rocks are schists, with infolded Palaeozoic limestone on the lower Alach; the isolated mountain mass of Taitaiga, which lies south of the Alach in front of the Sailyugem, is probably granite.

Let us turn our attention to a more southerly part of the Sailyugem.

From the mountain lake of Diulu-kul (lat. 50° 28' N.) the Tchulychman flows westwards to lake Teletzki and the Tom. On the north side of lake Diulu-kul the mountain mass of *Shap-shal*, the highest peak in the whole region, rises to over 10,000 feet. Adrianow has made the ascent over bare slopes of mica-schist. The northern ridge was covered with snow; the crest consists of light grey fine-grained granite, the south side of mica-schist, the north of a dark compact rock. 'The Shap-shal,' says Adrianow, 'is a ridge extending almost from west to east (280°) and united with the longest of the high ridges of the Tannu-ola; it stretches right away to the source of the Yenisei and separates Mongolia from the country of the Soyotes'¹.

Descending from the Shap-shal, Adrianow observed on the southern tributaries of the Kemtchik an east to west strike, which is visible in many places as far as the Yenisei. In addition to the shale, red sandstone also occurs. The wedge-shaped ridge which separates the lowest part of the Kemtchik from the Ulu-kem, i. e. from the upper Yenisei, bears on its highest part a transgressive outlier of red sandstone.

Thus far, therefore, the Tannu-ola completely resembles the west Sayan both in its east to west strike and in the transgressive outliers, which are almost certainly of Devonian age.

From here to the east, the rocks of the Tannu-ola are known along three traverses. We will take them in order from west to east, and will follow each one in a constant direction, from north to south.

¹ A. V. Adrianow, Journey to the Altai and the Sayan, Zap. Imp. ross. Geogr. Obsch., 1888, XI, p. 241 et seq. The height could not be determined by means of the aneroid Naudet which M. Adrianow carried.

Our knowledge of the first traverse is derived from the oft-mentioned labours of Krylow and Saitzew. It proceeds from the factory of Sharanov on the Ulu-kem (526 meters), crosses the river Diagol, and reaches lake Ubza in an east-south-easterly direction. During the ascent Krylow collected quartz-free porphyry (1,015 meters), and he found that all the four highest peaks of this part of the Tannu-ola (2,478, 2,571, 2,638, 2,707 meters) consist of quartzose sandstone and dark violet conglomerate. On the south slope, on the Tus-tag (1,484 meters), sandstone and conglomerate lie in flat or gently inclined beds. South-west of the Tus-tag (1,316 meters) a bed of rock salt, previously recorded by Potanin, was observed in dark violet sandstone, perhaps associated with tuff. The sandstone continues further (1,023 meters), and on the south as on the north slopes of the range quartz-free porphyry is exposed. We come to the end of the traverse at the Ubza-nor (810 meters) ¹.

All the specimens collected along this section of the Tannu-ola appear to belong to the Devonian system.

The second traverse has been described by Potanin; it runs almost due south from the confluence of the Ar-Torchalyk with the Ulu-kem to the Ubza-nor. Near the Ar-Torchalyk, on the north slope, Potanin observed fine-grained gneiss, fine-grained dark grey granitite, then grey limestone, some schists, dark red marl, and from the uppermost reaches of the river light grey and dark-colored sandstone. Some plant-remains which were collected in the Ar (or north) Torchalyk probably belong to the Culm, according to Schmalhausen. A steep ascent leads to the pass of Bainshagny, and thence, over the snow mountains which mark the highest crest, on to the south slope and so to the river Amryk. The walls of the narrow valley of the Amryk are formed of sandstone; blocks of conglomerate lie in its bed; and the river flows from it into the south Torchalyk, by which we reach the rock salt and finally the Ubza-nor ².

Let us return once more to the north foot of the Tannu-ola, i. e. to the valley of the Ulu-kem. East of the north Torchalyk the Devonian and Culm are followed by the Angara beds, which attain a considerable thickness. They consist of sandstone and conglomerate, dark shales also, and coal beds. On the right side of the Ulu-kem they occupy the valley of the Irbeck up to its sources; on the left side they occur on the Bain-gol and in the valley of the Eleges. *Phoenicopsis angustifolia* and a species resembling *Tchekanovskia rigida* have been recorded on the Irbeck ³.

The third traverse, made known by the works of Krylow and Saitzew,

¹ P. N. Krylow, *Izvestija Imp. ross. Geogr. Obsch.*, 1898, XXIX, p. 274; Saitzew, *Izvestija Univ. Tomsk*, 1896, p. 11.

² G. N. Potanin, *Sketches from the north-west of Mongolia*, III, pp. 114-118. Klemenz has also studied this section.

³ J. Schmalhausen, *Pflanzenpaläontologische Beiträge*, II, *Pflanzenreste aus der nord-westlichen Mongolei*; *Bull. Acad. Sci. Saint-Petersb.*, 1883, XXVIII, p. 426.

leads us through those deposits on the Eleges, which have been studied by Klemenzen and Adrianow, across the Tannu-ola in a west-south-westerly direction to the Ubza-nor. The Angara beds extend up to a considerable height. Above them the mountains everywhere present soft outlines and few outcrops. Tuff or tuffaceous sandstone appears to form the subsoil. This is also true of the highest point, a rounded summit situated south of the pass (2,523 meters), which appears to consist of tuff. On the southern slope of the Tannu-ola, in the upper parts of the Ak-karasuk, we reach quartz-free porphyry, and lower down on the river (1,670 meters) dark violet tuff.

On this line, as on the first, no rock has been collected older than the Devonian; this presents the same characters as at Minuzinsk.

Having thus glanced at the western part of the Tannu-ola, let us return to the Ulu-kem. The river assumes this name near the settlement of Safianov (long. 94° E.), where the Khua-kem, coming from the east-south-east, joins the Bie-kem, flowing in a great curve from the north (571 meters). Here the coal-bearing Angara beds are widely distributed, and appear to form the slopes both of the west Sayan and of the Tannu-ola up to a considerable height. Between the Khua-kem and the Bie-kem, however, there rises a mountain mass, first described by Krylow, which rivals the Tannu-ola and the west Sayan in height: its loftiest summit is called *Otyg*. The great bend of the Bie-kem to the north is caused by it. Coming from the south-west, quartz-porphyry is encountered on the foot-hill of Atshallygart (2,091 meters), and on the upper Ulu-O; on the Meshelik (1,644 meters), dark violet sandstone, and on the most easterly peak of the Otyg (2,583 meters), according to Saitzew's determinations, syenite-gneiss altered by dynamic metamorphism, diorite, a rock containing epidote, and quartz-porphyry. Beyond the Otyg and proceeding in an east-north-easterly direction to the other side of the upper Bie-kem, we reach the southern slope of the east Sayan (Ergik-targak), and on the upper Assas we meet with gneiss; basalt also occurs here.

Let us now return to the Khua-kem. According to Potanin, reddish sandstone and clay slate are still visible at the mouth of the Belbej (about long. 95° E.), and, higher up in the valley of this tributary, quartz-porphyry. It is not until we reach the river Djibej, lying 40 versts further up, that we meet with any important exposure of granitic rocks¹.

From this point for a considerable distance upwards the structure of the valley of the Khua-kem is unknown to me. Its highest part, the *Shishkit* or *upper Yenisei*, with the lake of *Dod-nor* and the smaller lake of *Turganor*, lies west of lake Kossogol, on the southern slopes of the Ergik-targak. We have already referred to these.

The southern slopes of the east Sayan, therefore, like the northern, are

¹ G. N. Potanin, *Sketches from the north-west of Mongolia*, III, pp. 122, 146; Adrianow, *Journey to the Altai, &c.*, p. 273.

characterized by Archaean rocks and numerous eruptions of basalt; the west Sayan, on the other hand, is distinguished not only by a different strike but by the Devonian transgression, which may be traced upwards from Minuzinsk. This transgression is marked by marine deposits of the middle Devonian, upon which rests rock salt, and then follows the horizon of the Culm plants; it reaches the summit of the Tannu-ola and appears also in the depression of the Ubza-nor. At the same time the strike of the Tannu-ola, like that of the middle part of the west Sayan, is due east and west. *The west Sayan thus resembles the Tannu-ola rather than the east Sayan.* The Angara deposits lie chiefly at the bottom of the valley of the Ulu-kem; marine deposits more recent than the middle Devonian are not known in this region.

All these points of resemblance persist as far east as about long. $95^{\circ} 30' E$. In the mountains lying further east, between the Khua-kem in the north and the Taz flowing to the Ubza-nor in the south, the prevailing direction—as regards the orography—is different, namely to the south-east; the mountains are marked on the Russian military map as the Adjanchorun and Sangiles, and are regarded as an easterly part of the Tannu-ola; Potanin found grey gneiss on the north side, in the upper valleys of the Djibej and the Chargi, and on the south side in the high pass of Chodsul. It is tempting to suppose that these eastern mountains belong to the ancient vertex, and that they are related to the Tannu-ola much in the same way as the east Sayan is to the west Sayan; but it is impossible at present to determine their actual relations. In long. $97^{\circ} 40' E$. these eastern heights give off, almost at a right angle, an important branch, the *Khan-taiga*. In the angle thus formed lies the lake of *Ter-nor* (1,225 meters). The western tributaries of the Khan-taiga flow through the Ter-nor to the Khua-kem, and the eastern through the Telgir Morin to the Selenga.

Potanin has rounded the bend of the mountains above Ter-nor, crossed the Khan-taiga, as well as a subordinate but high chain which runs parallel with it (2,160 meters), and examined the river-basin of the Telgir as far as lake Kossogol; he has also visited the above-mentioned lake of Dod-nor on the upper valley of the Yenisei, and the south side of the eastern chains. If we study his routes we obtain the following general results¹.

East of the outcrops of gneiss mentioned above, both in the south, to the east of the Khodsul Daban, and in the north on the river Chargi, Potanin encountered white limestone with flakes of iron glance on the bedding planes and traces of graphite. This limestone, which Potanin calls the 'limestone of the Tannu-ola,' is continued from the river Chargi to above lake Ter-nor; the jagged walls of the Khan-taiga, descending steeply to the lake, probably consist of the same limestone; at any rate, it forms the

¹ G. N. Potanin, *Sketches from the north-west of Mongolia*, I, p. 265; III, p. 3; 139, 146, 148, 153 et passim.

whole of the pass. Beyond the pass to the east, in the adjacent river valleys at the foot of the Khan-taiga, the limestone rests on granite and is traversed by dykes of orthoclase-porphyry. North-north-east from this point the Telgir Morin flows in limestone, and, bending first to the south and afterwards to the east, it forms the southern boundary of this broad limestone tract at a point due south of lake Kossogol and about 80 versts distant from the lake. At the south end of lake Kossogol stands the Mongolian post-house of Khal-göl; here Potanin observed a strike from north-west to south-east. This limestone region, which joins the eastern Tannu-ola, probably embraces, as we have seen, the whole of the Khan-taiga, a part of the upper course of the Telgir Morin, the southern half of the shores of lake Kossogol, the Buren-Khairkhan south of lake Kossogol, and all the heights as far as the Telgir Morin, so that its breadth here from north to south may be estimated at about 120 versts.

How this limestone region is continued, or in what manner it terminates, has not yet been ascertained. It is not known to extend into the valley of the Selenga towards the east.

In lithological character the rock recalls the thick limestones on the borders of lake Baikal.

We have now travelled from the Khan-taiga towards lake Kossogol and the Telgir Morin, i. e. towards the east. Potanin, however, also starting from the Khan-taiga, followed a route in a south-easterly direction across the Ikhe-chaldyn-daba (2,358 meters), and repeatedly met with red granite and limestone on both its slopes. In long. 99° E., on lake Sangin-dalai, he records the occurrence of rock salt: it would be interesting to know whether the Devonian transgression really reaches this point ¹.

Khangai. Those parts of the vertex lying south of lake Baikal are most intimately connected with the vast mountainous region of Khangai which occupies the north of Mongolia. The waters of the Khangai flow to the Yenisei, but they follow different routes. The valley of the Yenisei, which has been considered above, starts from lake Kossogol and runs at first to the west: in the earlier part of its course the river is called the Khua-kem and then the Ulu-kem: as we have already seen, it cuts through the west Sayan and turns to the north as it enters the region of Minuzinsk; then, and not till then, it receives the name of Yenisei.

South of the Ulu-kem, the Tannu-ola forms an orographical connexion which unites the Khangai and the ancient vertex in the east with the Sailyugem in the west, and thus separates the basin of the Yenisei from a region of depression which is without outflow, and covered with lakes. This region is bounded on the east by the Khangai, on the north by the

¹ G. N. Potanin, *Sketches from the north-west of Mongolia*, I, p. 274. Some bands of limestone run south-east and north-west, that is parallel to the chain itself and perpendicular to the river Shabir; Sangin-dalai, p. 253.

Tannu-ola, and on the west and south-west by the Gobi Altai; towards the south-east it is connected by a fairly narrow zone with the vast undrained regions of inner Asia. Piewtzow has named it the '*valley of the Lakes*.' It is traversed obliquely by narrow and sometimes very high rocky ridges, such as the Khankhukei, and between these ridges lie the lakes of Durga-nor, Kara-úsu, Kirghiz-nor, Ubza, Uriu-nor, and others.

The mountainous region of Khangai extends to the south to beyond lat. 46° N. Eastwards it merges into the *Kentei* and the mountain regions north of Urga, which have already been mentioned as continuations of the mountains of trans-Baikalia. In a tectonic sense no boundary separates the Khangai from the Gobi, since the denuded remains of a similar structure may be recognized in the adjacent parts of the Gobi itself.

The southern and eastern parts of the Khangai also send their waters to the Yenisei, but these tributaries mostly follow an easterly course to the Selenga, and only reach the main river by a very circuitous route through lake Baikal and the Angara. Lake Kossogol belongs to this system of easterly drainage, which extends westwards into the neighbourhood of the Uliasutai, close to the border of the valley of the Lakes.

The Khangai is a southern part of the ancient vertex.

If we regard the river Telgir Morin, south of lake Kossogol, as forming approximately the southern boundary of the limestone range which is connected with the Tannu-ola, then four degrees of latitude south of this boundary still belong to the Khangai. In the whole of the vast region between the river Orkhon in the east and the Dsaphhyn, flowing to the Kirghiz-nor, in the south-west, not a single pass, according to Klemenzenz, lies lower than 7,000 feet; some attain a height of 10,000 feet, while the peaks do not as a rule rise more than 1,000 feet above them. An exception is formed by the mountain mass of *Orkhon-Khairkhan-Tengri*, 80 kilometers east of Uliasutai. It reaches a height of 13,000 feet and bears a small glacier. Its lower part consists, according to Klemenzenz, of granite and its summit of melaphyre; it affords, therefore, another instance of high-lying lavas, such as distinguish the mountains around lake Baikal¹.

For a knowledge of this region we possess, in addition to the section drawn by Obrutschew from Kiakhta to the east, beyond Urga², a second section which has been studied by Potanin. This runs to the north-north-east across the whole breadth of the Khangai from the south border, in

¹ D. Klemenzenz, *Izviestija Sibirsk Otd. Imp. ross. Geogr. Obsch.*, Irkutsk, 1896, XXVII, annual reports, p. 60, and 1897, XXVIII, p. 158, and *Expedition to Mongolia in 1894*, op. cit., 1894, XXV, pp. 126-129; also *Voyages en Mongolie occidentale de 1885 à 1897*; *Bull. Soc. Géogr. Paris*, 1899, XX, pp. 308-329, map, in particular p. 317.

² V. A. Obrutschew, *Geological sketch of the caravan route from Kiakhta to Kalgan*; *Izviestija Imp. ross. Geogr. Obsch.*, 1893, XXIX, pp. 347-390, sections; also *Central Asia, North China, and Nan-shan*, 4to, St. Petersburg, 1900, I, in particular p. 20 et seq., maps.

about long. 101° E., to the point where the Selenga crosses lat. 50° N.¹ The fullest account has been furnished by Klemenzenz, who has traversed the Khangai in many directions. I owe most of my information regarding this region to personal communications which he has been good enough to make to me.

Let us begin our brief survey in the north-east.

In the south of trans-Baikalia a considerable part of the vertex disappears beneath the Gobi. Obrutschew recognizes in the ancient rocks south of Kiakhta the west-south-westerly continuation of the horst of Malkhan, the north-easterly continuation of which forms the Yablonoi range. Thus we have at once obtained an important result which we may connect with another remarkable fact. Near Urmuchtu, on the Shara-gol, hardly 90 versts south of Kiakhta, Obrutschew came upon a band of steeply upturned clay slates striking to the north-east, with remains of *Fenestella* and corals probably of Palaeozoic age. This, so far as I know, is the nearest approach made by marine fossiliferous sediments to the middle region of the vertex².

It is probable that this fragment, wedged in amongst older rocks, is a spur from that region of metamorphic schists and greywacke which extends through trans-Baikalia from the south side of the Malkhan to the springs of the Ingoda, and includes the southern parts of the Teherski and the Daurian mountains. It is, however, only the forerunner of a much more extensive zone of similar rocks.

The Devonian fossils of the Gasimur-Onon mountains have already been mentioned. Indeed the study of trans-Baikalia now enables us to recognize a very long band of metamorphic schists, greywacke, quartzite, and sediments of known Devonian age, which begins at Strietensk on the Shilka, strikes to the south-west across Nertchinsk, and is traversed by the Ingoda above the mouth of the Onon; then it suddenly expands to a great width on the line of the railway; again constricted, it forms the mountains of Gasimur-Onon and Erman on both sides of the Onon, which lies in a fault-trough, and finally enters Mongolia still keeping the same south-westerly strike. Here too the river Onon probably marks its course, for Obrutschew has recognized the same zone at Urga, where it is very broad. It appears 75 versts north of this town and extends perhaps 50 versts to the south of it. Near its southern border, at the settlement of Khadyn, Obrutschew found the remains of a *Conularia*³.

¹ G. N. Potanin, *Tangutan-Thibetan frontier of China and central Mongolia*, 4to, St. Petersburg, 1893, I, p. 481, 503 et seq., r.

² V. A. Obrutschew, *Geological sketch of the caravan road*, p. 354; also *Central Asia*, I, p. 10.

³ M. Obrutschew has very kindly entrusted to me a specimen of the rock, the surface of which presents a hollow cast of this fossil. The way in which the ridges cross the edge shows the correctness of the generic determination. The fossil resembles the *Conularia* of the Salt Range, but it is not possible to identify it more precisely.

This is the same schistose zone as that which Potanin encountered on the Tuj (long. $100^{\circ} 27' E.$) in the most southerly part of his section; here it is covered in places by basalt¹.

Finally, M. Klemenzen assures me that he has also recognized this zone on the river Baidarik (about long. $99^{\circ} 10' E.$), at the northern entrance to the valley of the Lakes.

Thus after leaving the Shilka and traversing the eastern part of the vertex, this girdle of schist, which in part at least is of Palaeozoic age, surrounds the whole east and south of the Khangai and unites that region with the vertex.

Still further west, even beyond the Baiderik, Klemenzen observed that the river Shara-ussu (south-east of Ulianputai) follows a line of fracture striking to the east-north-east, along which Carboniferous shales and limestones are traversed and altered by red quartz-porphry.

The inner parts of the Khangai consist of gneiss and ancient schists frequently traversed by granite. The ancient schists are folded, and strike, so M. Klemenzen tells me, for a long distance to the north-north-west, near meridian $101^{\circ} E.$ With this direction they cut across the valleys of the uppermost part of the Selenga, Khanyn-gol, the Khoitu-Tamir and Urtatamir, which are therefore, without exception, transverse valleys, and only towards the south border of the Khangai, north of the Ongyn, which flows to the south-east to the Gobi, does an east and west strike occur.

In several places patches of the plant-bearing Angara series appear; thus Potanin mentions beds with coal in the most southerly part near the station of Udjun, and also in the north, on the Altata, which flows from the gently rounded ridge separating the lower Orkhon from the Selenga.

The Khangai again resembles the vertex as regards the presence of basic lavas. The high-lying melaphyre of the Orkhon-Khairkhan-Tengri has already been mentioned. Basalts which appear to be of recent age are present in many places in the river valleys. Potanin found basalt to the south on the river Tuj; the entomologist Leder reached this locality from the north-east, and on his way discovered, among the ramifications of the great mountain mass of Subur-khairkhan, a valley running to the west (and tributary to the upper Tuj) which is occupied by a lava stream². This is in all probability a part of the great basaltic region, discovered by Klemenzen between the headwaters of the Orkhon and the Ongyn³. These points lie close to the south-east border of the Khangai, but even in the midst of the border great streams of melaphyre and basalt occur. For example, the

¹ G. N. Potanin, *The Tangutan-Thibetan Frontier*, p. 514.

² H. Leder, *Eine Sommerreise in der nördlichen Mongolei im Jahre 1892*, Mitth. k.k. geogr. Ges. Wien, 1895, XXXVIII, p. 107.

³ D. Klemenzen, *Report of Journey in Izviestija Sibirsk Otd. Imp. ross. Geogr. Obsch.*, Irkutsk, 1896, XXVII, annual reports, pp. 15-19.

Tchulutei (tributary of the right bank of the Selenga), according to Klemenzen, excavates its bed in basalt for a distance of more than 100 kilometers, and in the basin of this river, near lake *Terkhain-Zagan-nor*, the same observer discovered two craters formed of scoria and lavas¹.

All these circumstances indicate a structure corresponding to that of the vertex, and lead us to suspect in this district the existence of similar disjunctive lines. It is a remarkable fact that the strike of the Archaean rocks in the long stretch of country explored on meridian 101° is directed to the north-north-west and consequently somewhat more to the north than the folds of the Sayan on the west of the vertex. It is true, however, that the north-north-westerly direction also appears further north on the Yenisei.

The valley of the Lakes. The red and violet sandstones of the Devonian, often associated with porphyry, extend up to the highest peaks of the Tannu-ola which have yet been ascended, i.e. to a height of over 8,800 feet (2,682 meters). The Culm also extends to a great height. Then follows the south declivity. Close to the south foot of the mountains lies a vast plain, and in it the great lake of *Ubzu*. It marks the northern end of the valley of the Lakes.

From the western end of the Tannu-ola a lofty mountain range proceeds stretching to the south-south-east. It is about 180 versts in length, bounded in a peculiar manner and isolated on the west, south, and east. It is crowned by two peaks of great height, the Turgun and Kharkira: the latter bears on its east side the glacier of Barun-Sala. We will term this range taken as a whole the *Kharkira*.

The boundary of the Kharkira is formed in the following manner. Quite close to its union with the Tannu-ola, a deep caldron, in which lies the completely enclosed lake of Uriu-nor, has been formed by subsidence. South of this, the narrow but lofty range of Barmen (2,575 meters) runs west-north-west from the west side of the Kharkira to the Sailyugem. Then follows, on the west side, a much greater subsidence, that of the Atchit-nor, and from this lake flows the river Kobdo, the valley of which separates the west side of the Kharkira from the heights of the Gobi-Altai. On its east side the Kharkira slopes down to the valley of the Lakes.

When Potanin crossed the Sailyugem from the steppe of the upper Tchuja he encountered at a considerable height on the east side of this range, which descends to the Atchit-nor, a white conglomerate characterized, like the ancient conglomerates of these mountains, by a matrix which is not calcareous but of the nature of kaolin. The conglomerate extends from the tributary Djilga through the valley of the Katu, then, associated with

¹ D. Klemenzen, Account of two extinct volcanos in the mountains of Changai in northern Mongolia, *Izvestija Sibirsk Otd. Imp. ross. Geogr. Obsch.*, Irkutsk, 1897, XXVIII, p. 140 et seq., plates.

sandstone and dark slates, through that of the Bekom-bere, down to the plain in which the lakes lie.

Beyond the plain Potanin ascended the mighty Kharkira. Its highest pyramid consists of red granite, but red slate ascends high up to the snow fields, and in the narrow high-lying valley of the Khartarbagatei, which runs down to the east between the two peaks Kharkira and Turgun, Potanin observed conglomerate with a kaolin-like matrix, and at the same time coal seams; in the associated slates he found *Bornia radiata*, *Cardiopteris frondosa*, *Lepidodendron Veltheimianum*, and other plants of the Culm.

Coal measures are known both on the south-west toward the Atchit-nor and on the east side of the Kharkira.

The same conglomerate extends on the east down to the depression of the valley of the Lakes, and forms the range of hills of the Bomkhara on the south side of the Khankhukei, north of the Kirghiz-nor¹.

From the lofty peaks of Kharkira and Turgun the high ridge of the Yamatei leads to that of Barmen, mentioned above, which separates the two lakes of Uriu-nor and Atchit-nor. Klemenzen has ascended the Yamatei, and describes the view from it. Towards the north we see the deeply insunken Uriu-nor extending to the foot of the Tannu-ola, then Kharkira and Turgun and a part of the border of the Ubza. The favourable light enabled Potanin to recognize on all the peaks within sight bands of red rock which stand out in sharp relief from the dark underlying slates. Folds occur, and the red coal-bearing beds are also folded, but the strike of these beds is always a little different from that of the older schists. The strike of the latter fluctuates between north-north-east and north-north-west, while the red rocks strike east and west. Below, around the south end of the Atchit-nor, phyllite is seen with a strike to the north-north-east.

Devonian and Culm extend in unconformable transgression from the high regions of the Tannu-ola to those of the Kharkira. They also clothe parts of the outer slope of the Sailyugem, and are found both at the bottom of the valley of the Lakes in the east, and of the Atchit-nor in the west. These facts show that the Kharkira is a horst. 'From the Barmen,' says

¹ G. N. Potanin, *Sketches from north-west Mongolia*, 8vo, I, St. Petersburg, 1881, p. 304; III, pp. 8-48; *Conglomerates from the Kirghiz-nor*, p. 54; J. Schmalhausen, *Die Pflanzenreste aus der Ursa-Stufe im Flussgeschiebe des Ogur in Ost-Sibirien*, Bull. Acad. Imp. Sci. Saint-Petersb., 1876, IX, and 1877, X; *Pflanzenpaläontologische Beiträge*, II, *Pflanzenreste aus der nord-westlichen Mongolei*; specimens collected by Potanin and Adrianow; op. cit., 1883, XXVII, p. 426; Klemenzen also found coal measures and fossil plants on the Atchit-nor, in the plain of the Bukombere, which descends from the Sailyugem; *Izvestija Sibirsk Otd. Imp. ross. Geogr. Obsch.*, Irkutsk, 1897, XXVII, annual reports, p. 60.

Potanin, 'we look down upon the Uriu-nor three thousand feet below; no other caldron of Mongolia is so narrow and so deep¹.'

At this spot, then, we have before us a local, limited, and caldron-shaped inbreak.

Having described these inbreaks on the west side of the Kharkira, let us next enter the valley of the Lakes itself. The configuration of this region presents a remarkable peculiarity; this is the existence of a number of narrow high ridges, which run obliquely to the west-north-west or north-west from the slope of the Khangai to the Gobi-Altai and Kharkira; and a corresponding series of intervening, more or less independent, low-lying regions. In the west we were able to recognize a number of great subsidences even from the early observations of Potanin; here the situation is still clearer.

Klemenzen has shown that the valley of the Lakes is an area of subsidence and that the subsidences have taken place by stages along step-faults².

On the *first, southern stage*, in the latitude of the town of Kobdo, lie lakes Kara-usu (Ikhesaral, 1,170 meters) and Durga-nor (Kara-nor). The range of *Khara-Argalintu*, which comes far from the south-east and joins the south foot of the Kharkira, cuts off this stage to the north; while it is itself broken through by the outflow of the Durga-nor. Its north border coincides with a fault.

The *second stage* is divided into two parts: in the first or upper part lies the lake of Dseren-nor, close to the fault and 300 feet below the first stage. Up to this point Klemenzen was able to trace the deposits of the Gobi, but they do not extend further towards the north.

On a second and somewhat lower part of the second stage lies the Kirghiz-nor. This stage is bounded on the north by the lofty transverse range of *Khankhukhei*, which approaches the Kharkira south of Ulankom. We have already pointed out on its south side the conglomerates of the Bomkhara, observed by Potanin, which probably belong to the Culm and are traversed by long faults. Its north side, like that of the Khara-Argalintu, coincides with a fracture. Quartz-porphyry and felsite of Devonian or Carboniferous age are exposed along the fracture.

We now arrive at the *third and lowest stage*. On this is situated the Ubza-nor (810 meters according to Krylow, only 721 meters according to the military map), the surface of which lies about 1,000 feet below that of the Kirghiz-nor of the preceding stage.

Thus we reach the south foot of the Tannu-ola.

¹ G. N. Potanin, *Sketches from north-west Mongolia*, III, p. 15. Uriu-nor has no outflow; its water is salt; the official map of Russia gives it a quadrilateral form, with sides of about 12 versts; the plains which surround it at the mouths of the tributary streams appear to be quite small.

² D. Klemenzen, *Otschet Imp. ross. Geogr. Obsch. for 1896*, p. 96.

From these observations it follows that the northern and inner stage of the valley of the Lakes is the lowest; no process but subsidence could produce this result. We have here a broad inbreak, traversed obliquely by step-faults. But while the dividing ridges pass towards the south-east into the foot-hills of the north side of the Gobi-Altai, a long fault-trough lies between the latter and the south border of the Khangai. This extends in a broad curve from the middle stage of the valley of the Lakes, the Kirghiz-nor, to the Gobi, comprises the course of the river Dsapkhyn and the lakes at the mouth of the Baidarik, as well as that of other rivers coming down from the southern Khangai, and is accompanied on its north side along the Khangai, according to Klemenz, by a long belt of basaltic outcrops. This very long trough—typical of its kind—is the *Dsapkhyn trough*; it separates the Khangai from the horst-like spurs of the Gobi-Altai.

Gobi-Altai. The Kusnetzki Alatau and Sailyugem run more or less north and south. They are the eastern members of a great mountain group, which, as will be shown later, undergoes a complete change of strike in the immediate neighbourhood of the Mongolian frontier. This group forms the Altai proper, or the Russian Altai. The change of strike separates it, in the south, from the great Mongolian or Gobi Altai. The rocks are also different in the Russian Altai. Palaeozoic beds with eruptive cores prevail; in the Gobi-Altai, on the other hand, gneiss and Archaean rocks predominate.

Klemenz, coming from the south into the basin of the river Kobdo, extended his journey almost as far as the Russo-Chinese frontier. This indefatigable explorer reached the Zagan-gol, which flows down from the lofty goletz of Kiityn. This goletz marks the place where the watershed of the Gobi-Altai is crossed by the Mongolian frontier. Here schist with a west-north-westerly strike everywhere prevails, but on ascending the Sakssai to the Otshatai-Daban, which separates this river from the upper Kobdo, transgressive patches of dark red sandstone and conglomerate are met with¹.

We must therefore suppose that the Devonian transgression of the Tannu-ola and Kharkira extends as far as the headwaters of the Kobdo in the Gobi-Altai. The question might even be raised whether the horst of Kharkira is not simply a part of the Tannu-ola. The long sharp ridges which run from the Kharkira to the south-east, and the long fractures which, following the same direction, break up the Gobi-Altai into similar long horsts, resemble in every respect the disjunctive lines of trans-Baikalia. The chains of Khankhukhei or Argalintu, which traverse the valley of the Lakes obliquely, recall the range of Bargusin-Swjatoi-Noss-Olkhon, which similarly traverses lake Baikal obliquely; and the valley of the Lakes or the trough-fault of Dsapkhyn represents just as little as lake Baikal the boundary of a tectonic unit.

¹ D. Klemenz, *Journal* for 1896.

The *Gobi-Altai* is not a continuation of the Russian Altai; it is only separated from the Khangai by the subsidences of the valley of the Lakes, and is a marginal fragment of the vertex itself.

In order to obtain an idea of the Gobi Altai we must proceed far to the north-west into the river-basin of the Black Irtish.

South-east of lake Saissan rises the great mass of the *Saur* (3,633 meters). Muschketow has shown that it is the extremity of a range which proceeds through the Tarbagatai and the Tchingis towards the north-west, as far as the mountains of the Kirghiz steppe ¹.

In the south-eastern part of the Saur faults and subsidences occur. From the observations of Bogdanowitsch we obtain the following:—

A section drawn from lake Orkhu, i. e. from lat. 46° N. to the north-north-west as far as the Saissan (lat. 48° N.), meets the hill ranges of Orkhun-Nuntag, Semistau (or Urkashar), Tarbagatai (at the place of its union with the Saur), and finally Monrak, which lies between Tarbagatai and lake Saissan. These ranges are bounded on the north by fractures, which cut across the strike of the beds; Tarbagatai, which lies between them, is a horst, bounded by step-faults on the north and south. 'From the north slope of the Kuen-luen as far as the north foot of the Monrak on lake Saissan,' says Bogdanowitsch, 'we may trace the series of faults and flexures which have accompanied the subsidence of the plains of Kashgar, of Dzungaria, and the Saissan ².'

From the collections of Koslow, which have been studied by Obrutschew, it further appears that the whole east and north slope of the Saur mountains, using this term in its broadest sense, furnishes only basalt, melaphyre, and associated tuffs. This applies to the heights of Salburty and Kara-andyr-ula (both west of Bulun-tokhai), to the north slope of the lofty Saur, and to its western continuation, Monrak, south of the Saissan.

Thus the depression of lake Saissan and also probably its continuation towards Bulun-tokhoi assume the characters of a fault-trough, and indeed more or less those of a coulisse-trough. A fact which affords confirmation of this view, and which indicates the recent date of the subsidence, is furnished by Ignatiew, who was sent to examine the lignite beds on lake Saissan, and found that they plunged with an almost vertical dip beneath the waters on the north side of the lake, near the promontory of Tchakul ³.

¹ J. W. Muschketow, *Turkestan*, 8vo, St. Petersburg, 1886, I, and geological map, pp. 35 and 36. A very detailed work on the region lying south-east of Balchash, and even a geological map of the Dzungarian Alatau, was drawn up by Wlangali as early as 1849-1851, and published in the *Gorn. Journ.*, 1853, II (with many appendixes).

² K. J. Bogdanowitsch, *Geological investigations in east Turkestan*. Results of the expedition to Thibet in 1889-1890 under the direction of M. Piewtzow, published by the Russian Geographical Society, 1892, II, 4to, p. 86, r.

³ Ignatiew, *Coal measures in the neighbourhood of the outpost of Zaissan, Zapiski Sibirsk Otd. Imp. ross. Geogr. Obsch.*, Omsk, 1885, VII, no. 2, various communications, p. 7.

All subsequent observations tend to show that Bogdanowitsch had with great perspicacity found the right explanation. The whole of Dzungaria is traversed towards the east by escarpments which are sometimes ranged one above the other like gigantic stairs, and separated by long troughs, open or flattening out at both ends. The latter are frequently designated by the word *Kholai*. The 'gateway' north of Santskhu also exhibits this structure. The same explanation applies to the long rocky horsts of the Gobi-Altai and of its western border. *The Gobi-Altai itself is a horst situated between the valley of the Lakes and the subsidence of Dzungaria.*

That it is not a regular folded range is evident from the presence of great masses of gneiss at its western foot.

Koslow has furnished an admirable description of the Gobi Altai as a whole. According to him the west of the range to about the meridian of Kobdo is broad, with many peaks rising above the snow line; there is a sufficient rainfall, and convenient pasturage; the east, which is of much greater length, is barren and poor in water. Up to the neighbourhood of the Khuduk-nor, i. e. to about long. 98° E., there stretches an important and continuous mountain range, the *Altai-nuru*. In the north, towards the valley of the Lakes, but more especially in the south, towards the desert, it is accompanied by parallel ranges. Beyond long. 98° E. the whole chain breaks up into ranges of this kind; among them Ikhe-bogdo and Baga-bogdo, situated south-west and south-east of the Orok-nor, rise above the limit of perpetual snow. All these ranges adapt themselves more or less exactly to the crescentic curve of the Gobi-Altai. Koslow's companion, Kasnakow, who traversed the south side of the chain, believes that the Gobi-Altai terminates where the eastern end of the range of Gurban-Saikhan flattens out, near the temple of Shjuljute (between long. 104° and 105° E.)¹.

Of Koslow's work we only possess a preliminary report. Potanin has drawn four transverse sections across the Gobi-Altai which bear admirable witness to his devotion and perseverance. Three relate to the Altai-nuru; the fourth runs across Ikhe-bogdo. We will discuss this great range in connexion with these sections.

In contrast to the Russian Altai, gneiss appears here in great force.

Its importance is already shown by the *first section* from *Bulun-tokhoi* to *Kobdo*. The foot of the range consists of grey gneiss, and the upper course of the Black Irtysh, so far as it lies in the mountainous region, as well as that of the river Krau with the Kharbagatai, is situated in gneiss. Here this rock has a breadth of at least 70-80 versts, and extends nearly to

¹ P. K. Koslow, Letter written at the bivouac on the Ulan-nor, Nov. 20, 1899; followed by A. N. Kasnakow, Preliminary report on the journey from lake Chulmu-nor to lake Ulan-nor on the south side of the Altai, and W. F. Ladygin, Journey to the upper reaches of the river Urungu (Bulugun), *Izvestija Imp. ross. Geogr. Obsch.*, 1900, pp. 18-83, map.

the pass of Urmu-gaitu (2,961 meters), where it is met by chloritic clay slate. Beyond the pass comes the lake of Dain-gol, situated at a great height; the snow-covered summit of the Mustau rises on its western shore, and gneiss débris extends down to the lake. We next reach a zone of schists and granite mountains. The upper course of the Sakssai lies in green schists; porphyry also occurs. Above the Tal-nor and close to the ice of the highest crest a black rock appears with columnar jointing (basalt?). Many varieties of schist now succeed and continue as far as the pass of Terekti (3,200 meters). Once more grey gneiss becomes visible; the descent to the east into the valley of the Lakes takes place over formidable granite cliffs; Kobdo, on the west border of the valley of the Lakes (1,300 meters), lies in granite.

We may add that Prjewalski also met with gneiss, besides bluish granite and schists on the upper Urungu, on the west slope of the Gobi-Altai (long. 91° to 92° E.)¹.

M. Klemenz informs me that he has found marine Permo-Carboniferous fossils in the desert south of the Gobi-Altai at Nursu (likewise between long. 91° and 92° E., and more than 100 versts east-north-east of Gushen).

Four hundred versts south-east of the first section lies the pass of *Ulen-Daban* (between long. 93° and 94° E.), across which Potanin drew his *second section*, following the road from Khami to Kobdo.

This line runs with the meridian of Santochu; starting from this place we descend to the north into the 'Kholai' (715 meters), which leads from Dzungaria into the eastern Gobi; and within which Nursu appears to be situated. Beyond the Kholai there rises a long horst or scarp with the pass of Shar-nuru. This and its lofty prolongations to the west form a steep and continuous cliff on the north side of the Kholai, extending also east of the Shar-nuru. The pass is bounded by bare rocks of felsite-porphyry; on the north side lies schist, which strikes to the east almost parallel with the cliff. Some blocks of white crystalline limestone occur which have probably come from the higher summits. The descent to the north is gradual. Then follows a steep limestone cliff with horizontal stratification.

Here traces of fossils, probably Devonian, have been found. Crossing a steppe, we reach the foot-hills of the Ebschtsche, formed of spilite and greenstone showing concentric exfoliation. Finally we arrive at the foot of the principal chain of the Gobi-Altai.

At its foot exposures of gneiss occur. Ascending the river Barlyk, the gneiss is followed by intensely folded mica-schist, and this again, even before the summit of the pass is reached, and also on the pass of Ulen-Daban itself (2,819 meters), by chloritic clay slate rich in quartz-veins and other deposits of quartz such as we have already observed on the summit of

¹ G. N. Potanin, *Sketches from north-west Mongolia*, I, pp. 21-64. N. von Prjeswalski, *Travels in Thibet, &c.* German translation by Stein-Nordheim, Jena, 1884, p. 13.

Urmugaitu. Here also, on the north side of the pass, granite is intruded amongst the schists. The lake of Khulmu-nor lies in granite. Koslow has reached it from the west and estimates its height at 6,800 feet (2,072 meters), while east of it, also on the north side of the same mountain ridge, the Shargin-Zagan-nor lies at a height of only 2,500 feet (761 meters).

On the ridge of Nam-kotel, which comes next on the north in the section, are granite rocks of fantastic forms. Then follow chloritic slates again, here with interbedded limestone, and above the ridge of Detchen-Daban we reach the margin of the valley of the Lakes¹.

This section indicates that the horsts and steps towards the Dzungarian 'gateway' consist in all probability of upper Palaeozoic rocks, while the principal range of the Gobi-Altai exhibits on its west side first gneiss, then chloritic slate and granite.

About 220 versts further to the east-south-east the principal range of Altain-nuru is crossed by the pass of *Nur-kere* (about long. 96° 20' E.), which traverses the Burkhan-ola on the way from Khami to Uliasutai. Its height is not known, but it is much greater than that of Urmugaitu (2,961 meters) and of Ulen-Daban. It is across this pass that Potanin's *third section* is drawn. The first or southern step forms a steep escarpment, facing south, called Eren-nuru. Here a hard green rock crops out. North of Eren-nuru the desert extends up to the long bare granite ridge of Adjibogdo: at its southern foot melaphyre occurs. The slope of Adjibogdo is steep; towards the north it sends off several spurs. Descending these we meet with thick red conglomerates, in the midst of which an unconformity has been observed. Then, after crossing several secondary ridges, comes another deep depression, Buru, and finally we reach the foot of the Burkhan-ola, which belongs to the principal range of Altain-nuru. The first ridge, Buren-khara, is formed of a black rock. Then comes chloritic slate with quartz veins. Diorite now appears, but the slate continues and forms precipitous isolated crags on the summit of the Nur-kere. Granite also occurs in this locality. Slates and granite form the north slope down to the Zizirin-gol. Then follows a belt of serpentine, and with this we reach the fault-trough of the lake *Shargin-Zagan-nor*.

Here we must interrupt our description of the transverse section and cast a glance at the longitudinal extension of the range.

Starting from Kobdo, on the south side of the Karu-usu, Koslow entered the depression of Dserga, which runs towards the south-east; it was within this depression that Potanin collected plant-remains of the Angara series, near Oeschi. Koslow's route, following the north border of the Altain-nuru,

¹ G. N. Potanin, *Sketches, &c.*, I, pp. 114-119. In this case, the traveller started from the north. For the sake of uniformity, we shall continue to describe the formations from the south towards the north. Koslow, Letter written at the bivouac on the Ulan-nor, Nov. 20, 1899, p. 25.

led him to the pass of Khongar-obonyn-daban (8,300 feet, 2,529 meters), not far from Potanin's second pass, the Ulen-daban, and passing between cushion-shaped rocks of granite he descended to the lake of Khulmu-nor (6,800 feet, 2,072 meters). A second pass attains a height of 7,400 feet (2,255 meters), then we reach lake Tunkul (6,200 feet, 1,889 meters); and further on, after crossing another saddle, the depression sinks to an unexpected depth in the Shargin-Zagan-nor; this lake lies, as we have said, at a height of only 2,500 feet (761 meters). Still further east the watershed between the Shargin-Zagan-nor and the Bagan-nor lies at a height of 3,700 feet (1,127 meters), and is formed of red clay and conglomerate.

The Shargin-Zagan-nor (761 meters), situated on the northern border of the principal chain, the Altain-nuru, but separated from the fault-trough of Dsapkhyn by the chain of Taishir, has therefore been let down to a level almost corresponding with the surface of lake Ubza, the lowest part of the valley of the Lakes. Each of these lakes is completely isolated and without outflow.

Let us return to the transverse section.

The north side of the deep valley is formed by the precipitous southern slope of the chain of Taishir mentioned above. It is of considerable height, and, like the south side of the valley, formed of serpentine. Towards the north the Taishir is formed of limestone, below which, however, serpentine is visible. Thus, at the residence of the Khan of Djasaktu, we reach the fault-trough of Dsapkhyn. On the north side of this trough we encounter the band of basalt observed by Klemenzenz, which here surrounds the Khangai¹.

Between Potanin's third and fourth section Ladygin travelled towards the south, from the east end of the Altain-nuru to Su-tchou. The chief facts that we learn from his journey are the following. In the whole of this region so many chains and ridges, with an east-south-easterly trend, are ranged one behind the other, that it would not be easy to find a definite orographical boundary between the foot-hills of the Gobi Altai and the chains following the same direction, which must be regarded as the continuation of the Bei-shan. Here *it is clear that a general change of direction takes place from south-east to east-south-east and from east to east-north-east*; this change of direction dominates not only the course of the Gobi-Altai but the whole region of the Gobi itself, and, as we shall see presently, even parts of the Nan-shan².

The end of the Altain-nuru bears the name of Gytshigin-ula, and has been crossed at a height of 7,000 feet. The range consists of schists and

¹ P. K. Koslow, *Izvestija Imp. ross. Geogr. Obsch.*, 1900, p. 30; Potanin, *Sketches from north-west Mongolia*, I, pp. 183-216; for fossil plants from Oeschi, I, p. 302, III, p. 87.

² Ladygin, *Izvestija Imp. ross. Geogr. Obsch.*, 1900, p. 174 et seq.

granite. Then follow towards the south two ranges running to the east-south-east, Burgustin-nuru, and Ederyngin-nuru (4,500 feet, green schists, gold-bearing), and then a long depression, *Naren-khukhu-Gobi* (1,100 feet, 335 meters). This is the deepest place for a long distance around. It is bounded on the south by the long hill range of *Koko-tymyrty* (pass 5,000 feet high; peaks about 6,000 feet); this range, as it turns from south-east to east-south-east, forms a connecting arc which extends across the whole of this part of the Gobi, and unites the Adji-bogdo of the Gobi-Altai on the north-west with the chains of Tostu, Dushe, and the lofty Noin-bogdo on the east, passing through Koko-tymyrty and a long series of other ridges which join it.

The ridges which succeed to the south of the Koko-tymyrty cannot, however, be regarded as distinct from the Bei-shan.

Potanin's *fourth section* lies west of long. 101° E. and about 330 versts east-south-east of the third section. It does not cross the Altain-nuru, as in this region the range is completely broken up.

The lowest place on this meridian, *Gashiun-nor*, at the end of the Edsingol, lies probably no higher than 830 or 840 meters. North of it we meet with a series of long and frequently interrupted hill ranges. For information as to the southern ranges we shall make use of the recent observations of Obrutschew, and for the northern, which this observer has not visited, we have the descriptions of Potanin¹.

Leaving the shore of the lake, we travel northwards, and after crossing about 60 versts of desert reach the first ridge, *Sukhomtu*; it consists of supra-Carboniferous sandstone of great thickness, striking east-north-east (80°); then, beyond a depression of no great breadth, comes a far more important range, formed of several parallel ridges; in its southern and highest part these bear the names of Tostu, Dushe, and *Noin-bogdo*; they have already been mentioned as forming parts of the arc proceeding from Koko-tymyrty. Sandstone occurs at the south foot of the range, but the black peaks above consist of melaphyre. Blocks of basalt and limburgite which are derived from a peak at the east end of the Noin-bogdo lead us to suspect the presence of a recent eruptive centre at this point. Still further to the east-north-east lies the ridge of Deng, and the mountain of Khongar-oba, both of which diverge from the general strike. They consist of porphyry and tuff and, in the east, of granite.

Let us now turn our attention to Potanin's section across the Dushe. The north side of the range is formed of supra-Carboniferous sandstone. A broad depression separates it from the ridge of *Nemegetu*. This is not

¹ G. N. Potanin, *The Tangutan-Thibetan frontier*, I, p. 503 et seq.; Obrutschew, *Orographic and geological sketch of central Mongolia, Ordos, east Kansu and north Shensi*, *Izviestija Imp. ross. Geogr. Obsch.*, 1894, XXX, p. 239 et seq.; *Central Asia*, II, pp. 408-433.

so high as the Dushe (1,836 meters), and its outlines are less jagged. On the pass porphyrite and, in some places, granite appear. In the eastern part of this range, Dsolin, the strike changes to 290° ; here porphyry and sandstone traversed by dykes of porphyry are met with.

The depression, hardly 20–30 versts broad, situated north of the Nemegetu, is marked by the lowest point on this meridian (1,135 meters, Potanin), if we except the Gashiun-nor. Looking back, we see that both Nemegetu and the more distant but loftier Tostu present steep declivities to the north.

The next range to the north, *Bain Zagan* (1,670 meters), consists of gneiss; it rises gradually from the kholai, which it hems in with its foot-hills. It is of no great height, but remarkably broad; towards the north it descends to a little river, the Leg (1,440 meters), where basalt again crops out¹.

Before crossing the *Bain Zagan* the traveller, coming from the Gobi, has enjoyed a view, startling by contrast, of the mighty *Ikhe-bogdo*, of the wreath of snow patches which engirdle its broad summit and the neighbouring snow-capped heights. No woods cover its slopes and small bushes only occur in its valleys; the barrenness of the Gobi reaches upwards to the region of perpetual snow. The foot-hills, with steep declivities, advance as far as the Leg. The breadth of the *Ikhe-bogdo* amounts to 22 versts. Its north side is very steep and the pass difficult. *Ikhe-bogdo* consists of granite; at one locality schist is mentioned with an intrusion of syenite. Above these older rocks sheets of basalt rise in steps, and at the highest point which has been reached (2,534 meters) Potanin found himself on basalt. *Ikhe-bogdo* reproduces, far to the south, the features of the basalt-capped goltzi of which Munku-Sagan-Khardyk has already furnished an example².

Towards the north the range sinks to lake Orok-nor (1,240 meters), which is surrounded on the north by the Chodsu, a spur of the *Ikhe-bogdo*. Then comes the fault-trough of Dsapkhyn, here hardly 20 versts in breadth.

East of this section, in the Gobi-Altai, the hills of the Gurban-Saichan (Three mighty ones), ranged like steps, probably reach a height of 2,500 meters.

¹ M. Klemenzen tells me that further east, near Chatun-Suntul, an isolated mountain of columnar basalt rises in the midst of the desert.

² The basalts of the river Leg, and the encampment of Kiachtu on the *Ikhe-Bogdo*, have been described by Wenjukow, Verh. russ. k. min. Ges., 1889, 2. Ser., XXV, p. 245. For the eastern continuation of the *Ikhe-Bogdo*, see the account by Klemenzen in Izvestija Sibirsk. Otd. Imp. ross. Geogr. Obsch., Irkutsk, 1894, XXV, pp. 127–128. The continuity of the chains situated to the east (*Arzi-Bogdo*, *Gurban-Saichan*) has been established by Piewtzow. Further to the south-east they are joined by the Churchu, discovered by Prjewalski.

Such are the changes which affect the ancient vertex as we trace it beyond the Khangai to the south-west and south. In this outer region south of the Tannu-ola the valley of the Lakes is let down; and with this the breaking up of the border region into horsts, steps, and fault-troughs begins. Piece by piece, or rather strip by strip, the vertex descends to the Dzungarian 'gateway.' The Altain-nuru itself, the principal range of the Gobi-Altai, is one of these horsts. Although the lines of fracture and caldron inbreaks produce in places a veritable labyrinth of ramifying and intersecting ridges, of enclosed depressions and long open troughs, yet on the whole they are arranged on a common plan which marks them as appertaining to the peripheral disjunctive lines of the vertex; and the valley of the Lakes, with the trough of Dsapkhyn as well as the trough of Saissan, forms part of this plan.

No doubt the future has many fresh discoveries in store. Klemenzen believes he has found indications of overfolding towards the south in the southern part of the Russian Altai ¹.

Eastern Gobi. In studying the relations of the vertex to the eastern Gobi we have only one source of information at our disposal, namely Obrutschew's description of the line from Kiakhta through Urga to Kalgan ².

South of Urga, where the region without outflow begins with a great number of enclosed basins and caldron-shaped hollows both large and small, the mountains reach a height of 1,400–1,500 meters. Then follows not a level desert but a succession of mountains and hills. The mean height gradually diminishes; we reach the plain of Daitchin-dala (35 versts broad), which, as a rare exception, presents an open horizon on the east and west. We might almost suspect that it is a fault-trough. The ground sinks from 950 meters towards the centre to 850 meters at the spring of *Sain-usu*, the lowest point on the whole line. But in this neighbourhood there are no mountains of any height, and extending onwards for a distance of 340 versts is a region which Obrutschew regards as the central depression of the eastern Gobi. The hills to the south do not exceed 900–1,100 meters as far as the mountains of Tabun-Tochun (1,300–1,400 meters), and the highest point is finally reached at the Great Wall (1,625 meters). A steep escarpment occurs near Kalgan.

The Gobi sediments rest unconformably on the denuded remains of the ancient mountains; they consist of fine-grained conglomerate, friable

¹ D. Klemenzen, Bull. Soc. géogr. Paris, 1899, p. 315.

² V. A. Obrutschew, Geological sketch of the caravan route from Kiakhta to Kalgan : Izvestija Imp. ross. Geogr. Obsch., 1893, XXX, pp. 347–390, sections; Central Asia, I, p. 25 et seq., maps. Some observations may also be found in Potanin, The road through Sain Ussu to Mongolia, Izvestija Sibirsk. Otd. Imp. ross. Geogr. Obsch., Irkutsk, 1893, XXIV, pp. 56–63.

sandstone, red and greenish marls, and white calcareous marls. The basalt mountain of Tchernaiia-gora (Black mountain), situated a little south of the plain of Daitchin-dala, furnishes evidence to show that the Gobi sediments are in part older, and in part younger than the basalt¹. Here these sediments are dislocated and strike to the east-north-east, that is in the same direction as the underlying formations. Further south a large part of the central depression is covered by horizontal sediments of the same kind, broken up into tabular patches. The discovery of the jaw of rhinoceros or *Aceratherium* in the white marl of the table-mountain of Khuldyin-Gobi has shown that the freshwater deposits are of middle or late Tertiary age.

Starting from Urga, we will now follow Obrutschew for a certain distance in a rapid review of the ancient formations.

The Palaeozoic zone which starts from the Onon follows the road with a north-easterly strike. It includes the pass of Khalti-daban (1,650 meters), through which we reach the region without outflow. Next comes a band of basalt, and in the south of rhyolite also, apparently of recent age, then a broad band of gneiss striking to the north-east, and again volcanic rocks of recent origin on the border of the plain of Sahir-uche. A long band of porphyry occurs on the eastern border of this plain; in the south granite also appears. Then we reach the basaltic Black mountain, mentioned above, and the disturbed Gobi-deposits. At the spring of Gashiun (1,090 meters) the hills are of recent volcanic origin. Among them is a dome of rhyolite, which appears to mark a centre of eruption. Passing over crystalline limestone, schist, and granite, we reach the plain of Daitchin-dala and the point of lowest level. Beyond this plain the heights again consist of crystalline limestone and folded schists; granite dykes occur. The strike is constantly north-east. The ridge of Dolon-daban is gneiss; its strike ill-defined; on its south side lies the spring of *Ikhe-Ude* (or Udinsk, 930 meters), and in its vicinity the Russkaia stanzia².

Save for rare exceptions, the *Baikal strike to north-east or east-north-east prevails throughout the whole distance from Urga to this point*. Beyond *Ikhe-Ude* the direction is west-north-west or north-west. Although further on, as at Sadji-Chotu, the north-easterly direction sets in again, yet here also, according to Obrutschew's statements, an important change affects the principal strike. Still up to this point the general direction of the strike agrees with that of the vertex; there are similar ancient rocks with traces of Palaeozoic formations; and many exposures of volcanic rocks, though these perhaps are somewhat more frequently of acid type. *As far as the*

¹ V. A. Obrutschew, *Central Asia*, I, p. 69.

² According to the official map of Russia ($1'' = 40$ versts), *Ikhe-Ude* lies in lat. $44^{\circ} 29' N.$ and long. $111^{\circ} 6' E.$; it is possible that recent surveys may lead to a slight modification of these figures.

spring of Ikhe-Ude at least, i.e. nearly as far as the middle of the Gobi, the vertex is without a perceptible boundary.

As to the relation of the southern folds with a north-west strike to the Khingan it is not possible in the present state of observation to form any opinion.

In the extreme south the route followed by Obrutschew enters the region of the basalt flows of south-east Mongolia. The escarpment at Kalgan, about 500 meters high, exposes this basalt at the summit resting on a great thickness of loose conglomerates and sandstones belonging to the Gobi-series, with trachyte at the base. Kalgan lies on trachyte.

Conclusion. In order to bind the details together it seemed advisable to give a special summary of the first half of this chapter. The northern part of the vertex was surveyed throughout its entire breadth, from the cliffs of the horst on the Yenisei in the west to its junction with the northern continuation of the great Khingan in the east. We found that the eastern part of this vast region of Archaean rocks is characterized by the Baikal strike, to the west-south-west or south-west, and the western part by the Sayan strike to the east-south-east or south-east; and further, that both directions, at least as far as the existing accounts enable us to form a judgement, appear to unite in a north-to-south direction in the Primorskii Khrebet, a little west of lake Baikal. Finally, it was shown that an inbreak of a large part of this region had given rise to the amphitheatre of Irkutsk, which is surrounded by marginal folds. These folds belong to the Cambrian and Silurian platform, which extends as far as the Arctic Ocean; and taken in connexion with the posthumous folds of the Angara beds they afford evidence of a reduction of the area originally occupied by the amphitheatre; while the disturbed position of the rocks in the Primorskii Khrebet, and the overthrusting on the island of Olkhon, indicate a similar reduction of area in pre-Cambrian times. It was also made clear, however, that the folding movements in the ancient vertex were followed by disjunctive processes, which resulted in the formation of the long troughs and fractures east of lake Baikal, the troughs on the Geese lake, the Djida, and Khilok, and finally the two parts of lake Baikal. The basic lavas lying at great heights were mentioned; the age of some of the basalts was traced back to the Permian epoch, while the age of the others was shown to be very recent.

The second half of this chapter has dealt with the extension of the vertex to the south.

A broad zone of slates and greywacke, to which the Devonian outcrops of eastern trans-Baikalia belong, runs from the north-east into Mongolia. An outlier of this Palaeozoic zone is first met with 70 kilometers south of Kiakhta; but the principal zone begins at Strietensk on the Shilka, becomes split up in its course to the south-west, then reunites, reaches the

valley of the upper Onon, passes Urga, and comprises the whole mountain region of northern Mongolia as far as the mouth of the valley of the Lakes; it proves beyond dispute that the Khangai forms part of the vertex.

Even beyond this marginal region the normal strike of the Baikal to the east-north-east prevails as far as the springs of Ikhe-Ude in the eastern Gobi.

In the western part of the Khangai we do not see the normal direction of the Sayan, east-south-east to south-east, but the strike, as far as we know it, is directed more to the south-south-east; at the centre, towards the south border, it becomes east and west.

That disjunctive processes have occurred in this region also is shown, not only by the numerous outcrops of basalt within the Khangai itself and by the recent craters on the Terchain-Zagan-nor, but more particularly by the structure of the marginal region on the west and south. The trough of Dsapkhyu, the valley of the Lakes, the deepest part of which—Ubza—lies furthest within the mountains, the troughs between lake Saissan and Bulun-tschoi, all the troughs of the outer border of the Gobi-Altai, extending far out into the Dzungarian desert, and finally the breaking up of the Gobi-Altai itself into long horst-like strips—all these phenomena show that disjunctive processes have operated in this region on a gigantic scale. In the valley of the Lakes the long narrow horsts which traverse it obliquely, such as Khankhuchei and Argalintu reproduce the features of Swjatoi Noss and Olkhon. These great disjunctive lines follow approximately the Sayan direction and the arc-like curvature which is seen throughout the vertex.

Nor are the high-level lavas absent. Melaphyre forms the ice-capped summits of the Olkhon-Khairkhan-Tengri, east of Uliasutai, and basalt crowns the Ikhe-bogdo, which rises on one of the detached branches of the Gobi-Altai, between the continuation of the Dsapkhyu trough and the Gobi.

In the intervening region of Minuzinsk the case is different.

The most striking feature here is the transgression of the Devonian, which is frequently associated with Culm. These rocks ascend far above 8,000 feet, and they have been recognized not only on the summits of the Tannu-ola and of the Kharkira—a range which projects far into the valley of the Lakes—but also in some of the depressions of this valley and probably also around the sources of the Kobdo. The transgression as such, however, does not affect the tectonic features. The essential difference lies in the fact that the strike is different from that of the west Sayan and of the Tannu-ola, for in both of these ranges it is directed east and west or to east-north-east. Thus we find that the Yenisei, above Krasnoiarsk and the continuations of the east Sayan, cuts through a series of horseshoe-shaped

folds of Devonian rocks, and these folds, according to existing accounts, are identical in character with the posthumous folds of the Angara beds in the middle of the amphitheatre of Irkutsk.

We may suppose that Minuzinsk represents another independent region in which contraction has taken place, and we may perhaps have here the remains of an independent vertex lying between the east Sayan and Kusnetzki Alatau. Unfortunately many parts of the south are but little known, and such problems as the extension of the overthrust on the Tasskyl, and the structure of the eastern part of the Tannu-ola, must remain for the present unsolved.

Over the whole extent of the regions discussed in the second part of this chapter the Mesozoic and the Tertiary aeras are represented solely by plant-bearing beds.

CHAPTER IV¹PERIPHERAL FORMATIONS TO THE EAST OF THE
VERTEX

The watershed of the Arctic Ocean. The Great Khingan. Plain of the upper Amur. Aldan mountains. Bureya mountains. The Little Khingan. Manchuria. Sikhota Alin. Hokkaido and Saghalien. Summary.

The watershed of the Arctic Ocean. The first detailed accounts of the great river Helong Kiang, or Amur, and of the fertile regions which border it, appear to have reached Tomsok in the year 1636. They spread rapidly in Siberia, and in July, 1643, Vasili *Pojarkow* set out from the newly erected town of Yakutsk to explore and subdue these regions. He proceeded with a considerable troop of 'promyschlenni' (hunters, chiefly sable hunters) up the Aldan, then followed the Utshur, and next, travelling in a south-westerly direction, the Konam, where he was obliged to winter; then he crossed the watershed, not far from the height of Atytchan, which will be discussed later, and finally reached the Amur by the Gilyui and the Zeya. The return journey took place across the sea of Okhotsk.

In 1647 the 'promyschlenni' announced in Yakutsk that they had succeeded in finding a much shorter and easier route. This led from the Lena up the Olekma and its long tributary the Tugir. From the source of the latter it was easy, by following the river Urkan, to reach the Amur a little below the existing town of Amasar. In the same year the Cossacks erected a fortified station on the Tugir, and in 1649 the expedition of the Yerofei *Charabow*, so important in the history of the country of the Amur, took place from Yakutsk along this route. That this line was again abandoned on account of the difficulties it presented is untrue. In 1651 the route across the Tugir was followed by the Cossack Tchetchigin, and in 1652 by Sinowiew; along this route also a good deal of immigration took place from the upper Lena, many exaggerated reports having been spread of the prosperity of the new country; it is recorded that Chabarow's messengers were able to reach Yakutsk from the Amur by this route in 23 days.

It is true that from this time onwards the route across the Tugir fell more and more into disuse, but this was not on account of geographical difficulties. In 1654 Beketow for the first time reached the Amur from the west by the Ingoda and Shilka; in 1655 an edict was issued that tribute was no longer to be sent to Yakutsk, but direct to Moscow. The attention of the central government was directed to the Amur, and from this time

¹ Revised by T. W. Edgeworth David, F.R.S., Professor of Geology in the University of Sydney, New South Wales.

onwards communication with Yakutsk and the road across the water-parting was abandoned.

But affairs on the Amur did not develop favourably. Among the Russian immigrants there were few inclined to settle permanently. The Cossack fortress Albasin was stormed by the Chinese, rebuilt by the Cossacks, and again besieged by the Chinese. Then in 1689 a congress assembled at Nertchinsk with the object of arranging matters amicably. The chief representative of Russia was Fedor Golowin; the Chinese ambassadors had brought with them the two Jesuits, Father Gerbillon and Father Pereira, to assist in the negotiations and to act as interpreters.

Both sides were earnestly inclined towards peace, but they were in the midst of a vast wilderness, and were attempting to draw boundaries in a completely unknown country. Subsequently a Russian version of the discussions was published by the Imperial Academy in St. Petersburg, while a report was furnished from the point of view of the Chinese by Father Gerbillon, in a very interesting memoir published in the work of Du Halde¹.

The boundary in a meridional direction was not hard to find; it was agreed to fix the Argun as the limit south of the Shilka, and the little Gorbitza as that north of the river. But the Chinese did not approve of the Amur as the east-to-west boundary. Consequently it became necessary to adopt its northern line of water-parting, which was at that time regarded as a mountain range. 'The promyschlenni,' says a Russian account of 1740, 'generally call the whole of this range *Stanovoi Khrebet*. They say that the range which has to be crossed on the way from Yeravna to Nertchinsk, and is there called *Sablenoi* (probably Yablonoi) *Khrebet*, is connected with this range in the direction of the source of the river Tchita, a tributary of the Ingoda, having an easterly trend'².

In the accounts of the conference of 1689 these two names do not yet appear.

¹ Geschichte der Gegenden an dem Flusse Amur von der Zeit da selbige unter russischer Oberherrschaft gestanden; Müller, Sammlung Russischer Geschichten, II, 5. und 6. Stück; 8vo, St. Petersburg, bei der kays. Academie der Wissenschaften, 1758, pp. 293-448 (also contains accounts of the movements of the Russians in the region of the Amur before 1689); P. J. B. du Halde, Description géographique, historique, chronologique, politique, et physique de l'Empire de la Chine et de la Tartarie Chinoise, fol., Paris, 1735, maps; IV, pp. 163-251: Second voyage fait par ordre de l'Empereur de la Chine en Tartarie par les Pères Gerbillon et Pereira, Missionnaires de la Compagnie de Jésus à la Chine en l'année 1689; cf. also Gerbillon, op. cit., p. 57.

² (Müller): Von dem Amurflusse, besonders von der nördlichen Seite desselben und dem zwischen dem russischen und chinesischen Reiche bestimmten Gränzgebirge, wie auch von der Gegend des Udfusses und deren übrigen zwischen dem Ud und Amur in das Weltmeer fallenden Flüssen. Auf Ihro Kays. Majestät eigenhänd. Befehl v. 1. Febr. 1740, und Befehl aus dem hohen dirig. Senat v. 8. Febr. dess. J. verfertigte Nachricht. Reprinted in A. F. Büsching, Magazin für die neue Historie und Geographie, II. Theil, Hamburg, 1768, pp. 483-518; in particular p. 487.

In drawing up the treaty it was added on the Chinese side, in order to more closely define the east-to-west range, that it ended towards the 'Eastern Sea' in a long rocky promontory. The Russian deputies, however, strongly protested, being unwilling that that question should be raised, for the Chinese, by their new wording, were proposing a continuation of the boundary along the watershed as far as Tchutchkoi Noss, which would have involved a loss to Russia of the districts on the Uda; they were able to lay two maps before Father Gerbillon, from which they proved to him that this Noss lay very far to the north, according to their assertions almost in latitude 80°. This promontory had, in fact, been discovered by Deschnew in 1648, and subsequently several expeditions had been sent to the Anadyr and to Kamtchatka. Father Gerbillon saw the impossibility of maintaining his claim; he therefore assumed that at the sources of the Gorbitza there were *two lofty rocky chains*. One of these ran due east parallel to the Amur; he proposed that the deputies from Moscow should accept that as the boundary. The second chain, which he called *Nossé*, ran towards the north-east; between them lay the country on the Uda¹. This hypothesis was made the basis of the treaty of Udinsk. After Father Gerbillon had succeeded in proving to the Chinese the extreme remoteness of the Noss, it was considered sufficient to employ very indefinite wording with regard to the eastern end of the watershed, and to make a reservation with regard to the Uda.

The information given by Father Gerbillon about this part of Asia has been embodied in the great cartographical works of the Jesuits, and these works until quite recently formed, in a general way, the foundation of all the maps of the Chinese empire.

The existence of two mountain ranges north of the Gorbitza is no longer accepted. The political boundaries established at that time have likewise ceased to exist. These attempts, however, though in themselves praiseworthy as intended to bring about a peaceful settlement of a dispute over frontiers in an uninhabited and unknown land, gave rise to errors which have not yet entirely disappeared. One of these is the conception of that extremely long boundary range which Father Gerbillon, probably as the result of a misunderstanding, designated by the name of Nossé (Tchutchkoi Noss); this range was supposed to extend from the cape to the Tchita, and still appears on many of our maps under the general name of Stanovoi. Now this theory does not accord with the facts.

The description by Middendorff may serve as the basis for an inquiry into the true state of the matter².

¹ Père Gerbillon, *Second Voyage*, &c., p. 198.

² A. Th. v. Middendorff, *Reise in dem äussersten Norden und Osten Sibiriens während der Jahre 1843 und 1844*, 4to, IV, 1, St. Petersburg, 1867, maps; pp. 114, 140, and in particular p. 211 et seq.

According to this distinguished investigator the general name of 'Stanovoi range' was conferred by the Cossacks, at the time when they conquered the country, on a mountain system 4,000 versts long which forms the main line of water-parting from the cape of Tchutchkes to Dauria. In this long range, according to Middendorff, the following elements must be distinguished: (a) *The Aldan* mountains; (b) the eastern part of the dividing range, the Stanovoi mountains of Pallas or the *Dseja* (*Zeya*) mountains, from the affluents of the Silimdji and the Kureja (about long. $131^{\circ} 30' E.$) nearly to the head waters of the Olekma (about long. $121^{\circ} 30' E.$); (c) the western part of this dividing range, or the *Olekma* mountains, as far as the watershed of lake Baikal (long. $113^{\circ} E.$ approximately); (d) the *Yablonoi* from this point to the Gobi.

Middendorff based this description on the accounts of his predecessors, and on observations made during long and arduous journeys along the southern slope of this central region. He did not cross the hypothetical watershed, but he brought the unexpected news that, in consequence of the vague wording of the treaty of Nertchinsk, there was complete uncertainty as to the position of the boundary of China, and moreover that the Chinese had placed their boundary marks much further south than the Russians had ever supposed.

The consequence of his accounts was that several expeditions were sent out to discover the watershed. Maydell has enumerated all of them; Schwarz, the distinguished astronomer of the great expedition which travelled through Siberia in the years 1855-1858, even at that time expressed doubt as to the existence of such a long and continuous mountain range¹.

Several years later an attempt was made to establish communication between Tchita and the gold-placers of the Olekma. Among those sent out to discover a new route was Prince Kropotkin. After many travels in these regions Kropotkin declared in 1875 that the long rampart said to extend to Kamtchatka was simply a 'product of the imagination,' and that such a continuous range as the supposed Khrebet Stanovoi, forming the watershed between the Arctic and the Pacific Oceans, did not exist, either high or low, steep or flat².

¹ Baron Gerhard Maydell, *Reisen und Forschungen im Jakutskischen Gebiet Ost-sibirien*, II; Schrenk und Schmidt, *Beiträge zur Kenntniss des russischen Reiches*, 1896, 4. Folge, II, pp. 164, 206, 274, 320 et passim. Important facts concerning the orography of this region are given in Fr. Schmidt, P. v. Glehn, and A. D. Brylkin, *Reisen im Gebiete des Amurstromes und auf der Insel Sachalin*; Baer und Helmersen, *Beiträge zur Kenntniss des russischen Reiches*, 1868, XXV, maps.

² Kropotkin, *Sketch of the Orography of eastern Siberia*, *Zap. Imp. St. Petersb. geogr. Obsch.*, 1875, V, pp. 1-140, maps; p. 56 et passim. The existence of the eastern Stanovoi range is most emphatically denied in the same author's *Memoiren eines Revolutionärs*, 8vo, Stuttgart, 1900, II, pp. 10-14.

Kropotkin has furnished a very clear description of the mountainous mass of the Vitim. From Zipa onwards through three degrees of latitude, and for a long distance towards the east, the greatest uniformity prevails. A vast forest of larch covers the whole country. 'The landscape,' says Kropotkin, 'has lost all individuality'¹.

The picture presented by this part of the vertex is that of a primitive Archaean continent, long since deprived of its original form, cut through at variable distances by disjunctive lines marked by basalts and porphyries; and furrowed by the ramifications of rivers which have cut back their channels both from the north and from the south. Travellers who have sought to follow the watershed of the two seas have not reached a long continuous mountain chain, but primitive forest, moss-covered masses of rock and extensive morasses, interrupted here and there by lakes.

Further east, however, so Kropotkin believed, from the sources of the Tchitchatka (a left tributary of the Amasar, long. 120° 30' E.) to those of the Gilyui (a right tributary of the upper Zeya, sources long. 125° 45' E.) the watershed on the site of the alleged Stanovoi is formed by ridges, similar and parallel to those of Gasimur, which approach from the desert of Gobi in a north-easterly direction.

Later observations have confirmed this view.

In the spring of 1883 J. Martin set out, from the localities where auriferous sand is washed on the south side of the Patomske Nagorie, to cross the Stanovoi. After a long and arduous journey between the Olekma and the Vitim he crossed the Tugir at a level of about 600 meters, then encountered on the Stanovoi rounded mountain masses, which here and there reach a height of 1,300 to 1,500 meters, and after crossing the watershed in continual heavy snowstorms, followed the Amasar to the Amur. His wanderings through this wilderness had lasted nine months. 'It is to be observed,' says Martin, 'that in the region traversed by me the Stanovoi shows a less marked relief than the watershed between the Vitim and the Olekma.'

In the following year Martin visited the line of the Stanovoi between the upper Olekma and the Zeya, and here encountered the same configuration of the ground. Here too he saw rounded ridges above which mountains in the form of sugar-loaves (*goltzi*) rose here and there to a height of 1,000 or 1,500 meters².

From this point onwards the works of Russian geologists afford us a fairly clear idea of the country.

Gerasimow has placed it beyond doubt that the horst of Yablonoi does

¹ Kropotkin, *Olekma-Witim*, p. 378, in his *Orography of eastern Siberia*, p. 63.

² J. Martin, *Voyage dans la Sibérie Orientale*, C. R. Soc. géogr., Paris, 1887, pp. 226 et seq.

not form an elbow towards the east around the source of the Tchita, as asserted by the promyschlenni in 1689, but that it follows a rectilinear course between the Vitim and Karenga¹.

About two degrees further to the east Gedroitz advanced up the river Kuenga and its left tributary, the Aleur. So far as can be judged he did not quite reach the watershed, but the steep border of a plateau, perhaps the edge of a horst extending to the north.

Still further east the Shilka range rises near Strietensk, north of the river Shilka. It maintains a north-north-easterly direction, and appears to be intimately connected with the Borshtshevoshnie. In this mass Gedroitz reached the *heights of Urium* (852 meters, lat. 53° 45' N., long. 119° 12' E.), between the upper course of the Tcherni Urium and that of the Amasar. Towards the north-west this ridge descends directly to one of the uppermost tributaries of the Olekma. Towards the east, in the upper part of its course, the Amasar is joined by the little river of Tchitchatka mentioned by Kropotkin.

The next point of the watershed was reached by M. Iwanow on the *Sergatchinskaja Sopka* between the uppermost tributaries of the Uruschi and those of the Oldoi (lat. 54° 38' N., long. 122° 40' E.). This region is a high plateau with isolated ridges and peaks; the *Sergatchinskaja* is the highest of these, and rises 800 meters above the valley bottom. The plateau descends to the south-east to the great plain of the Amur, of which it forms the border. It consists of Archaean rocks, which strike N. 40°-60° E., and along its eastern margin towards the plain there is a zone of sedimentary rocks probably of Devonian age. Only traces of corals and Polyzoa have been found in it. M. Iwanow conjectures that this plateau reaches the Shilka towards the south-west, and is continued to the north-east across the Ur to the lower Gilyui. In any case, it is very similar to such ranges of eastern trans-Baikalia as strike to the north-east, or it may be the continuation of one of them. The junction would take place slightly north of the end of the Great Khingan, somewhere in the region of the Amasar. Thus the *Sergatchinskaja* indicates that the vertex is continued north of the Great Khingan. The inhabitants of the region on the Amur call it Yablonoi, following the ancient tradition, although it has nothing in common with the Yablonoi³.

¹ Gerasimow, Djel. Dor., 1899, XIX, pp. 14, 15. 'The watershed . . .,' says Gerasimow, 'does not consist of a single simple chain, but is produced by a whole series of unimportant segments belonging to ranges tectonically distinct.'

² Gedroitz, Djel. Dor., 1897, VI, pp. 83-127; p. 89, a description of the watershed. All the place-names given here are borrowed from the Russian map on the scale of 1"=40 versts. This map itself requires revision in accordance with recent observations, and the names are only intended to aid the reader in a general localization.

³ M. Iwanow, Geological observations in the basin of the upper Amur, in the region of the Zeya and Bureya, and on the west flank of the Little Khingan, Djel. Dor., 1898, VIII, pp. 51-79, maps; in particular p. 54 et seq.

As early as 1856 Ussolzow travelled up the Oldoi, then turned to the right branch of the river, and crossing the desert found himself in a steep country covered with granitic débris. After long wanderings attended by many hardships he reached the upper Gilyui, and at its sources the mountain group of *Atytchan*, which he regarded, in accordance with the conception of the time, as a continuation of the Yablonoi. He ascended the river Kudula to the watershed, which he found covered with marshes, the effluent streams from which took different directions. Unfortunately his accounts furnish no further details ¹.

Investigation of the gold deposits on the upper Zeya has produced unexpected results. Between the two tributaries of the river, the Ur and the Gilyui, near the region in which the continuation of the range visited by M. Iwanow is supposed to lie, an important mountain range, the *Khrebet Tukuringra*, trends from the north-west towards the valley of the Zeya. Makerow states that the valley of the Gilyui and the whole Tukuringra consist of red and grey gneiss, strike N. 290°–330° W., the prevalent dip being to the south-west, the bands being sometimes vertical, sometimes forming steep folds which occasionally pass, as on the upper course of the Chugdor, into imbricate structure. Towards the north-east, on the Ilikan, granite succeeds. On the south slope of the Tukuringra phyllite is present, also graphitic schist, striking N. 295°–300° W., and dipping north-east ².

Here on the Tukuringra we have reached a region where the strike of the rocks no longer corresponds to that of the Baikal folds of the vertex and the Sergatchinskaia, but to that of the eastern chains. At the same time a folding towards the east makes its appearance.

From the Denn (left tributary of the Zeya) brown sandstone with *Cyathocrinus* and *Streptorhynchus* is known ³.

Thus we obtain the following conception of the watershed between the Arctic and the Pacific Ocean :—

The Yablonoi, which is a part of the horst of the Malkan mountains, coming in a gentle curve from Mongolia, does not bend to the east, but runs in a straight line to the east-north-east between the Vitim and Karenga. The horsts and mountainous belts lying further to the east, which all follow a north-north-east to east-north-east direction, form this part of the water-

¹ Ussolzow, Journey to the sources of the Gilyui and the Zeya in the summer of 1856, *Viestnik, Imp. ross. Geogr. Obsch.*, 1858, XXII, pp. 143–160.

² J. Makerow, Geological Sketch of the gold-bearing Beds in the basin of the Amur, *Izvestija Sibirsk Otd. Imp. ross. Geogr. Obsch.*, 1889, XX, no. 3, p. 38. Middendorff has also seen the Tukuringra and recognized its connexion with the dividing range; *Reise, &c.*, IV, p. 217 note. Jatschewski has also visited these gold beds; *Matér. Géol. Russie*, 1889, XIII, p. 228 et seq., map; also W. A. Jantschukowski, *Gorn. Journ.*, 1890, I, p. 358.

³ A. Stuckenberg, *Materialien zur Kenntniss der Fauna der devonischen Ablagerungen Sibiriens*, *Mém. Acad. Imp. Sci. Saint-Pétersb.*, 1886, 7^e sér., XXXIV, no. 1.

shed indirectly, building it out of a series of great cross ridges. Probably they follow this direction, some to a greater, some to a less distance, into the Taiga and then die away, while between them or on their denuded ridges the rivers of the Pacific Ocean encroach from the south, those of the Arctic Ocean from the north.

Among these mountain belts we must include the Sergatchinskaia, the border of which, probably of Devonian age, forms the north-west margin of the plain of the Amur.

In the region of the Zeya, the Tukuringra, like the Great Khingan, lies outside the vertex.

Kropotkin's views may be summed up as correct. The Olekma range of Middendorff merges into the spurs of the vertex. We shall attempt presently to analyse the eastern part of the watershed. The line of the Stanovoi and Yablonoi must disappear from our maps.

It is evident that retrogressive erosion has deeply affected the position of the watershed in the region under discussion. This is also the case on the southern part of the watershed between the Yenisei and the Amur, but here on the broad Archaean ridges, which run to the Kentei, the tectonic lines have exercised less influence on the course of the rivers; the rivers follow such lines in places, while in others they abandon them; and it is thus that on the upper Tchikoi and upper Ingoda, for example, a perfect labyrinth of river lines has become developed, whence Gerasimow was able to trace the sources of the Ingoda up to the zone of schist on the south side of the Sokhondo.

The Great Khingan. D. B. Iwanow has shown that the range of *Niukdja*, which the maps mark as an outpost of the Great Khingan situated north of the Amur, and between this river and the Zeya, does not exist, but that the interval between these rivers is occupied by a broad plain¹. The existence of the range of *Ilkhuri-Alin*, marked as running in the same direction south of the Amur, is also unconfirmed by trustworthy accounts, and we only know that a watershed of some sort exists in these regions between the tributaries of the Nonni and those of the Amur.

The works of Gedroitz have acquainted us with the unexpected breadth of the Khingan on the Argun and the lower Shilka; his investigations extend along the Mongolian frontier nearly as far as the great depression of lake Kulun (lat. 49° N.). M. Obrutschew has kindly placed at my disposal a list of rocks collected by Kropotkin² and Manakin³ on their

¹ D. B. Iwanow, *The Watershed of the rivers Amur and Zeya*, Djel. Dor., 1899, XII, pp. 31-64, map.

² P. Kropotkin, *Description of the journey from the post-house of Staro-Zuruchaitu by the town of Mergen to Aigun on the Amur*, Zap. Sibirsk. Otd. Imp. ross. Geogr. Obsch., Irkutsk, 1865, VIII, pp. 1-57. Andronnikow, who travelled from Staro-Zuruchaitu to Zizikar, brought back porphyry, melaphyre, and basalt.

³ M. Manakin, *Description of the journey from Staro-Zuruchaitu post-house through*

respective travels; he has also examined the collections made by Potanin and Palibin in 1899 in the course of two journeys, reports of which have not yet been published, and has sent me lists of the rocks. Potanin's line runs from lakes Tarei, Kulun, and Buir, passes to the temple of Tchakylssumé in long. 118° E. and somewhat south of lat. 46° N., then crosses the Khingan in a south-easterly direction to the temple of Khan-tabyn-ssumé (long. $119^{\circ} 15'$ E., lat. 45° N.): and finally runs along the east slope and back to the Argun in long. 118° E. The botanist Palibin came from Urga to the Kerulen, entered the region of the Khingan in long. 118° E. and lat. 44° N., crossed this range and descended to the river Sharamuren, reached the mission station Tun-tsia-in-tse (long. 118° E., lat. $42^{\circ} 30'$ N.), and finally Kalgan.

Neither of these itineraries reaches the Ilkhuri-alin; a considerable part of their course lies in the more southerly part of the Khingan.

The principal facts are as follows:—

The Great Khingan is traversed by the lower Shilka and the Amur. Its breadth is from 180 to 200 versts, or about the same as that of the Alps between Lucerne and Como. Only the western part of the section is known in detail, but the early observations of F. Schmidt show that the prevalent strike is the same as in the east. Gneiss and ancient schists, then deposits probably of Palaeozoic age, with granite, porphyry, and diabase, form these mountains. Here, in the north, recent volcanic formations play but a trifling part. On the other hand, a great belt of granite 'of dioritic type' makes its appearance, and close to the north border runs down from the Shilka in a south-south-east direction to beyond lat. 52° N. Its breadth varies, and according to existing descriptions may well attain 30 versts.

It is difficult to understand how this broad and mighty chain can terminate almost suddenly on the north of the Shilka as it approaches the Sergatchinskaia Sopka, which strikes to the north-east in the Baikal direction; yet the observations of Iwanow lead to the conclusion that it does so.

The recent volcanic rocks which are to be seen near Nertchinskii-Savod, along the upper Argun and on lake Kulun, must be regarded as a part of those very extensive eruptive outcrops, of comparatively recent age, which accompany the whole of the Khingan from this point onwards.

According to Obrutschew the specimens which have been collected between the river Kerulen and the lakes of Tarei confirm the view that the rocks of south-east trans-Baikalia are continued to the south-west into Mongolia.

Kropotkin left the Argun north of lat. 50° N., and crossed the Khingan in lat. $49^{\circ} 30'$ N.; Manakin's route at first coincides with that of Kropotkin, the towns of Mergen and Aigun to Blagoviechtchensk on the Amur, Zap. Tschitinsk. Otd. Imp. ross. Geogr. Obsch., Tchita, 1898, III, pp. 1-70.

but he crossed the Khingan a little further to the north. Both travellers observed, not only in the west but also on the summit of the Khingan, and in a great part of the eastern slope, clay slates and granite, in places porphyry and upturned red sandstone; notwithstanding a suspicion that on one of the two journeys granite and rhyolite were frequently mistaken for one another, yet we may fairly conclude that south of lat. 50° N. the general structure does not differ essentially from that to the north, and that here also ancient rocks form the greater part of the Khingan proper.

Somewhat further east of the Khingan, beyond long. $123^{\circ} 30'$ E., the case changes completely. If we cross the Khingan at the sources of the Nomin we encounter on the east side, according to Potanin, some parallel chains of granite and porphyry with an almost meridional trend and a particularly steep eastern declivity. The mountain of *Shater* at the bend of the Nomin is, according to Manakin, an extinct volcano, with a well-preserved crater¹. In like manner, according to Potanin, east of this volcano, towards the town of Mergen, the remains of a crater are to be seen at the union of the rivers Guila and Gan; and north-east of Mergen on the road to Aigun, the rocks are strewn with blocks of vesicular lava. The mountain of *Koronan* on this route bears a crater. About 100 versts east-south-east of Mergen lies the mountain of *Ujun Kholdongi* (lat. $48^{\circ} 40'$ N., long. $126^{\circ} 27'$ E.), which according to Chinese accounts was in eruption in 1720².

Thus the town of Mergen is surrounded by a volcanic region of recent date, which measures 200 versts from west to east, from the Shater to the Ujun Kholdongi. After passing the Koronan, as we journey from Mergen to Aigun we reach a ridge 557 meters high between the Nonni and the Amur, on which granite and diorite are exposed, but on the slope to the Amur we again meet with great blocks of lava.

Even at Bibikovo, 60 versts above Blagovestchensk, recent lavas still appear, and Kropotkin thought he recognized traces of a crater.

The volcanic region of Mergen forms an eastern extension of the volcanic rocks of the Khingan and at the same time a part of the border of the eastern Gobi.

Another important volcanic region lies much further south, in the desert west of the Khingan. Lermontow reached it towards *Amagolon-Khan* (Bogdy-ola, lat. $43^{\circ} 45'$ N., north-north-west of Dolon-nor), and it has been described by Muschketow. The highest part is formed of a conical peak with a horseshoe-shaped depression, resembling a crater. It consists of basalt, tachylite, limburgite, and other rocks. Its height above the sea is

¹ Diameter 400 meters, depth 36 meters, relative height 163.5 meters; the crater opens on the west side. The walls descend at an angle of 45° to the marsh, which fills the crater. They are formed of grey and red lava and scoria; Manakin, op. cit., p. 45.

² J. W. Muschketow, *Physical Geology*, I, St. Petersburg, 1891, p. 248.

2,266 meters, but since the steppe lies here at a level of 2,019 meters, its relative height is small. Nevertheless it forms a landmark for the caravans far and wide ¹.

Potanin, coming from the north, encountered granite, porphyry, and clay slate down to about lat. 45° N. South of this latitude the existence of volcanic rocks at a great number of places on the eastern slope has been made known through the collections of Putiata and Borodowski, and the description by Muschketow. Basalts have been met with at a number of places east and west of long. 118° E., between lats. 43° 30' and 42° N. Trachyte appears at Ghu-antu-kat (north of lat. 41° N.; long. 118° E.). The descriptions of these travellers confirm the statement that the Great Khingan possesses only an eastern slope, and represents as it were the landing at the head of a staircase. Muschketow has recently described it as the result of a fault: 'It is a high terrace,' he says, 'by which Mongolia descends to Manchuria, one of the gigantic steps by which eastern Asia gradually sinks to the sea' ².

Prjewalski, travelling from Peking to the north, reached the Great Wall at Hu-bei-kou (221 meters). Thence he travelled for about 180 versts through valleys excavated in gneiss and granulite to the town of Dolon-nor (1,263 meters), on the slopes of the Great Khingan; north-west and west of this town the Mongolian platform rises at once to over 2,000 meters; on the summit the previously rocky character of the landscape disappears and we suddenly enter the monotonous Gobi ³.

The town of Dolon-nor lies on ancient rocks traversed by quartz veins; then follows to the north-west quartz-porphyry, and the steps which take us to the summit of the Gobi appear to be formed of the same rock.

It is, however, the southern end of the Great Khingan that is of special interest. It has been repeatedly pointed out by Ferdinand von Richthofen that the outer border of the faults and flexures of Shansi, which forms the western border of the great plain, corresponds in direction with the trend of the Great Khingan. In his famous attempt to construct a tectonic map of North China, Richthofen designated the hypothetical continuation of the chief fracture 'the line of the Khingan'; and he has recently pointed out that the mountains of north Tchili are probably connected in an arc-like curve with the Khingan, to the north or north-north-east of Peking ⁴.

¹ Geological notes on east Mongolia, Gorn. Journ., 1881, II, pp. 80-98, map.

² L. J. Borodowski, Materials for an account of the Expedition of Colonel Putiata to the Khingan, Zap. Sci. Soc. of the district of the Amur, Vladivostok, 1894, III, 155 pp., map; Muschketow, Verh. russ. k. min. Ges., 1893, 2 ser., XXX, p. 448.

³ Prjewalski, Reisen in der Mongolei, &c., p. 88 et seq. (German by A. Kohn, Jena, 1877).

⁴ Richthofen, China, II, p. 520 and pl. VI; Ueber Gestalt und Gliederung einer Grundlinie in der Morphologie Ost-Asiens, Sitz. k. preuss. Akad. Wissensch., Berlin, 1900, XL, pp. 888-925, in particular p. 900 et seq.

Avoiding details which have already been given (II, pp. 229–238), we may sum up as follows:—

Between lat. $53^{\circ} 20'$ and lat. 52° N., and between long. 120° and long. 123° E., folds of ancient rocks, on the west side accompanied by a great belt of granite, cross the lower Shilka and the lower Argun obliquely. In this region their direction is south-east, but it soon becomes north and south. At Nertchinskii-Savod recent volcanic rocks rest against the west side of the great range. Towards the east, in the neighbourhood of the sources of the Nonni, near Mergen, there lies an extensive region of recent volcanic activity. For a long distance the meridional continuation lies somewhat west of the meridian of 122° E.; between lat. 50° and lat. 49° N., the great range bends in a gentle arc, first to the south-south-west, then to the south-west; accompanied by volcanic rocks, it reaches the meridian of 116° E. not far from Dolon-nor, in lat. 42° N., and passes, as Richthofen conjectures, into the line of subsidence of Peking. Its lavas are probably connected with the great lava-fields of southern Mongolia.

In the north, as we have seen, the Great Khingan is a very broad folded range; on its east side, however, it sinks in a mighty step, resembling a flexure or fracture; this is also the case to the south near Dolon-nor, and it is to this downthrow on the east that the lines of subsidence of Peking also correspond. In some places the Khingan appears to die away towards the east, but observations are still very incomplete, and we do not know whether this is due to a flattening out of the flexure or to lavas being piled up in front of it.

The porphyries as well as the trachytes and basalts of the Khingan are of later date than its folding. On the horsts in the neighbourhood of Peking a transgression of flat-lying Cambrian beds is known to occur. No such transgression has been observed in the north. On the other hand, no trace of recent eruptive rocks has been recorded along the flexures of Peking. In fine, the great Khingan certainly represents a broad step between the high-lying land in the west and the lower land in the east, or, to use Richthofen's apt expression, 'a great step in the country.' How far it is also a line of 'overflow' (Ueberwallung) in Richthofen's sense, will be discussed on a later page.

Plain of the upper Amur. The north-west margin of the western plain of the Amur is formed by the border, probably Devonian, of the Sergatchinskaia range, which trends to the north-east, and M. Iwanow observes that along this border granites and syenites occur, accompanied by aureoles of contact¹.

The contrast in the directions of trend is here very marked. The ranges

¹ M. Iwanow, Geological explorations in the basin of the upper Amur, in the region of the Zeya and Bureya and on the west flank of the Little Khingan, Djel. Dor., 1898, VIII, p. 63.

of trans-Baikalia maintain their north-east to east-north-east direction; in the Khingan, on the other hand, the north-west direction prevails in the north; still further to the north-east the Tukuringra also trends north-west.

It seems, however, as though this north-west trend belongs only to the more northerly regions; the strike of the Khingan becomes due north and south, and soon begins to assume a north-north-easterly trend, which becomes more and more pronounced towards the south, as though on the whole there were a tendency to return to the trend of the vertex.

The structure of the plain north of the upper Amur is not quite simple. Close to the east border of the Khingan the Angara beds appear with *Asplenium Whitbyense*, *Tschekanowskia rigida*, &c., and these beds cover the whole western part of the plain; their outcrops can be traced on the Amur to beyond long. 126° E., and also to the north on the Ur and on the Zeya to just east of long. 128° E.¹ They are overlain by white Tertiary sands and clays with brown coal which cover the eastern part of the plain as far as the Zeya, and along this river, from its bend to its confluence with the Amur, they form the cliff of the *White mountains* or Bielgorie, the striking appearance of which was remarked by Milowanow as early as 1681.

The Tertiary covering, however, is in places of very trifling thickness; Archaean rocks crop out from beneath it, as, for example, on the upper Tygda, but they have no orographical significance. A remarkable mass of granite separates the Zeya from the Amur near Blagovestchensk. In long. 126° 30' E., at Zagaian on the Amur, the granite is capped by a patch of white Tertiary rock; at this spot beds of lignite which have been on fire for many years attract the attention of travellers.

In these scattered exposures of the Archaean foundation M. Iwanow recognizes the prevailing trend to the north-north-east. But even the Angara beds, which form the western part of the plain, do not, according to this observer, lie horizontal, but along the Amur, in the region between the Great Khingan and the first locality where the Archaean foundation again crops out, they exhibit folding with a north-north-east strike. *The plain has been formed by the denudation of these folds*².

The Tertiary beds reappear beyond the lower Zeya. They are covered by still more recent alluvial deposits which form the immediate subsoil of these fertile prairies. This territory ends towards the south in an escarpment, which often stands a considerable distance back from the Amur. All

¹ F. Schmidt, *Reisen im Gebiete des Amurstromes*, &c., pp. 21, 23 et seq., and p. 173; O. Heer, *Beiträge zur Jura-Flora Ost-sibiriens und des Amurlandes*, *Mem. Acad. Imp. Sci. Saint-Petersb.*, 1884, 7^e sér., XXII, no. 12; M. Iwanow, *Djel. Dor.*, 1898, VIII, p. 64, and 1899, XII et passim.

² M. Iwanow, *The watershed between the rivers Amur and Zeya*, *Djel. Dor.*, 1899, XII, pp. 41, 48, in particular pp. 56 and 61.

the country at the foot of this escarpment is exposed to the floods of the great river. Finally this escarpment reaches the west side of the Little Khingan, and at Paskova (long. $132^{\circ} 45' E.$) the Amur cuts through the range in an erosion valley.

The Little Khingan is one of those long mountain chains which converge in so striking a manner towards the north of the sea of Okhotsk. The folds just mentioned, which strike to the north-north-east in the plain of the Amur, are probably only the prelude to the great harmony of movement which dominates a large part of eastern Asia.

It will be advisable to describe these chains in the order of their succession from the continent to the sea. The most important elements are: (a) the Aldan mountains on the west side of the sea of Okhotsk; (b) the Turkana range, the Bureya mountains with the Little Khingan and the chains of Manchuria; (c) Sikhota-Alin; (d) Saghalien and Japan.

The Aldan Mountains. This range reaches a height of about 1,200 meters. In the east it descends sheer to the sea of Okhotsk; its western slope gives rise to the river Aldan, which, as we have seen above, flows through an extension of the Cambrian platform of the Lena. Its direction is north-east, parallel to the coast; yet in the south, north of the mouth of the Uda, it makes a bend from the north-east to the east-north-east, and in places becomes due east and west. This bend accords with Meglitzki's statement that the western border marks the east side of the upper course of the Maia, and there passes to the west of Nelkan and further on runs between the Great and Little Aim. Still further to the south-west, according to the same observer, on the watershed, a patch of Angara beds rests on granite at lake Tok; it is possible that this locality also belongs to the Aldan mountains¹.

In the southern half of the Aldan mountains the older observations have been superseded by the works of Bogdanowitsch, from which we obtain the following abstract²:—

The bend, in the south, is very distinct. On the lower Uda, between

¹ N. G. Meglitzki, Description of the expedition of Yakutsk in 1851, edited according to the manuscripts, diaries, and collections of N. G. Meglitzki by M. P. Melnikow, Gorn. Journ., 1893, III, pp. 324, 326. Ditmar has also crossed the range between Nelkan and Aian, but unfortunately he has published little on the subject; K. v. Ditmar, *Reisen und Aufenthalt in Kamtschatka*; Schrenck und Maximowicz, *Beiträge zur Kenntniss des russischen Reiches*, 1890, 3. Folge, VII, pp. 71–77.

² K. Bogdanowitsch, *Einige Mittheilungen über den Gang der Arbeiten der Ochotsk-Kamtschatskischen Berg-Expedition*, *Izviestija des Vereins der Berg-Ingenieure*, St. Petersburg, mitgetheilt von L. A. Jatschewski, Dec. 9, 1896; also *Izviestija Imp. ross. Geogr. Obsch.*, 1897, XXXIII, pp. 43 et seq. (Letter from Aian of 15 Oct., 1896); *Résultats des explorations et des recherches de l'or accomplies par l'expédition Okhotsk-Kamtschatka sur la côte nord-ouest de la mer d'Okhotsk*, published by the Department, of Mines, St. Petersburg, 8vo, 20 pp., map; K. Bogdanowitsch und K. Diener, *Ein Beitrag zur Geologie der West-Küste des Ochotskischen Meeres*, Sitz. k. Akad. Wiss.

the adjacent tributaries of Jana and Tuktan, there is a short independent mountain fragment, the Khrebet Tutkan, which runs to the north-west, and with the Saladjak, a foot-hill of the Aldan range, almost encloses a right angle. Perhaps the Tutkan must be included among the mountains east of the Uda, and the Uda does not reach the Aldan mountains at all.

According to Bogdanowitsch three parallel chains may be distinguished in the region he explored, which extends from the south to the mouth of the Aldama.

The first and most westerly chain, the *Djudgjur*, attains the greatest height and forms the watershed; it consists of porphyry, granite, and gneissose granite. From this chain the porphyry pebbles are derived which Meglitzki and Ditmar mention as occurring on the western border of the mountains, though they repeatedly refer to the contemporaneous occurrence of comparatively recent eruptive rocks, including vesicular lavas. Meglitzki first met with garnets to the west of Nelkan, and at Nelkan itself and in the valley of the Vatam (south of Nelkan) he found glassy volcanic rocks.

The second range, designated by Bogdanowitsch the *Nemerikan mountains*, is formed of granite, syenite, and hornblende gneiss. In the south, on the bend to the west-south-west, it becomes broader; towards the north-east it diminishes in orographic importance, sometimes so far as to lose the appearance of an independent range; but it may be recognized throughout its whole extent by its peculiar stratigraphical series.

The third range, the *Primorskii Khrebet*, is extremely rocky and descends to the sea in steep cliffs. It consists of quartzite, slates, and limestones, with bands of diorite and gabbro and some diabase. M. Bogdanowitsch very kindly sent me fragments of a hard sandy limestone from Aian; it contains shells scattered through it in layers; and Diener has recognized these as upper Devonian. I am inclined to think that the quartzite and diorites also belong to the Devonian. Meglitzki's statements lead us to conclude that these 'greywackes' extend along the coast still further to the north-east.

At cape Magdalinda, Meglitzki also observed a patch of horizontal plant-bearing beds. As regards the north of the Aldan mountains my information is limited to the accounts of Erman, but these are still of value, though they date as far back as 1829¹.

Wien, 1900, CIX, pp. 349-369. I owe M. Bogdanowitsch hearty thanks for entrusting me with the fossils collected on these arduous journeys.

¹ A. Erman, *Reise um die Erde durch Nord-Asien und die beiden Oceane in den Jahren 1829-1830*; 8vo, Berlin, 1833-1848, atlas; Abth. II, pp. 206-429, and III, pp. 1-96. As regards the plateaux on the Marekanka mentioned in III as striking across to the east-north-east, and thus corresponding to the direction of the Verkhoiansk mountains, it is uncertain whether they are bedding planes or great dykes; cf. the representation in the atlas.

Erman left the valley of the Aldan at Aldanskaia (somewhat south of lat. 62° N.) and travelled east-south-east to the Okhota. It is not impossible that his route lay partly in the foot-hills of the Verkhoiansk mountains. He had hitherto observed, as far as Aldanskaia, horizontal beds of limestone similar to those of the Lena. But beyond this point the limestone becomes affected by violent disturbances, and the country, hitherto low, rises to between 600 and 700 meters. At first, near Garnastach, only grey limestone was met with, dipping steeply to the south-west. The highest range is formed by the Sem Khrebtii (Seven mountains); they consist of clay slates, also dipping to the south-west. Erman then reached the valley, several miles wide, of the upper *Allachjuna* (546 meters), which descends from the lofty range in the north-east; this forms an important line of demarcation between two petrographical regions, and is compared by this observer to the valley of the Inn, in Tyrol.

To the east of the Allachjuna follow mountains formed of a different clay slate which dips steeply to the west; boulders of granite are also seen, and next come rocky mountains (1,053 meters) of a grey eruptive rock with glassy felspar, believed to be phonolite. Then, just before gaining the watershed, we reach the highest point, the mountain of the *Kapitan* (about 1,200 meters). The ascent leads across steeply inclined flag-stones striking to the north-north-east, and from the summit we find that the broad mountain tract to the south and east assumes the appearance of three parallel chains which run to the north-north-east. The phonolite extends up to this point, and is associated with hard greywacke containing pebbles and with coarse quartz conglomerate; there is a steep dip to the west. Boulders of granite also occur.

The greywacke forms the watershed; it terminates at the broad valley of the Ketanda. East of this valley rises another mountain range with jagged peaks: it consists of porphyry, and extends to the sea. Near Okhotsk granite is exposed along the shore and in a few islets. Granite, a laminated coal-bearing rock, porphyry, and trachyte have been traced east of Okhotsk and into the vicinity of the river Marekanka. The action of the eruptive rocks on the sediments has given rise, according to Erman, to the natural glass known as *Marekanite*.

Greywacke has also been mentioned as occurring on the east slope.

The conception we thus obtain of the Aldan range, more or less hypothetical, it is true, is as follows:—

On the east is a rocky range formed of quartzite, limestone, and diorite which are, in part at least, Devonian; it is broader in the south than in the north: this is the Primorskii Khrebet.

Then comes the Archæan range of the Nemerikan mountains. To the north our knowledge of this range is very incomplete; it is uncertain whether the granites of Okhotsk belong to it or not.

Then a great ridge of porphyry, associated with granite and also perhaps with recent eruptive rocks, runs from south-south-west to north-north-east through the whole Aldan mass. To this belongs the principal chain of Djugdjur. It is distinguished at several places, as well as on the Marekanka, by pitchstone and Marekanite.

To the north-west, beyond the Ketanda, the Devonian probably crops out again and forms the range of the Kapitan; it is accompanied towards the north-west by a grey eruptive rock (phonolite).

The hills to the west of the broad valley of Allachjuna are probably distinct from the Aldan mountains.

No curvature of the range from the north-north-east to north, such as is marked on the maps near Okhotsk, can be inferred from the foregoing facts. The bed of the Arka (left tributary of the Okhota) is still in the porphyry.

Bureya range or Little Khingan. We have already observed that the short range of the Tutkan mountains to the north of the lower part of the Uda follows a north-westerly direction. To the east of this river also, between Tchumakan and the adjacent cape of Djuktchangra, Bogdanowitsch found clay slate, with beds of crystalline limestone which strike south-east (110° to 160°); it looks as if the closely crowded chains coming from the far south-south-west underwent a sudden deflexion to the north-west at the head of Uda bay¹. But only a little further to the east all signs of this disappear. On the *island of great Shantar*, Meglitzki found the strike to be north-north-east (30°), and on the adjacent coast north 75° east². Thus the east border of the Aldan range, following the Devonian zone, appears to end in a longitudinal fault, but the south coast of the sea of Okhotsk is not the result of a transverse fracture; it is a rias coast, the chains seeming to disappear downwards in a gently inclined transverse flexure.

The first chain of importance east of the mouth of the Uda is the *Tyla range*, which forms the promontory of Tylskoi between the rivers Tyla and Torom. Next to it on the east is the lofty *Ala range*, which extends to the river Tugur, and is described by Bogdanowitsch as the continuation of the Little Khingan. It forms to the south the watershed between the Salamja, a large left tributary of the Zeya, the Niman, a left tributary of the Bureya, the Bureya itself in the west, and the Amgun in the east. It is continued beyond the peninsula of Dugandja by the Shantar islands.

In the northern part the chains of this range consist of clay slates, phthanites, and sandstone, which are traversed and altered, according to Bogdanowitsch, by diabase and porphyrite as well as by micropertithic granite and quartz-porphyry. Tuffs also occur. It was in this series of rocks, on the west side of cape Dugandja, that Meglitzki and Bogdanowitsch

¹ Bogdanowitsch and Diener, *Ein Beitrag zur Geologie der Westküste des Ochotskischen Meeres*, Sitz. k. Akad. Wiss. Wien, 1900, CIX, pp. 353.

² Meglitzki, *Gorn. Journ.*, 1893, III, pp. 309, 319 et seq.

found Jurassic fossils, while Middendorff found Trias fossils (*Pseudomonotis ochotica*) on the east side of the same cape¹.

Cape Dugandja belongs to the north-west part of the mountains. Further south, granite, syenite, and extensive exposures of porphyry make their appearance.

The same range was crossed by F. Schmidt further to the south.

F. Schmidt came from the mouth of the Amur, that is to say from the north-east. He ascended the valley of the Amgun, then that of the Nemilem and the Kerbi, and reached the mountains in lat. 52° N.; the crest of the range is not far from its east border; it is about 6,000 feet high, and consists of granite; elsewhere mica-schists and clay slates were seen. Beyond the crest, which we must doubtless regard as the continuation of the principal range of the Ala mountains, lie the highest sources of the Bureya. In its valley, above the confluence of the Niman, and thus about lat. 51° 40' or 51° 30' N., the traveller entered a country of much lower relief, in which Angara beds with *Asplenium Dicksonia* and other plant-remains were encountered, here, strange to say, associated with Ammonites and Belemnites. Down the valley follow coal beds with similar plant-remains and likewise Belemnites. The beds are folded, and the seams of coal are vertical. Now we reach at last the mouth of the Niman. The Angara beds extend along the Bureya; but, a few days' journey further down, the river again crosses a broad parallel range formed at first of red granite, afterwards of limestone with graphite, and finally of porphyry. Lignite-bearing beds rest against the porphyry to the south; then we come to the Amur².

The range of granite, limestone, and porphyry, just mentioned, probably corresponds with the south-west end of the *Turkana Mountains*.

These mountains form a range running parallel with the Little Khingan on the west. For nearly its whole length it runs west of the Bureya; it becomes lower towards the south-south-west and finally disappears; after, as seems probable from the statements of F. Schmidt, it has again been cut through obliquely by the Bureya. It ends in broad ridges which sink beneath the plain, without reaching the Amur. M. Iwanow, who crossed the range

¹ The two capes, Mali and Bolshoi Dugandja, are directed to the north, and their continuation is the island of Feklistov, the most westerly of the Shantar group. On the west side of the peninsula of which they form the termination we see the little river of Byrrandja, and on the east side cape Nikta and the bay of Magma. Meglitzki mentions Jurassic with Belemnites, Pecten, and Pholadomya from the locality of Byrrandja, that is from the west side. Middendorff, who visited the peninsula somewhat later, discovered the Trias with *Pseudomonotis ochotica* at cape Nikta and south of the bay of Magma, that is on the east side. Bogdanowitsch found the fossils identified by Diener as Jurassic in the interval between the mouth of the Byrrandja and cape Dugandja.

² F. Schmidt, *Reisen im Gebiete des Amurstromes*, &c., pp. 144-168.

140 versts to the north of the Amur, came on rocky ridges of muscovite granite with dykes of aplite, sometimes converted by pressure into gneiss, and, towards the Bureya, i. e. more to the east, he observed porphyry ¹.

It will be seen from the preceding account that a Mesozoic transgression coming from the north entered the region between the Turkana range and the Little Khingan, but there is no evidence as yet to show that it extended further to the south.

As regards the continuity of the mountain chains there can be little real doubt, since D. Iwanow, travelling from Khabarovska, i. e. from the south-east, proceeded somewhat further than lat. 50° N., and met everywhere with a constant strike. On the east side, the range (Khrebet Patchan) gives off several parallel couliesses (Sungatchan, Diaki-unokhta, Mandan), which towards the Amur dip in isolated ridges beneath the plain. Belts of Palaeozoic rock traverse the range, and in one of them, exposed in the pass of Kulteka, east of the Khrebet Patchan, D. Iwanow found fossils which are to all appearance Devonian ².

The southern part of the Little Khingan is the best known. It is cut across by two natural transverse sections. The first begins in the valley of the *Great Bira*, which crosses the mountains from east to west in lat. 49° N.; it then proceeds westwards up the tributary Kichtan. Here, close to the west border of the Little Khingan, it is only separated by the pass of Lagar from the upper course of the river Khingan, which follows the western foot of the mountains. The course of this section affords a convenient crossing for the railway. The second section is formed by the *eroded gorge of the Amur*. This is 110 versts long, and, generally speaking, runs to the south-south-east, so that at its western end, near Pachkova, the section lies very near the trans-Siberian railway line, while its south-east end, near Ekaterino-Nikolsk, lies more than a degree of latitude distant from it.

The gorge of the Amur, known also as the *ravine of Kamnifyn*, confines the great river, over some of its reaches, within a breadth of one verst; it has been described by Schmidt, Anosow, and other observers. Batzewitsch, by comparing this section with that of the railway line on the Great Bira, has proved that the regular strike of the several zones is to the north-north-east ³.

We may remark first, that above the ravine, the western foot of the Little Khingan, from the lower Bureya to the river Khingan, is marked by

¹ M. Iwanow, Djel. Dor., 1898, VIII, p. 72.

² D. B. Iwanow, Geological observations in the region of the Amur, the basins of the Tunguska, Unma Kur, and Great Bira, Djel. Dor., 1897, IV, pp. 45-58, and 1898, VIII, pp. 21-50, maps. According to Lutugin the fossils are *Productella sp.* and *Spirifer medialis*; op. cit., VIII, p. 29.

³ L. Batzewitsch, The Little Khingan beyond the Amur, and its eastern spurs, Djel. Dor., 1898, VIII, pp. 1-19; also preliminary report, op. cit., 1897, IV, pp. 8-11.

a long zone of basaltic mountains. These basalts and the zone of porphyry which lies next to them have led M. Iwanow to conjecture that they represent the margin of a sunken area¹.

The zone of porphyry, which is perhaps the same as that which has already been mentioned as occurring much further to the north, between the Little Khingan and the Turkana mountains, forms the whole west side of the Little Khingan. On the line of the railway it reaches the pass of Lagar; in the cañon it covers the whole stretch from Pashkova to Radde, a distance of 36 versts, and is then continued into Manchuria. Where the porphyry occurs the bed of the Amur is very narrow and rocky.

The porphyry is followed by a series of folds which strike to north-north-east, and exhibit granite, gneiss, and mica-schists; these extend as far as the end of the gorge. Mica-schist, micaceous gneiss, and biotite-bearing sandstone occur above Sujusnia in a steep undercut cliff; in the west limb of a syncline formed by this sandstone there is an important bed of graphite. A few versts further down we meet with white crystalline limestone containing scales of graphite. It dips at first to the north, then forms an anticline and dips to the south-east, and then once more to the north. Finally beds of bright-coloured quartzite crop out with a very steep dip and extend to the eastern border of the range. Somewhat north-east of Ekaterino-Nikolsk a zone of basalt also makes its appearance at the eastern foot of the chain.

With the exception of the basalt these zones exposed in the river channel reappear on the line of the railway, where it follows the river Bira; the eastern border of the folded ranges, however, is covered unconformably by horizontal beds of the Angara series in precisely that locality where the railway line issues from it. The Angara beds are overlain near Krasnji-Jár by a horizontal sheet of red porphyry. Another long parallel band of Archaean rocks makes its appearance in the Schuki mountains; and these also are bordered on the east by the Angara series. Finally we reach the margin of the eastern plain.

We have now traced from the Shantar islands to the ravine of the Amur, i.e. *over more than nine degrees of latitude*, one of those long fascicles of folds which are characteristic of this part of Eurasia. I must leave others to decide which name—the Bureya mountains of Middendorff or the Little Khingan—has the greater right to this group of folds².

¹ M. Iwanow, Djel. Dor., 1898, VIII, p. 73.

² The Chinese maps give the name 'Little Khingan' to another range which lies south of the Amur and comprises the eastern tributaries of the Nonni as far as Mergen. The Russian 40-verst map also places the Malya Khingan south of the Amur, following approximately the statements of the Chinese. The southern border of the erosion valley of the Amur would thus still fall within the Little Khingan. When the Russians, following the Amur, reached this place they learnt that the heights south of the ravine of Kaminfyn were called by the Chinese the Little Khingan, and they naturally extended

The folded ranges which run parallel with it along the Okhotsk coast down to the Amur present, so far as they are known, a similar structure, but they are much shorter. The micropertthitic granite of cape Dugandja has been traced by Bogdanowitsch as far east as the lakes west of Nikolaievsk.

As the ranges of this chain disappear towards the south, they give place to the vast depression, interrupted only by isolated ridges and great lakes, which extends onwards between the east slope of the Little Khingan and the valley of the Amur nearly to Khabarovska. Among the foot-hills which lie nearest the river, the isolated basaltic hill of *Alé*, to the west-north-west of Khabarovska and on the lower course of the Tunguska, is regarded by Batzewitsch as an extinct volcano.

Manchuria. The structure of northern and central Manchuria has been made known in detail by the very instructive works of Anert¹.

We may first point out that Manchuria consists of two sharply defined regions: to the north-west, the plain on which the western bend of the Sungari deeply encroaches; and to the east and south-east, the mountainous country which sends its waters to the Sungari and to the Mudan-dsjan,—an important tributary of the Sungari, opening into it at San-sing.

The mean height of the plain amounts to 162 meters, and the river beds are excavated in it to a depth of 30 meters. On the border of the plain these channels reveal two groups of deposits, namely an upper horizontal group consisting of sandstone and laminated shales in which fish-remains are occasionally found, and a lower folded group formed of red and yellow clay with nests of argillaceous sandstone. The inclination of the beds in

the designation to the whole range which confines the Amur. Meanwhile Middendorff, coming from the north, gave the long range between the Bureya and Amgun the name of *Bureya range*, and Semenow has proposed the name of *Dausse Alin*, which is in use for a part of the range in the north. The name Little Khingan, however, had meanwhile become so established among the Russian settlers, that in making surveys for the railway this name was again adopted, and during the recent political disturbances the range has been termed simply 'the Khingan.' In support of this choice it may be mentioned that the little river Khingan flows at the entrance to the ravine on the north side of the Amur. The following facts must be borne in mind: the range is certainly continued to the south-south-west across the Amur, and thus actually comprises the extreme eastern part of the range lying south of the Amur, and termed by the Chinese and by the 40-verst map, the Little Khingan. This end of the range is, however, different from the mountains of Mergen and the chief region of the Chinese Little Khingan, and the whole range is completely different from the very remote Great Khingan; cf. Batzewitsch, *Djel. Dor.*, 1898, VIII, p. 11. On the diversity of application of the term Khingan among the Chinese see also Middendorff, *Reise in den äussersten Norden und Osten Sibiriens*, IV, 1, p. 214 note.

¹ E. E. Anert, Preliminary Report of the Manchurian Expedition of the Royal Russian Geographical Society, Geological part, *Izviestija Imp. ross. Geogr. Obsch.*, 1897, XXXIII, pp. 164–192. The older bibliography of this region will be found in Richt-hofen, *China*, II, pp. 65–68.

this folded group may amount to 45° and even exceed 60° . The strike of the folds is north-east to north-north-east.

At about 50 versts above Bodune on the Sungari (lat. $45^{\circ} 10' N.$) sand begins to cover these deposits of the plain, and from here a sandy desert stretches away towards the south in the direction of Mukden, towards the west to the foot-hills of the Great Khingan, and towards the north-west in the direction of Zizikar. In the west and north-west this desert is bounded by the volcanic rocks of the Great Khingan and of Mergen.

Of the northern border of the desert little is known except that north of the Sungari, between this river and the ridge of Tun-ni-vodzsi, another range of hills is interposed, called the Khei-shan or the Black mountains, and that one of the left tributaries of the Sungari brings down andesitic pebbles from these regions, thus confirming the conjecture that here too volcanic rocks form an important part of the border of the plain ¹.

South of the Khei-shan, on the Sungari, the folds forming the basement of the plain maintain their general direction to the north-east and north-north-east.

The mountains of eastern and south-eastern Manchuria have a mean height of somewhat more than 900 meters, and consist of a series of long parallel folded chains. Three of these assume particular importance, namely:—

1. The long range which under various names, such as *Kentei-Alin*, *Tshan-lin-dosa*, *Loë-lin*, and others, begins in lat. $47^{\circ} N.$ and terminates in the region south-east of Ninguta. It follows the general trend of the valley of the Suri and encroaches on the basin of lake Khanka. We may assume that the folds of the western Sikhota-Alin are continued in this range of hills, which, as we shall see directly, are cut through obliquely by the Usuri.

2. West and south of the preceding, the mountain range of *Dsjan-huan-dsailan*, which arises between the valleys of the Mudan-dsjan and the Sungari, and terminates west of Omosso or even further south.

3. Still further to the south and west, the *Lo-ja-lin*, to the north-east of Kirin.

In addition to these principal chains, however, there are many secondary ridges. They all consist of ancient rocks, such as gneiss, mica-schist, and clay slate, as well as black quartzite, granite, porphyry, and diorite. Fossiliferous beds have so far not been found. Coal-bearing beds rest unconformably against these rocks, particularly between the Lo-ja-lin and the Dsjan-huan-dsailan, north-east of Kirin, as well as in many other places, and coal is mined at one locality 150 versts to the south of Kirin.

The mountains of Manchuria form a natural group of parallel mountain ridges, but, as Anert has pointed out, they do not include any central chain

¹ This is also suggested by Anert.

running through the whole length of the country. Their relations with the southern end of the Little Khingan are very clear. D. W. Iwanow has given a diagrammatic sketch on which he marks a gentle bend of the trend line, within the Little Khingan, passing from north-north-east to north-east and returning to north-north-east near the headwaters of the great Bira; the range has the latter direction where it crosses the Amur¹. In Manchuria a similar deflexion of the strike takes place to the north towards San-sin: the result is that the Sungari, near this town, flows in a longitudinal valley, while the Mudan-dsjan intersects the folds obliquely.

The mountains of Manchuria do not come into direct contact with the Little Khingan, which terminates not very far south of the Amur, but they form coulisses all running in the same direction.

Their relations with the Sikhota-Alin are still closer.

Anert observes that the coal-bearing beds, just as in the case of those on the border of the desert, present folds striking in a north-east to north-north-east direction. While, however, these younger sediments show everywhere a tendency to be folded along lines parallel with the direction of the high ranges, we see that the strike of the ancient rocks forming the cores of these ranges deviates more or less from this general direction.

'As a rule, the strike of the mica-schists, quartzite schists, clay slates, and sandstones,' says Anert, 'is very nearly identical with that of the ridges, but in addition there are frequent cases where the strike of the rocks is almost at right angles to that of the ridges, showing that complicated relations exist here. It is probable that before the formation of the folds, the denudation of which produced the existing ridges, these ancient rocks of the core possessed a strike which was quite different from that of the folds'².

This fact, in addition to the east-and-west direction of the folds of the Archaean rocks east of lake Khanka, which we shall discuss directly, is the more significant, since another observer, E. von Chohnoky, mentions the east-and-west strike as occurring again further to the south.

It is true that Anert, on his journey eastwards to Ninguta, encountered four parallel crests with a north-north-east strike, and the same direction, sometimes becoming north-east, also prevails between Omosso and Kirin; in like manner, Chohnoky observed a north-east strike in the neighbourhood of Chun-tshun; but west of this place he observed the east-and-west direction in the mountain chain of Thushan, as well as further to the south-west in a chain which is connected with the Tshang-pai-shan. Besides these observations we have the important statement of Richthofen that to the south the fractures and flexures of Peking extend as far as Kai-ping,

¹ D. W. Iwanow, *Djel. Dor.*, 1897, IV, pl. III.

² Anert, Preliminary Report of the Manchurian Expedition, *Izviestija Imp. ross. Geogr. Obsch.*, 1897, XXXIII, p. 190.

and there make a bend convex to the south, while trending to the north-north-east parallel with the I-wü-lü-shan; it is probable that a flexure follows the west border of the valley of Mukden ¹.

It is difficult to form an opinion in this case, not only on account of the incompleteness of the maps and observations, but also owing to the large area covered by comparatively recent lavas, of which the northern outliers have been described by Anert; according to Cholnoky, these occupy the whole upper region of the sources of the Sungari, and only terminate on the road from Kirin to Mukden, where their escarpment has been taken for an independent range striking to the north-east.

Mesas of basalt already make their appearance above the ancient rocks on the road from Vladivostok to Ninguta. They attain a great extension in the valley of the Mudan-dsjan, near Ninguta, where they attracted the attention of Younghusband, and also in the neighbourhood of Omosso ².

A lava-flow with its scoriaceous surface still unweathered, and of later formation than the valley or the adjacent basaltic mesas, descends, according to Anert, from the western mountains south of Ninguta. It has filled the valley of a tributary, the Shitu-dsjan, and extends across the principal valley, that of the Mudan-dsjan, so as to form an important lake, the *Bel-ten* (Bir-ten). The Mudan-dsjan on leaving this lake plunges over a waterfall into a gorge 32 meters deep, excavated in black lava ³.

In the uppermost region of the sources of the Sungari, in the bordering range of Korea, rises the volcanic mountain of *Peik-tu-shan* or *Lao-pai-shan*, the 'old white mountain' (lat. 42° N., long. 127° 40' E.). It has been described by Campbell. For nine months of the year it is covered with snow, and remains white for the rest of the year owing to its covering of pumice. In the crater lies a lake at an altitude of 7,500 feet; its

¹ E. von Cholnoky, Kurze Zusammenfassung der wissenschaftlichen Ergebnisse meiner Reise in China und in der Mandschurei in den Jahren 1896-1898, Verh. Ges. f. Erdk. Berlin, 1899, pp. 251-261; and Vorläufiger Bericht über meine Forschungsreise in China, Peterm. Mitth., 1899. Owing to the incomplete condition of the existing maps, it is difficult to compare these statements, but as Cholnoky also asserts that the latter range is connected with the rocks striking east and west which reach the straits between Kirin and Mukden at Tje-lien-shan, this hypothetical range running east and west should lie in about lat. 42° 30' N. For Kin-tshou-fu and Mukden, cf. F. von Richthofen, Gestalt und Gliederung einer Grundlinie, &c., p. 904.

² Younghusband, Proc. R. Geogr. Soc., 1892, XIV, p. 158.

³ Anert states that four streams of lava may be seen on the walls one above the other. The damming thus appears to have taken place in repeated stages; Preliminary Report of the Expedition to Manchuria, &c., Izviestija Imp. ross. Geogr. Obsch., 1897, XXXIII, p. 171. The botanist Komarow, who travelled through the country with Anert, describes the contrast in colour between the white foam and the black rocks; he mentions a crater in the west, and thinks it possible that the eruption may have taken place in late historic times; he points out that the Manchurian chronicles mention an event of this kind which is said to have occurred somewhere in the neighbourhood of Ninguta, Izviestija Imp. ross. Geogr. Obsch., 1898, XXXIV, pp. 139-143 and p. 181.

circumference, according to James, amounts to 18 kilometers. Volcanic formations extend from this point not only towards the north but also to the south, reaching far into the valley of the upper Yalu¹.

The Peik-tu-shan is included by Campbell in the range of Tshang-pai-shan: it is not certain whether this range is the same as that mentioned by Cholnoky under the same name.

Sikhota-Alin. A broad plain of recent alluvium borders the lower Amur; sedimentary beds crop out from it, which are apparently of later date than the mountain chains, and at the confluence of the Gorin with the Amur (lat. 50° 45' N.) they have afforded fossils of the genus *Aucella*². The isolated heights which occur within the vast depression between the Little Khingan and the Sikhota-Alin trend towards the south-south-west. The most important group, that of *Chechzir*, rising like an island from the lower country, attains a height of 1,066 meters. It runs along the right side of the Usuri to its confluence with the Amur; at its foot, at the very entrance to Manchuria, lies the town of Khabarovska. The Chechzir consists of granite, ancient schists, quartzite, and crystalline limestone, overlain by younger beds, which extend to a great height, and belong probably to the Angara series. Towards the Usuri the Chechzir terminates in a fault, along which the whole series of strata stands vertical. D. Iwanow regards the Chechzir as a part of the Sikhota-Alin³.

Let us turn our attention to this chain.

Its northern extremity at once affords unexpected information. The Amur as it approaches the sea is compelled to make so sharp a bend that near Nikolaievsk its course is directed to the south-east. Its northern bank is rocky. The promontory which narrows the gulf of Tartary, north of the mouth of the Amur, forms on the south, cape Tabach, at the very mouth of the Amur itself, and towards the north, cape Puir. On the north bank of the Amur, as far down as cape Tabach, Batzewitsch observed high cliffs of a porphyritic rock with plagioclase and hornblende in a reddish matrix, and then going to the north towards cape Puir, that is on the west coast of the gulf of Tartary, he found thin flaggy beds of greenish sandstone standing on end. Still nearer cape Puir rises the *Gora Polosata*, or 'striped mountain,' visible from afar; even from Saghalien in clear weather, owing to its remarkable colouring. It is not an independent mass, but the last fragment of a long crest, and consists of vertical beds, warm brown, red, yellow, and white in colour, with thin layers of white and rose-red quartzite. The strike is due east and west⁴.

¹ C. W. Campbell, A journey through north Korea to the Ch'ang-pai-shan, Proc. R. Geogr. Soc., 1892, pp. 153 et seq.

² D. W. Iwanow, Djel. Dor., 1898, XVI, p. 90.

³ Batzewitsch, Djel. Dor., 1897, IV, p. 7; D. W. Iwanow, op. cit., 1898, XVI, pp. 44, 45, 93.

⁴ Batzewitsch, Gorn. Journ., 1890, III, pp. 134-143.

More to the south, at Mariinsk, a broad isolated ridge of trachyte dominates the surrounding country far and wide, and forms the northern boundary of lake Kisi; out of the waters of this rises a little island also formed of trachyte. It is not till we go south of this place (about lat. $51^{\circ} 35' N.$) that we meet with the regular folded ranges of Sikhota-Alin, which extend in a south-west direction through more than nine degrees of latitude.

Our knowledge of this chain has been very considerably increased by the works of D. Iwanow. He has crossed its north part several times, explored the greater part of the east coast, and endeavoured to give a connected account of its most striking tectonic features ¹.

All the ranges so far known consist of Archaean rocks; but there are belts of rock which are possibly of Palaeozoic age, and sheets of sandstone and conglomerate which are still more recent, and probably belong to the Angara stage; fossils have not been found except in the extreme south. Eruptive rocks of very various ages also make their appearance.

According to the observations of D. Iwanow the direction of the folds does not correspond exactly to that of the coast. From the north down to the bay of Saint Vladimir (lat. $44^{\circ} N.$ about) the two directions certainly coincide, and the coast is everywhere bordered by very long ridges. But beyond the bay this is no longer the case; the folded ranges strike out to sea, and may even be continued in the islands, since the bays become deeper off Vladivostok and a rias coast makes its appearance.

It has long been ascertained that some of the bays of the east side, such as de Castries, are surrounded by basalt, but it now appears that a belt of recent eruptive rocks, continuous, as far as is known, from the mountain of Dieliesniak (lat. $45^{\circ} 25' N.$) to de Castries (lat. $51^{\circ} 30' N.$) i.e. for more than six degrees of latitude, forms the border of the coast, so that there appear to be but few localities at which the Archaean inliers reach the sea ².

Long erosion valleys traverse the mountains; the ridges frequently break up into 'goltzi,' the loftiest of which do not exceed 5,000 feet (1,500 meters). In the interior recent eruptive rocks are not absent, but they are never more than sporadic.

The west slope of Sikhota-Alin, as it sinks gradually to the Usuri, is often

¹ D. W. Iwanow, The range of Sikhota-Alin, *Djel. Dor.*, 1898, XVI, pp. 1-118, map.

² Thus Iwanow's map marks recent volcanic rocks from this most southerly point for 130 versts towards the north, and for an almost equally long distance north of cape Stalistnaia. The south and north parts of the region between Emperor bay (*Imperator-skaia Gaban*) and de Castries, embracing more than two degrees of latitude, are of recent volcanic origin; the central part is unknown; basalts and melaphyres are the most important rocks; it appears, however, that certain porphyries and even diabases surrounded by zones of contact must be regarded as an older phase of this great line; cf. D. W. Iwanow, Beds of magnetic iron in the region of the bays of St. Olga and St. Vladimir. Limestone is described here, converted into white marble by porphyrite; *Gorn. Journ.*, 1898, no. 1, pp. 44-58, map.

broken up into comparatively low foot-hills and interrupted in some of the river valleys by wide plains. Our knowledge of this side of the mountains rests on the observations of M. Iwanow ¹.

The rocks are the same as those on the east side; basalt-flows also emerge from some of the valleys. *The valley of the Usuri, however, is not a longitudinal valley.* This appears very clearly between lat. 47° and 46° N., where its direction is almost that of the meridian. Travelling towards the south, and soon after passing mount Samur, composed of eruptive rocks, we reach the quartzite belts of the ridge of Zifaku, which strike to the north-east, and maintaining this direction form the Tiger mountains; in thus passing from the valley of the Usuri into that of the lower Bikin they intersect obliquely the course of the Usuri, where they reveal the true strike, which is north-east or north-north-east. Even far up in the valley of the Bikin, as well as in that of the Iman, the north-east to north-north-east strike prevails.

Somewhat further south, near the railway station of Usuri ², where an anticline of dark grey mica-schist is exposed, the north-east strike is found to have become almost due east and west, so that the Usuri here flows **across** the folds of the ancient rocks. This almost due east-and-west strike prevails in all those foot-hills on the east side of lake Khanka which consist of gneiss, gneissose granite, and mica-schist. From M. Iwanow's observations, however, it would appear that there must be two sets of folds which cross each other. On the east side of lake Khanka and extending far away to the north-north-east in the valley of the Usuri, a long series of isolated limestone mountains is to be seen, which belong probably to the Carboniferous; they rest directly on granite and gneiss, and show signs of having been originally continuous; but besides this we find more to the south a somewhat younger series thrown into folds which, in contrast to the nearly east-and-west strike of the oldest rocks, run almost due north and south. This is the case at the Rock of Lindonau, where at the foot of the great mountain of Bielzova the rivers Daubiché and Ullaché unite to form the Usuri. This less ancient series consists of quartzite and clay slates, and is invaded by dykes of quartz-porphyry; the Trias appears to form part of it.

In the most southerly part of the region, in the neighbourhood of Vladivostok, and especially on the west shore of the bay of the Usuri, upper Carboniferous strata characterized by *Spirifer fascifer* and, on another horizon, by *Productus cora*, crop out. Tschernyschew correlates these deposits with the upper Carboniferous of the Urals and the lower *Productus* limestone of the Salt range. The Trias also is represented by marine beds

¹ M. Iwanow, Report on Geological Observations in the region of the Usuri, Djel. Dor., 1897, IV, pp. 15-44, maps; Batzewitsch, op. cit., pp. 2-8.

² More exactly at the mouth of the Kuburche, somewhat south of the station of Usuri, south of the mouth of the Sungari, which flows out of lake Chanka.

which consist for the most part of shales and sandstone; these, according to M. Iwanow, rest unconformably on older rocks. It is true that they have been subject to subsequent disturbances and dip sometimes to the south, sometimes to the south-east or north-west, in accordance, as it would seem, with the curvature of the ancient formations. It is these Trias deposits which extend into the valley of the Daubiché and appear to reach mount Bielzova ¹.

Hokkaido and Saghalien. In our wanderings towards the east we have reached the sea, both in the region of Okhotsk and the Sikhota-Alin. Extended before us lie the island arcs, teaching us that the fundamental features in the structure of Inner Asia characterize likewise the adjacent parts of the Pacific Ocean.

On an earlier page (II, pp. 175–185) we distinguished the following arcs: (a) *Liu-kiu*, penetrating into the southern part of Kiu-shiu (b) *South Japan*, on the south continued perhaps towards China by the Tshusan islands; on the north, bent back in the Akaishi sphenoid towards the syntaxis in the great fault region; (c) *North Japan*, proceeding from the syntaxis with a deflected trend in the mountains of Quanto, continued towards the north in the southern part of Yezo (Hokkaido); (d) *Central Yezo and Saghalien*, distinguished by the development of the Cretaceous formation; (e) *Kuriles*, continued into east Kamtchatka; (f) a fragment in central and western Kamtchatka.

This conception of the leading tectonic features has been confirmed by a number of subsequent investigations; at the same time, there are many points on which, thanks to recent discoveries, we can now speak with greater precision. This is particularly true in the case of Japan.

The trend-lines which E. Naumann traced out long ago (II, p. 177) have been shown by the work of Harada and many other distinguished Japanese geologists to be correct in all essential points ². But we see now more

¹ Karpinski, *Geologische Untersuchungen des Herrn Margaritow an den Ufern des Golfes von Ussuri, nahe bei Wladiwostok, und T. Tschernyshev, Ueber eine Sammlung aus dem Carbon der Umgegend von Wladiwostok*, Bull. Com. géol. Saint-Pétersb., 1889, VII, pp. 349, 353 et seq.; D. L. Iwanow, *Gorn. Journ.*, 1891, no. 8, p. 251; E. von Mojsisovics, *Sitzb. k. Akad. Wiss. Wien*, 1892, CI, p. 376; K. Diener, *op. cit.*, 1895, CIV, pp. 268–274, and *Triadische Cephalodenfauna der ostsibirischen Küstenprovinz*, Mém. Com. géol. Saint-Pétersb., 1895, XIV, no. 3; and D. L. Iwanow, *Die Triasablagerungen im süd-ussurischen Gebiete*, tom. cit., pp. 3–8, map; A. Bittner, *Versteinerungen aus den Trias-Ablagerungen des Süd-Ussuri-Gebietes*, Mém. Com. géol. Russie, 1899, VII, no. 4. Mojsisovics distinguished two Cephalopod faunas, the more recent of which he correlated with the Muschelkalk; the older and richer fauna (*Proptychites*-sandstone) is correlated by Diener with the *Otoceras* beds of India; this accords with the results obtained by Bittner, who shows that almost all the bivalves correspond with those of the Werfen shales. Entirely different is the locality of *Rasdolnaja*, a little north of Vladivostok, which belongs to the beds with *Pseudomonotis ochotica*.

² In particular Toyokitsi Harada, *Die japanischen Inseln, eine topographische geologische Uebersicht*, I, Berlin, 1890, 8°, 126 and maps; E. Naumann, *Neue Beiträge zur*

clearly than was possible before how the volcanic chain of the Shichito islands enters the *fossa magna*—the line or fissure of the syntaxis. The classification of the fossiliferous beds has likewise made great progress. In the islands of Japan we are now acquainted with marine deposits which, disregarding an ancient group containing Radiolaria, represent the upper Carboniferous and very various epochs of the Mesozoic aera; at the same time we have learnt, though so far only from a study of the floras, to distinguish several horizons in the coal-bearing sediments of the Angara series. The coal of Nagato, east of Shimonoseki, is associated with a Rhaetic flora¹, that of Kaga is assigned to the middle Jurassic², and the plant-bearing beds of the island of Shikoku would seem to belong to the period of the Weald or Neocomian³.

Of particular importance in connexion with the island arcs are the investigations of Jimbo in Hokkaido⁴. Starting from the south-west, that is from Honshiu, we may now recognize as we proceed to the north the following elements in the structure of this great island. *Oshima*, the part lying farthest to the south-west, consists of isolated fragments of ancient masses of schist with occasional intrusions of granite. In the intervals between them rise volcanos; such, for instance, are the islands of Koshima and Oshima towards the south-west, and Esan and Komagatake on the east coast, the latter situated at the entrance of the almost circular bay of Uchiura (Volcano bay), which is itself only another of those caldron-shaped inbreaks, of which Gassan, Chokai, and others afford examples on the north-west coast of Honshiu (Fig. 17, II, p. 177). Thus this part of Hokkaido may be regarded as a continuation of Honshiu.

The mountain group which rises north of the bay of Uchiura and appears on the map to form a second widening out of the island is almost entirely composed of andesitic rocks. Above them rise several volcanos; the loftiest of these, Makkarinupuri (1,963 meters), stands in the centre.

This great volcanic accumulation is called by Jimbo the *mass of Shiribets*. It is possibly continued towards the north as the andesitic mass of Mashike on the west coast, and even still further in this direction, as the island volcano of Rishiri.

Geologie von Japan; Peterm. Mitth., *Ergänzungsheft* No. 108, 1893, and the great special map of Japan published by the Royal Japanese Geological Institute.

¹ Matairo Yokoyama, On some fossil Plants from the Coal-bearing Series of Nagato. *Journ. Coll. Sci. Tokyo*, 1891, IV, pp. 239-247.

² Matairo Yokoyama, Jurassic Plants from Kaga, Hida, and Echezen, *Journ. Coll. Sci. Tokyo*, 1888, III, pp. 1-65.

³ A. G. Nathorst, *Beiträge zur Mesozoischen Flora Japans*, *Denkschr. k. Akad. Wiss. Wien*, 1890, LVII, pp. 43-60, pls.; M. Yokoyama, Mesozoic Plants from Kozuke, Kii, Awa, and Tosa, *Journ. Coll. Sci. Tokyo*, 1894, VII, pp. 201-231.

⁴ K. Jimbo, *General Geological Sketch of Hokkaido*, 8vo, Satporo, 1892, 79 pp., and maps; also *Unsere geologischen Kenntnisse von der Insel Hokkaido in Japan*, *Verh. russ. k. min. Ges. St. Petersburg*, 1894, 2. Ser., XXXI, pp. 305-311.

East of the mass of Shiribets lies a deep subsidence. East of this again a zone of middle Cretaceous strata rises in a number of important outcrops from beneath the covering of Tertiary sediments; it may be traced from Urukava, not far from the southernmost extremity of Hidaka, in a northerly direction through the whole island to cape Zoya, its northernmost point, thus extending through more than three degrees of latitude. The beds are upturned, folded and in some places inverted; their prevalent dip is towards the east. They consist of shales, sandstone, and conglomerate, and, as a rule, just as is the case in Saghalien, cannot be separated from the Tertiary beds which rest upon them. They have been regarded, ever since the first publications of Naumann, as the continuation of the Cretaceous rocks of Saghalien, a view which has now been confirmed by the discovery of *Helcyon giganteus*, a species so characteristic of Saghalien, in the zone of Hokkaido. The investigations of Yokoyama, the comparative studies made by Kossmat, and the presence of *Gaudryceras Sacya* and *Tetragonites Timotheanus*, species so characteristic of the lower Ootatoor group of India, have led to the conclusion that the stratified series extends down to the lower Cenomanian. Michael believes that he has recognized in Saghalien the equivalent of the Emscher marls (lower Senonian)¹. Thus within the island arcs also we discover evidence of the great Cretaceous transgression.

East of the Cretaceous zone of Hokkaido rises a zone of Palaeozoic deposits and ancient schists, which like the Cretaceous may be traced through the whole breadth of the island: like it also striking regularly to the north and reaching the north coast only a little to the east of cape Zoya. In the south a long range of granite emerges from its midst, and trends likewise to the north: Jimbo names this southern part the *Hidaka chain*. It disappears towards the middle of the island beneath the andesites and rhyolites of the mighty volcanic group of *Optateshike*, and north of this it is extensively covered over by lavas or Tertiary sediments.

It is to the Cretaceous and the Hidaka zones that the island of Hokkaido owes its lozenge-shaped form. The first of these zones, as we have seen, forms cape Zoya in the north; the second, cape Erimo in the south. The country east of the Hidaka zone differs in structure. Hitherto the meridional direction has prevailed, but now, as was already recognized by Lyman, the line of the *Kuriles* (in Japanese, Chishima) enters Hokkaido.

Yokoyama has established the remarkable fact that in the extreme east of Hokkaido the Cretaceous formation with *Inoceramus* and other characteristic fossils again makes its appearance; it occurs near the town

¹ M. Yokoyama, *Versteinerungen aus der japanischen Kreide*, *Palaeontographica*, 1890, XXXVI, pp. 159-202; Kossmat, *Jahrb. k. geol. Reichsanst.*, 1894, XLIV, p. 470, and *Untersuchungen über die südindische Kreideform*, *Beitr. Pal. Geol. Oest.-Ung.*, 1895, IX, pp. 119, 133; also R. Michael, *Ueber Kreidefossilien von der Insel Sachalin*: *Jahrb. k. preuss. geol. Landesanst. für 1898*, pp. 153-164.

of Nemuro and even further away, on the island of Shikotan, which lies opposite the southern Kuriles. We should not hesitate to describe these Cretaceous outliers as remnants of the outer zone of the Kuriles, were it not for the remarkable fact that an andesite breccia occurs in them, and that consequently the volcanic activity in the Kuriles must date back to Cretaceous times.

From Kunashiri, the southernmost island of the Kuriles, the volcanos run in a regular crescentic curve and, passing from west-south-west to west, traverse the east of Hokkaido till they reach, first the volcano of Nutapkau-shipe (7,500 feet, 2,285 meters), and finally the above-mentioned group of Optateshike (6,000 feet), which is seated on the granite range. In the valley of the Teshio also, Jimbo mentions contemporaneous andesite breccia as occurring in the principal Cretaceous zone, west of the range of ancient schist.

This arrangement, and especially the position of the Optateshike group, leads to the conclusion that *the volcanic line of the Kuriles actually encroaches on the folded schistose and granitic range of Hidaka, which runs at right angles to it.* This, then, is the nature of the encounter between two important trend-lines, one of which is volcanic.

Tertiary freshwater beds with brown coal, capped by Tertiary marine deposits, mantle around on nearly every side the mountain ranges mentioned above.

We can now enter upon a more precise study of the relations between Hokkaido and *Saghalien*. *Saghalien* likewise consists of ranges of Palaeozoic or even older schistose rock, above which the stratified series begins with the Cenomanian or lower Senonian. The strike is the same. The number of parallel chains is greater. Volcanos are absent.

The maps often mark a promontory in the south of *Saghalien* running off to the south-east and terminating at cape Aniva. This gives an erroneous impression. Glehn and Schebunin have shown that in reality there are three parallel mountain ridges striking from north to south and separated by longitudinal valleys¹. The first of these, lying to the east, terminates in cape Aniva, and on the north is cut off from the next by the bay of Morvin. Glehn calls it *the range of the south-eastern extremity* (VI, Fig. 7). The second meridional chain is named by Glehn the *Soya-Sussnaya range* (V, Fig. 7). Its south foot rises from the east coast of the bay of Aniva; it reaches a height of 760 meters; its length, like that of the first range, is about 80 versts, and it terminates on the east coast. The third range we will term with Poljakow the *great Saghalien range*

¹ P. von Glehn, Reisebericht von der Insel Sachalin, Baer und Helmersen, Beitr. zur Kenntniss des russischen Reiches, 1868, XXV, pp. 191-300; map by Schebunin. A general map, in F. Immanuel, Die Insel Sachalin, Peterm. Mitth., 1894, XL, pp. 49-60, pl. V.

(IV, Fig. 7). Beginning at cape Crillon, it is continued in a meridional direction as far as lat. 51° N.¹

The two short ranges (V and VI), and the southern part of the Saghalien range (IV) consist, according to Glehn and Lopatin, of crystalline schists and marble, and are surrounded in places by white marls with fish-remains, the age of which is unknown, but it is probably Tertiary².

The two short ranges do not extend into Hokkaido, where they would come within the region of the Kuriles. The junction must be sought across the strait of La Pérouse, from Zoya towards cape Crillon. We know that cape Zoya is Cretaceous, and that the ancient mountains of the zone of Hidaka reach the north coast of Hokkaido somewhat further east. Nevertheless this locality is still west of the meridian which passes through cape Erimo in the south.

Either, therefore, the principal chain of Hokkaido has not a strictly meridional course, but is diverted a little towards the north-north-west, or it does not correspond to the great range of Saghalien, but to a fresh coulisse.

The east side of cape Crillon shows white marls; the west side consists of the same crystalline schists as the two eastern ranges. But just beyond the river Oko (lat. $46^{\circ} 40'$ N.) a series of sediments containing brown coal rests against the rocks of the west coast, and follows it far towards the north in isolated patches. Lopatin crossed the island in a south-westerly direction; starting from Nai Budschi on the east coast (lat. $47^{\circ} 25'$ N., close to the northern end of the second, or Soya-Sussnaya, range), he encountered only metamorphic rocks with many quartz veins and little patches of Tertiary. He noticed, however, that the pebbles in the bed of the river afforded granite, porphyry, and diorite.

Once the eastern ranges have disappeared, the great Saghalien range for a great distance forms alone the bulk of the narrow island. After having already reached a height of 3,000 feet it sinks in lat. 48° N. to a height of 700–800 feet, to rise again later. In the west, as in the east, beds of brown coal occur along the coast. In this region the ancient rocks disappear in a manner not yet ascertained, while the mountains apparently preserve the same direction; their place is taken by much more recent rocks. At the Pic de Martinière or Ktöus-pal (lat. $50^{\circ} 15'$ N.), Schmidt found extending up to the summits, which reach a height of 5,000 feet, hard grey semi-crystalline sandstone, of Cretaceous or Tertiary age; this, dipping steeply, everywhere forms the surrounding crests³.

¹ J. S. Poljakow, *Reise nach der Insel Sachalin*, translated from the Russian by A. Arzruni, 8vo, Berlin, 1884.

² Lopatin, Report furnished to the general Government of East Siberia, *Gorn. Journ.*, 1870, no. 10, p. 47 et seq. (for the south, see in particular p. 67).

³ Schmidt in Glehn, *Reisebericht von der Insel Sachalin*, Baer und Helmersen, *Beiträge zur Kenntniss des russischen Reiches*, 1868, XXV, p. 253.

From about lat. 49° N. onwards a second chain, the *Tym mountains*, coming from the east and clearly converging to the north, joins the great Saghalien range (VII, Fig. 7). In the south it bounds Patience bay; on its inland side it is separated from the western mountains by the two longitudinal valleys of the Poronai and the Tym. Its northern end, which forms the 'sugar-loaves,' is situated near lat. 52° N. Poljakow, who travelled from the Alexander valley, near Dui (lat. $50^{\circ} 50'$ N.), across the Saghalien range to the river Tym, and down this river to the northern end of the Tym range, observed no other rocks than quartzite and grey sandy clay; according to this observer, the valley of the Tym is a syncline, and the mountain ranges on the right and left, formed of steeply inclined quartzite and friable sandstone, are anticlines ¹.

According to Lopatin, however, crystalline rocks also are to be seen on the Tym, and these form the east coast along the side of the Tym mountains ².

It would appear that the lower course of the Tym, where it cuts off the Tym mountains, does not correspond to a transverse valley. Poljakow states that the eastern range is pushed aside as it were by the western. In fact both Glehn and Schebunin represent the great Saghalien range as terminating on the west coast near Dui or somewhat north of it, in lat. 51° or $51^{\circ} 30'$ N., and from there onwards the country to the north assumes more and more the form of a broad irregular plateau of which the highest part, Engis pál (2,000 feet), is the corner of a broad ridge, but not a true chain. This uneven plateau first takes the place of the great Saghalien range in the west, and then that of the Tym range in the east, so that at last it alone occupies the whole breadth of the island.

North of cape Khoindcho (lat. $50^{\circ} 50'$ N.), which consists of crystalline rocks and the adjacent cape of Dui, close to the place where the end of the great Saghalien range is supposed to lie, a very varied series of steeply inclined and, according to some statements, even overfolded sediments is exposed on the west coast. These furnish the rich Cretaceous fauna of Saghalien, described by Schmidt, which is so clearly allied to that of Hokkaido and to the Cretaceous fauna of India. The marine series begins with the middle Cretaceous. But Tertiary deposits, both freshwater and marine, are not wanting. Glehn has described the whole series of exposures, which extends up to cape Uandi, a distance of about 70 versts ³. It looks as if this whole zone of more recent sediments were cut off at an acute angle

¹ Poljakow, *Reise nach der Insel Sachalin*, pp. 23, 67.

² Lopatin, Report furnished to the general Government of East Siberia, *Gorn. Journ.*, 1870, no. 10, p. 70.

³ Glehn, *Reisebericht von der Insel Sachalin*, Baer und Halmerssen, 1868, XXV, p. 242 et seq. Marine cretaceous deposits rest on leaf-bearing beds with *Alnus*, *Fagus*, &c. Considering the surprising facts already brought to light by the study of the Cretaceous flora, I hesitate at present to speak definitely of overfolding.

by the coast, and as though they were striking north-north-west, towards the gulf of Tartary.

In the north, at Uandi, the crystalline foundation again crops out (lat. $51^{\circ} 35' N.$), and is followed by steep beds of sandstone; further north, the whole west end of the hilly country, dominated by the Engis pál, is occupied exclusively, so far as we know anything of it beyond the tundra, by sandstone, probably of Tertiary age, which extends to the brackish-water lake of Pronge (lat. $53^{\circ} 45' N.$). Batzewitsch has described the sand and friable sandstone of Pronge. The latter contains carnelian and chalcedony, as is everywhere the case with the Tertiary sandstone of the Amur. The dip indicated by Batzewitsch (*hora* 3 north-east, under 20°) indicates a north-west strike. The sandstone extends across the whole island from the west to the east coast, and contains no organic remains; it is described as Pliocene. East of the watershed an anticline brings up beds of clay which contain petroleum; this issues from them to form a little lake. On the east coast also petroleum is known¹.

Once again a sharply-jagged crest arises. It curves in a peculiar bend to the north-west; extends, 2,000 feet in height, into the western promontory, and terminates in the rocky cliffs of cape Maria (VIII, Fig. 7). A last range, similar to the preceding but not quite so high, follows it on the north and ends in cape Elisabeth, the most northerly point of Saghalien (IX, Fig. 7). The geology of these remarkable promontories is not known; Glehn conjectures that the older plant-bearing beds of Khoindcho crop out at their foot, since coal is said to occur near Pilo, at the south foot of the southern range².

Thus it is not only in Hokkaido and in the Tym mountains, but in several other places also, and especially in north Saghalien, that the true strike appears to diverge from the meridian towards the north-north-west; in the north the great island terminates with the two hook-shaped rocky ranges which break off in the promontories of Maria and Elisabeth. Thus the east-and-west strike of the Tertiary sandstone in the Polosata Gora, north of the mouth of the Amur, acquires particular significance. *It appears as though these outermost parts of the ranges which converge towards the gulf of Okhotsk were about to make a bend to the west.*

The most important alteration which it seems desirable to make in our enumeration of the trend-lines of the island arcs (p. 136) affects the arc *d* (Hokkaido and Saghalien); this should be no longer regarded as an independent element.

Both Naumann and Harada agree that the north part of Honshiu is disposed in successive zones. Harada expresses himself most decidedly on

¹ L. Batzewitsch, Description of the naphtha springs of Sachalin, Gorn. Journ., 1890, III, pp. 129-150, pl. VII.

² Glehn, Reisebericht von der Insel Sachalin, Baer und Helmersen, 1868, XXV, pp. 219, 229, 251.

this point, and following him we recognize (Fig. 7), I, an inner zone of sediments, much broken up and mantled over by eruptive rocks; II, the so-called nuclear zone, consisting of gneiss and crystalline schists; and III, the outer sedimentary zone. Great volcanos appear within the region of the zones I and II; a deep furrow, the so-called 'median line' of Harada, runs in this part of Japan across the zone III.

This furrow reaches cape Shiriasaki at the northern end of Honshiu, and it is generally agreed that the deep depression which separates the eastern part of Hokkaido from the smaller western part of the island may be regarded as the continuation of the 'median line' of Honshiu. The fragments of ancient rocks in Oshima, with the associated volcanos, the volcanic mass of Shiribets, that of Mashike (in so far as it does not belong to the Kuriles), and even the volcano of Rishiri, would thus correspond to zone II, and perhaps, in Oshima, also to zone I. The outer folded zone of North Honshiu (III), which is in part of Mesozoic age and includes Abukuma and Kitakami (Fig. 17, II, p. 221), does not appear in Hokkaido under this form. Since in Honshiu transgressive patches of middle Cretaceous make their appearance along this zone, we might conclude that the Cretaceous zone of Hokkaido should be regarded as the continuation of the eastern border of zone III. We shall see, however, that the relation may possibly be of an altogether different nature, and without, for the moment, expressing any opinion on this point, we will mark the Cretaceous zone of Hokkaido as III a. The chain of Hidaka, which is continued in the great Saghalien range, may be numbered IV. Putting the valleys on one side, and confining our attention to the mountain chains, we may give the number V to the Soya-Sussnaya mountains which run on the east of IV, and VI to the eastern coast-range. Still further east rises the Tym range (VII), and numbers VIII and IX indicate the short bent ranges of the northern extremity of Saghalien.

From this it appears that the ranges nearest the exterior, those numbered VIII and IX, are at the same time the most northerly, and that two features dominate the whole structure—first, a peculiar echelon-like arrangement of the coulisses towards the north, and next, the general convergence towards the sea of Okhotsk.

Owing to the prevalence of an almost meridional trend, the first of these features finds expression in the position of the northern end of the several ranges. The ancient rocks of II (or I) are visible as far as lat. $42^{\circ} 40' N.$, and the accompanying volcanos, as far as Rishiri in lat. $45^{\circ} 8' N.$; III a, the Cretaceous zone of Hokkaido, disappears with cape Zoya in lat. $45^{\circ} 30' N.$, and the ancient rocks of zone IV reach the sea south of Dui in lat. $50^{\circ} 52' N.$ Then follow the short ranges in south Saghalien, V, extending to lat. $47^{\circ} 35' N.$, and VI, to lat. $46^{\circ} 48' N.$; then the Tym mountains, VII, to about lat. $51^{\circ} 45' N.$; and finally VIII and IX, to lat. $54^{\circ} 18'$ and $54^{\circ} 22' N.$

In this account we have disregarded the appearance of ancient rocks at Uandi, north of Dui, and we admit that the Cretaceous rocks between Uandi and Dui do not belong to the same zone as those in Hokkaido.

Whether the isolated occurrences of ancient rocks east of the Hidaka zone in Hokkaido are to be regarded as the southern continuation of the short ranges V and VI cannot be determined from existing observations. But, in any case, it is clear that the line of the Kuriles enters the zones which run from Honshiu to Saghalien.

There are even indications that this encroachment of the Kuriles on Hokkaido takes place to a far greater degree than the observations so far published have led us to suspect. Not only are the Cretaceous rocks of Nemuro, on the south coast of Hokkaido, followed by a basin of brown coal which strikes to the west-south-west, but Mr. Ogawa informs me that the same strike of the Kuriles is encountered in the Palaeozoic belts of the south-west as far as Oshima, indeed even near cape Shiriasaki and in the northernmost parts of Honshiu. At the same time indications of a recurvature to the west-north-west have been observed in the most northerly parts of Kitakami. Thus it would indeed appear as though an intercrossing produced during variable movement, and an ancient syntaxis with the Kuriles actually existed in the extreme north of Honshiu.

Possibly this is also the case further south, in Kiu-siu. I owe to Mr. Ogawa the additional information that Mr. Sugawa has observed indications of the trend-lines of the Liu-kiu islands on the south coast of Kiu-siu, and that they may be recognized in older sediments even as far as the north coast of Kiu-siu.

Further, the sericitic and semi-crystalline schists which form the Hidaka zone where it dips beneath the sea at cape Erimo have been discovered very unexpectedly on some small islands to the east off the outer coast of Kitakami. On the peninsula of Tshori in Quanto, near the north border of the great indentation in Honshiu, Palaeozoic limestone strikes due east straight out to sea. These are the indications, remote from one another, it is true, which show that the zone of Hidaka is continued into the syntaxis of central Japan.

Summary. The region discussed in this chapter extends over 25 degrees of longitude, from the point where the lower Shilka enters the rocks of the great Khingan to the eastern shore of Saghalien, and over 26 to 27 degrees of latitude, from the valley of the Okhota to the great foss of Honshiu near Fusi-yama.

The horsts of the ancient vertex have disappeared one after the other beneath the 'taiga' along the watershed of the Arctic Ocean. In the northern part of the great Khingan and in the Tukuringra a divergent trend makes its appearance, and we might imagine that a new tectonic plan

was about to supervene. This is not the case. Across the fertile plains of the Amur, across the gloomy primaeval forests of the Turkana mountains and the Little Khingan, to the deserts of Saghalien and the great deeps of the sea off the coast of Japan, a common arrangement governs the trend-lines, and this, as the direction turns more and more towards the north, finds its expression in the convergence of all the chains towards the north of the sea of Okhotsk. These chains are the Aldan mountains, the Turkana mountains, the chain of Bureya mountains and the Little Khingan, the chains of Manchuria and the Sikhota-Alin, and finally those of north Honshiu with Hokkaido and Saghalien. At the same time this region belongs to the vertex, since it is arranged on the whole according to a common plan.

The picture we have presented grows even larger in the light of a discovery which has been communicated to me by Mr. Ogawa. Limestone containing Nummulites has been shown to occur in the Peel islands of the *Bonin group*. The Bonin islands form two separate zones which run south and north. The eastern zone, to which the Peel islands belong, is formed of andesitic rocks, probably of considerable age: it disappears towards the north. The western zone is a series of recent volcanic cones, in part still active; these are: St. Augustine, Krusenstern, Sulphur island, St. Alexander, and Rosario. In the neighbourhood of St. Alexander a submarine eruption has been observed. This western zone also disappears towards the north, but it reappears in the line of Ponafidin, Volcano island, Aoga-shima, Hatshija-shima, and other volcanic islands, all of recent origin and for the most part still active; this line enters the great foss of Honshiu near Fusi-yama.

It therefore becomes not improbable that the eastern zone of the Bonin islands represents the remains of a cordillera, and that the group possesses a structure like that of the arc of the Liu-kiu or of the Antilles, and should therefore be regarded as an independent island arc. Since evidence has been given which points to a continuation of the Hidaka zone to south Quanto, and since the Hidaka zone is the chief zone of Saghalien (IV, Fig. 5), we may even suppose that trend-lines so remote from one another as Bonin and Saghalien might meet in central Honshiu.

The bow-like arrangement of the *Marianne* islands, which also run north and south, renders it probable that these islands also represent an independent arc, the cordillera of which is not visible.

If we could remove the sea, then these island arcs, all rising from great abysses, would appear as mighty mountain chains. Arc succeeds arc. *In the direction of the Ocean we know of no limit to the wonderful arc-producing power which emanates from the vertex of Eurasia.*

It certainly looks, however, as if the radii, towards the periphery of the structure, become too long. The arcs then divide by bending back upon

themselves, and syntaxis often takes place between the resulting segments. The south-west end of the Aldan range is recurved; recurvature may also be seen in the north end of Saghalien, as well as in the south part of Sikhota-Alin, where the recurvature of the folds takes place in the neighbourhood of lake Khanka. The indent or syntaxis, which coincides with the *fossa magna* in Honshiu, is probably due to the same cause.

The long strike-fractures of the vertex are not absent in the periphery. One of them forms the rocky east coast of the Aldan mountains; to the south of the sea of Okhotsk, where we might expect a transverse fracture, a rias coast occurs. The second example is furnished by the east border of the Sikhota-Alin, with its long belt of accompanying basalts; here too we find in the south, instead of a transverse fracture, a rias coast. In like manner basalt outflows border the foot of the Little Khingan, both on the east and west, in the neighbourhood of the Amur. These long lines belong to another category than those fractures which manifest themselves in the series of caldron inbreaks on the west coast of Japan, and to explain them we must have recourse to disjunctive processes similar to those which have affected the vertex.

The fractures tend to follow a longitudinal rather than a transverse or any other direction; yet it is to be observed *that the longitudinal fracture of the Sikhota-Alin does not follow the bend of the folds in the southern part of the range.*

This fact must be regarded as important. Disjunctive lines resulting from tension may show a tendency to follow for a long distance a more or less rectilinear or gently curved folded range, but they do not follow a sharp bend. Anert points out that in Manchuria the recent but already denuded folds of the plain strike regularly to the north-north-east, while within the ancient rocks (i. e. within the mountains which, according to their outer form, also run to north-north-east) a divergent strike, running due east and west, occurs. We might suppose that the older bends are cut through by the straighter disjunctive lines, and *that some disjunctive lines may determine locally the trend-lines of the posthumous folding.*

Startling as this conjecture may seem, it must not be forgotten that—in the amphitheatre of Irkutsk for example—the boundary of the Archaean determines the course of the marginal folds.

The case alters as soon as we pass west of the Lido-ho from the folded regions of the coast and of Manchuria into the tableland of north-east China. There not only fractures occur, but also lines resembling flexures; these are unknown in the folded mountains, where, however, it would certainly be difficult to establish their presence. More recent eruptive rocks are absent along the fractures of Shansi. But the fractures of the tableland not only correspond in disposition with trend-lines of the folded country, but also describe (I-wu-lu-shan to Hong-shan, Tai-hang-shan) precisely similar

curves from the south-south-west to the west-south-west or west, *with the same convexity towards the south-east as that described by the folds in the folded country* (north part of the Great Khingan, north Saghalien, south Aldan mountains, lake Khanka); in the latter the movements are perhaps indicated in certain cases by the transition from fracture to rias coast (bay of Saint Vladimir to Vladivostok). That the bent folds may also be cut through by fractures is evident from what has already been said regarding the complicated relations in Manchuria.

As we approach the Pacific Ocean the marine Mesozoic deposits make their appearance. The Trias of Usuri, the beds with *Pseudomonotis ochotica*, the middle Jurassic of the coast of Okhotsk, the Aucella beds, which enter the valley of the Amur, and the traces of the Volga stage, all indicate communication with the north. We next recognize as far away as Saghalien the middle Cretaceous transgression to which, as represented in Europe and in its extension up to the strait of Turgai, we ascribe a southern origin.

At the same time the plant-bearing beds, not only in Siberia but also in the plain of the Amur and of Manchuria, show us that a great continent, frequently covered by vast sheets of fresh water, has existed here for an extremely long period—in certain regions since the Carboniferous, in others at least since the Rhaetic period.

This is the eastern part of Angara-land. It is affected by numerous lines of dislocation with the downthrow to the east. Yet notwithstanding this, the region of dry land has, in the course of ages, step by step extended itself towards the east; had it not done so, the Mesozoic deposits would not be visible. Its growth may be explained partly by subsequent foldings, but chiefly by the fact that elsewhere subsidences on a much grander scale have taken place within the regions occupied by the ocean.

This part of the world affords an exceptional opportunity for determining with some degree of precision the permanence of a continent. In the whole course of the long period represented by the fossiliferous sediments of our planet, the phylogenetic thread of organic life has never been broken, though the process of evolution has to all appearance been neither uniform nor continuous. Changes in the environment must have had a great influence, especially the repeated changes in the extent and boundaries of the ocean. The denizens of the dry land and of fresh water react to these changes in a completely different manner from those of the sea. In the case of the former the uninterrupted continuity of the phylogenetic thread presupposes a long stability of certain places of refuge which for marine forms of life are never wanting. The extreme conclusions deduced from this principle, correct in itself, together with considerations regarding the great depth of the seas, have led to the doctrine of the universal stability of both continents and oceans, a theory which nature does not confirm to

this extent. In Angara-land, however, we see a large area of the earth's surface, which from a very remote period has been apt to serve as a place of refuge for terrestrial and freshwater animals; under favourable circumstances, new colonies may have radiated outwards from it in all directions, as from Linnaeus's island of Paradise.

Angara-land is not the only region of this kind.

CHAPTER V

THE ALTAI AND THE ALTAIDES¹

Tomsk. Kusnetzki-Alatau and Salair. Inner arcs of the Altai. Kirghiz mountains. Thian-shan. Bei-shan. San-sjan-tsy. Lun-shan. West Nan-shan. Syntaxis of Nan-shan and the arc of Yarkend. The Altaides.

THE undulating plain which extends to the east, and still more to the south of the town of Tomsk, is of great importance in the study of the Altai. Although covered for vast distances by continuous marshy forest, and in no way remarkable for its relief, it has become one of the best known parts of Siberia. This is owing to several circumstances, first among which must be counted the valuable local investigations of Professor Saitzew, of Tomsk; and next, the surveys for the Siberian railway, which goes through this region, as well as the special survey which is now being made of the Altai for the crown domains; simultaneous with all these undertakings is the discovery of workable coal, which has given rise to a good deal of prospecting.

From the sum of existing observations we may conclude that *beneath the plain lying east and south of Tomsk are the ends of three mountain ranges which converge till they meet.* The first of these ranges comes from the south-west and occupies the north-west and north of this region; we will term it for the present the *Kolyvan range*. The middle range comes from the south-south-east, and further south bears the name of *Salair*. The third or eastern range, almost parallel to the middle one, is the *Kusnetzki Alatau*. This forms the boundary in the direction of Minuzinsk².

After crossing the steppe of Baraba, and passing Omsk and Kainsk, we reach ancient rocks on the right shore of the Obi above and below Kolyvan. At the confluence of the Inja near the railway these consist of steeply upturned beds of slate and sandstone, striking north-east and pierced by granite veins. The granite also forms an island in the Obi. Derjavin has found similar rocks near Guseletova, above the confluence of the Berda, and Saitzew met with the granite much lower down, near Kruglikov; so that these rocks, all striking north-east to north-north-east, have been traced

¹ Revised by Professor W. W. Watts, Sc.D., F.R.S.

² We may obtain a good general idea of this region by comparing the geological map of the districts between the lower Tom and the Obi drawn up under the direction of A. A. Inostranzew, and affixed to the 'Travaux de la Section géologique du Cabinet de sa Majesté', III, Petersburg, 1898, with the geological map on the same scale by Krasnopolski of parts of the districts of Tomsk and Mariinsk, Djel. Dor., 1898, XIV.

down the Obi for a distance of more than 150 versts. The granite, according to Derjawn, is later than the slates and sandstone, and is surrounded by a zone of contact alteration¹.

The granite disappears; Devonian rocks set in, and proceed, in the direction of the trend of the granite outcrops, beneath the plain to Tomsk and beyond; they are also visible to the east of this town.

Such, then, is the Kolyvan range. Although it hardly ever attains any considerable height, it nevertheless forms part of an important tectonic element. This is shown by its breadth, the constancy and independence of its strike, and the steepness of its folds. Towards the north-north-east, beyond Tomsk, the range, as we have seen, disappears beneath the northern plain; towards the south-south-west it is in part cut obliquely by the Obi, and disappears along this river; further away it disappears in like manner beneath the northern part of the steppe of Barnaul. Derjawn, however, considers that the hills bordering the steppe of Baraba, on the west bank of the Obi, also possess a foundation of ancient rocks; he also regards the strikingly parallel course of all the river-channels on the left of the Obi, below Barnaul, as an indication of the subterranean continuation of this range². As to the true cause of the direction of these superficial river-courses I have no means of judging, but it may be observed that the continuation of the Kolyvan range will possibly be found in the mountains of the Kirghiz steppe, beyond the Irtysh.

To the south, beyond the Inja, there projects from the Kolyvan range a great dome of porphyry, the mountain of Bugashak, and a little further east lies a long and completely crushed basin of Carboniferous limestone and coal-measures, quite close to the boundary of the Salaïr; this is the *coal basin of the Elbash*. It has been described by Inostranzew: its strike is directed to the north-north-east; the coal is anthracitic, and stands almost vertical. The post road from Tomsk to Barnaul runs along the east side of the basin. In the boundary zone between this district and the Salaïr, on the post road south of the river Berd, dynamo-metamorphic rocks make their appearance³.

In regard to the northern end of the *Salaïr* unexpected information has been furnished by the works of Derjawn and Inostranzew. This mighty branch of the Altai, after diminishing in height towards the north, terminates abruptly, south of lat. 55° N., in a long transverse escarpment, about 100 meters high, which bears the name of *Tyrgan*. The range consists for the greater part of beds which are probably lower Devonian; they are

¹ A. Derjawn, Djel. Dor., 1896, I, p. 83 et seq., map; A. Saitzew, op. cit., 1896, V, p. 95 et seq., general map on p. 97; G. G. von Peetz, Travaux de la Section géologique, 1896, I, pp. 97-197; in particular Derjawn, op. cit., 1898, III, pp. 9-29.

² Derjawn, Travaux de la Section géol., 1898, III, p. 22. The fossils found near the town of Tomsk belong to the Devonian.

³ A. A. Inostranzew, Travaux de la Section géol., 1898, II, pp. 1-117; in particular pp. 16 and 18.

accompanied by numerous bands of diabase; on the Tyrgan, granite is exposed¹.

The western group of the Salaïr forms, as we have seen, the coal-basin of the Elbash, which strikes to the north-north-east alongside the Kolyvan. Towards the east and north-east, upper Devonian rests upon the beds of the Salaïr, which are probably lower Devonian; then follows Carboniferous limestone, and finally the lower beds of the great coal-basin of Kusnetsk. This whole series gradually passes from a north-north-west to a north-west and west-north-west direction, and envelopes the north border of the Salaïr. Since Carboniferous beds have also been discovered beneath the plain to the north of the Salaïr, at Nova-Isylinskaia, it is evident that the Salaïr is bounded on the north by an offset of the Kusnetzk basin, which runs towards the north end of the Elbash basin, and that the two basins thus unite north of the Salaïr².

As a further consequence, the Kolyvan range reaches on the north the immediate neighbourhood of the Kusnetzkii Alatau.

It was formerly believed that the great coal-basin of Kusnetzk, which lies between the Salaïr and the Kusnetzkii Alatau, terminated to the north at Balakhonka, on the Tom (lat. 55° 32' N.). But just as it is prolonged towards the north-west at the northern end of the Salaïr, so, as is shown by the excavations made near the headwaters of the Masatovskii Kitat, it is prolonged towards the north by a long narrow band which runs between the Tom and the Inja, and at length crosses the railway line. This narrow syncline, which is bordered on its south-eastern side by Carboniferous limestone, indicates the true boundary beneath the plain between the Kolyvan range and the Kusnetzkii Alatau³.

Only a few signs of the northern extremity of the *Kusnetzkii Alatau* are visible north of the railway. It almost entirely disappears before reaching the line, and what is to be seen is only its western moiety, that is the stratified series which begins with the lower Devonian and dips towards the west or towards the coal-field of Kusnetzk. Thus it happens that the Devonian still visible east of Tomsk belongs almost entirely to the range of Kolyvan.

¹ Derjawn, Geological observations in the district of the Tom, Gorn. Journ., 1893, II, p. 110 et seq.; also Djel. Dor., 1896, I, p. 75 et seq.; Inostranzew, Travaux de la Section géol., 1898, II, in particular p. 5 et seq.; also B. Cotta, Der Altai, sein geologischer Bau und seine Erzlagertstätten, 8vo, 1871, map (refers to north Salaïr); and Nesterowski, Description géologique de la partie nord-est de la chaîne de Salaïr, en Altaï, Ann. Soc. géol. Belg., 1875, II, pp. 12-33, map.

² This bend around the end of the Salaïr and the outcrop of the Carboniferous deposits of Kusnetzk are described in detail by Polenow, Travaux de la Section géol., 1897, II, pp. 98-130.

³ Krasnopolski, Djel. Dor., 1898, IX, pp. 58-73; and Jaworowski, tom. cit., pp. 85-108, map; also Krasnopolski, op. cit., 1898, XIV, pp. 1-96, map.

We have now reached long. 86° E., and beyond lat. $56^{\circ} 30'$ N. Further north, lies nothing so far as we know, but plains, marshes, and primaeval forest. Up to this point, however, the elements we have been able to distinguish are: (1) the Kolyvan range; (2) the coal-basin of Elbash, which must be regarded as a crushed syncline on the east side of the Kolyvan range; (3) the Salaïr, which terminates prematurely, thus enabling the syncline of Elbash to unite around its north end with the element next in order; (4) the coal-basin of Kusnetz; this forms the second syncline; and finally, to the east of this syncline, (5) the Kusnetzkii Alatau.

Kusnetzkii Alatau and Salaïr. The Kusnetzkii Alatau, like the Salaïr, presents in the middle a band of altered rocks, which are regarded as lower Devonian, and on each side of this come zones of upper Devonian and Carboniferous limestone. In several places granite crops out; in the lower Devonian long, broad bands of diabase are to be seen. Tschihatschew rightly regarded this range as the north-eastern boundary of the Altai. On the north its rocks strike to the north-north-west. Near Blago-Nadejini they still strike north-north-west (325° – 330°), but according to the same observer, the trend of the range and the strike of the rocks turn round together, somewhat east of the source of the great Juss (Ussa, right tributary of the Tom), towards the south-south-west, to unite with the mountains of Teletzk¹.

Thus the trend of the Kusnetzkii Alatau is not rectilinear, but the range forms an arc slightly convex towards the east. This explains how it is that Tschihatschew brings into connexion with this range all the south-south-west trending or nearly meridional chains situated between longs. 89° and 90° E., as for example the Abakan mountains and the boundary range which extends beyond lat. 50° N.

In this south-eastern part of the range, another bend in the strike undoubtedly occurs, whilst the form of the mountain ranges is affected by numerous intrusive masses of granite, syenite, and diorite. Malewski's observations, made on his journey along the frontier from the upper Bukhtarma, i. e. from long. 87° E. as far as the latitude of lake Teletzk, show that in this great range, running first apparently to the east and then to the north, the schistose rocks strike mainly to the north-east, paying no regard to the form of the range or the position of the snow-clad goitzi².

¹ P. de Tchihatschew, *Voyage scientifique dans l'Altai oriental et les parties adjacentes de la frontière de Chine*, 4to, Paris, 1845, atlas, pp. 324, 403.

² Malewski, Report on an excursion along the south-east of the Altai mountains in the course of the year 1869; Gorn. Journ., 1870, II, pp. 72–95, geological map. P. 78: above *Ussun Tabata* (upper Bukhtarma), amphibolite schist, strike NE. P. 79: Chinese picket *Tchindagatna* lies on granite; the great goletz adjacent to it is formed of diorite; on the watershed of the Bukhtarma dark schist resembling diorite occurs, as well as mica, and chlorite schists and clay slate, with irregular stratification; dip 77° NNE. (=strike ESE.). P. 83: foot-hills of the ridge of *Kurtchum*; siliceous schists, strike NE. P. 84: schists run to N. and NE.; source of the Oichor, Chinese frontier-stone *Suak Ulan-doba*

In like manner, Adrianow encountered vertical mica-schists with a nearly east-north-east strike (260°) beyond the headwaters of the Tchulyshman, where, on Mongolian territory (lat. $50^{\circ} 18' N.$) the Kyndyk-Pup or Navel mountain rises from the midst of lake Kendykty (8,200 feet) and the Bukom-Bere flows south-east to the Atchik-nor ¹.

The Kusnetzkii Alatau should reach the Gorba range on the east side of lake Teletzk; the Sailyugem and the boundary range mentioned above would thus represent fragments of arcs lying further towards the outside. Nevertheless the fact that all these ranges again make a bend near the headwaters of the Tchulyshman, the Bashka-ussa, and the Tshuya has a significant bearing on the structure of the Altai.

The distance from the most northerly spurs of the Kusnetzkii-Alatau, in the plain south-east of Tomsk, to that point in the great range south-east of lake Teletzk, where the middle Tchulyshman in all probability cuts through the continuation of this range, amounts to five degrees of latitude, and thence to the southern outposts on the frontier is two degrees more.

Let us again turn to the north.

Against the west side of the Kusnetzkii-Alatau rests the coal-basin of Kusnetzk previously mentioned. Thanks to the works of Bogdanowitsch, Derjawn, Werjukow, and others, it is the northern part of this basin which is the best known ². Apart from the narrow spurs in the north and

(2,828 meters, E. of long. $88^{\circ} E.$). P. 85: diorite and dioritic schists, also porphyry; boundary mark, *Zogan-borgasu*, clay slates, limestone, feldspathic rocks; strike of the slates, N.; here the road runs to Kobdo and Uliasutai. P. 85: picket Suok (east of long. $89^{\circ} E.$), diorite and dioritic schists, also clay slates, chiefly vertical, strike NE. P. 87: picket *Kak-nor* (2,520 meters; here the range turns to the north above the steppe of Tchui and is now known as the Sailyugem or western end of the Sayan), schists alternate with dioritic rocks, strike east; on the way to the picket porphyry occurs. The data which follow, on p. 88, appear to refer to more recent Carboniferous deposits of the upper Tchuya, and are therefore omitted. P. 89: picket *Karaguya* (north of lat. $50^{\circ} N.$, west of and above the river Bukom-bere already mentioned), black schists, strike NE. The peaks of the Sailyugem consist of granite and syenite, both flanks of schist. The neighbourhood of lake Djuvan-kul, where the closest contact with Tannu-ola occurs, consists of granite and syenite; the river Tchulyshman flows from this lake. P. 93: as we approach the Tchultcha, black and green clay slates appear with an increasing development, strike NE.; on the watershed of the Karasuluk syenite occurs; towards lake *Kawa-kul* diorite, also on the pass of *Sur-daba*, which forms the watershed of the Abakan. P. 94: the few exposures on the rivers which flow down to the Tchultcha show schists, very steep, folded, strike SE. For an orographical description of the frontier range, cf. E. Schmurlo, The mountain passes of the south Altai, *Izvestija Imp. ross. Geogr. Obsch.*, 1898, XXXIV, pp. 590-601.

¹ A. W. Adrianow, Journey to the Altai and the Sayan in 1881, *Zap. Imp. ross. Geogr. Obsch.*, 1888, XI, p. 222.

² From the abundant literature on this subject I will only mention: D. J. Bogdanow, Geological sketch of the north-west part of the Carboniferous basin of Kusnetzk; *Verh. russ. k. min. Ges.*, 1883, 2nd ser., XVIII, pp. 149-204, maps; P. Wenukow, Geological explorations made in the summer of 1894 in the north part of the Carboniferous basin of

north-west the major axis of the productive region, from Balakhonka to the south end of the basin, measures about 240 versts; the breadth amounts to 80 or 100 versts. All the beds lie conformably. Above the Carboniferous limestone, Derjawn mentions some traces of Culm, and then follow the coal-measures, usually with a very steep dip. According to the later investigations of Zeiller, the coal-measures extend upwards till they reach the chronological horizon of the lower Gondwana¹.

On the west side of the basin overthrusting sets in over an extensive tract from the direction of the Salair, so that the coal-measures dip towards the west, beneath the Carboniferous limestone. Then a larger syncline follows on the east towards the centre of the basin, and after this an anticline still further towards the east, in the direction of the Kusnetzki Alatau. On its extreme eastern border we again see the beds steeply upturned. The term basin is therefore not quite exact. In the middle of the region considerable masses of melaphyre crop out.

The river Tom flows through the whole coal-field, from Kusnetz on wards, but its bed lies nearer the east border. At Kusnetz it receives its important tributary, the Kondom, which comes from the south and south-south-west. On the banks of the Kondom we see how the basin becomes closed on the south. Inostranzew has made important observations on the tributaries of its right bank, the Tylbess and Mundibash. Below Ail, on the Kondom, the Carboniferous limestone crops out from beneath the coal-measures. The succeeding parts of the underlying beds are altered by intrusive masses of porphyry and porphyrite. Rocks rich in epidote, garnet, and magnetite make their appearance, and form a zone running from north-north-east to south-south-west. Laccolites have also been observed².

In following the border region between the Salair and the Kusnetzki Alatau, we have now approached the river Biya, which flows from lake Teletzk. Many years ago Helmersen observed with great acumen that *the mountains which the Biya cuts across between the lake and the bend of the river at Sandipskoje, are the continuation of the Salair*³.

Since Helmersen was aware that an easterly strike prevails further west, he was much surprised to find that it is only the short northern part of the hook formed by lake Teletzk which corresponds to a transverse valley,

Kusnetz; Travaux de la Section géol., 1895, I, pp. 55-87; A. Derjawn, On the coal basin of Kusnetz, Djel. Dor., 1896, I, pp. 96-101, with a map of the outline of the basin.

¹ The entire bibliography of this subject is to be found in B. K. Polenow, New ideas on the age of the coal-basin of Kusnetz, Travaux Soc. Nat. Saint-Petersb., 1896, XXVII, pp. 283-293.

² A. A. Inostranzew, Geological excursions into the district of the Altai in 1894. Travaux de la Section géol., 1895, I, p. 1 et seq.

³ G. von Helmersen, Reise nach dem Altai im Jahre 1834 ausgeführt; Baer und Helmersen, Beitr. zur Kenntniss des russischen Reiches, 1848, XIV, p. 48 and 109.

and that the direction of the larger part, lying in the meridian, differs but slightly from the strike of the beds. In the north part of the lake he observed in the clay slates, first, a strike to the south-west, the beds being upturned and frequently vertical; then along the whole of the east shore, and in particular on the slopes of the mountains of Gorbu, a strike to the south-south-west; on the west shore the direction approaches still more nearly to that of the meridian ¹.

The views of Tschihatschew on the direction of the Kusnetzkii Alatau, and those of Helmersen on the southern continuation of the Salaïr, are in complete accord.

These ranges both strike, in their northern part, to the south-south-east and are separated by the coal-basin; then in about the latitude of Kusnetz, their strike bends gradually to the south-south-west, and with this the coal-basin is tilted up. In the southern frontier range the deflexion to the south-west is complete.

The bend of the Altai. The bend of the Salaïr and the Kusnetzkii-Alatau, as well as the constant direction to the north-east, which was observed in the boundary range, are the beginning of an arc-like curve which dominates the whole orographic centre, and with this the highest parts of the Altai.

We may first observe that in these great mountains, as well as in the whole western part of the Altai to beyond the Irtish, not a single band of gneiss of any importance is known to exist; indeed this rock is seldom met with at all in these mountains, and never except as a strictly local occurrence, a remarkable contrast to what is found in other lofty folded ranges. On the other hand, we meet with schistose rocks in surprising abundance, mica-schist, chlorite schist, and clay slate, the last named with beds of limestone, and towards its summit Devonian or lower Carboniferous fossils, which are found at many localities. These schists, like those in the Salaïr and the Alatau, are pierced by granite, syenite porphyry, and diorite in dykes and bosses. In the contact-zones lie many of the famous ore-bodies of the Altai. The basalts of the ancient vertex have now disappeared. The intrusive masses seem to form many of the *goltzi*; but by no means the whole of them; and the conscientious observer Gebler expressly mentions that no granite is to be found in the moraines of the glacier of the Bielucha, but only chlorite schists ².

¹ G. von Helmersen, *Reise nach dem Altai*, Beitr. zur Kenntniss des russischen Reiches, 1848, XIV, pp. 59, 95 et seq.

² F. Gebler, *Übersicht des Katunischen Gebirges, der höchsten Spitze des russischen Altai*, Mém. Savants étrangers, Acad. Imp. Sci. Saint-Pétersb., 1837, III, pp. 455-560, map; in particular p. 509; for an idea of the landscape formed by the *goltzi* of the lofty Altai, see the description of the botanist W. W. Sapodjnikow, *The Altai*, 8vo, Tomsk, 1897, with maps and photographs; cf. also Branner, *Results of the Branner-Agassiz Expedition to Brazil*, IV, Proc. Washington Acad. Sci., 1900, II, p. 191, pl. X: An exfoliated peak of quartz-monzonite at Sete de Setembro, Rio Mucury.

Gebler's ancient map gives an excellent idea of the arc-like plan of the mountains, and this accords with the strike of the rocks. Coming from the east, that is from the plateau of the Tchuya, the range of Yik-tu is inserted between the Yassater and the Topolevka, its steeply inclined beds striking from east-north-east to west-south-west. Then it is cut through by the Argut, and west of this lies the Bielucha and the vertex of the arc. The peaks of the Yik-tu reach a height of 4,000 to 4,200 meters, according to Sapodjnikow, and those of the Bielucha 4,400 and 4,540 meters¹. In the tract lying between the Argut and the mouths of the Koksus and Katunj, the direction of the range passes first to north-west and then to north-north-west.

Helmersen also lays great emphasis on the arc-like plan. He regards the Bukhtarma as the longitudinal valley of the foremost arc. While Malewski found that the strike was still north-east on the uppermost reaches of the Bukhtarma, near Ulan-Dabassu, Helmersen found that it had already become north-west in the middle course of the river. North of the Bukhtarma the mountains of Kholsun rise as the western fragment of a first arc. Then follows a great arc-like furrow, partly represented by the valleys of the upper Katunj, the Koksus, and Yassater, and north of this lies the highest arc of the Katun mountains mentioned above, with the Bielucha².

It would appear that the middle Katunj, from Ujmon to its union with the Argut, must also be regarded as the longitudinal valley of an arc, and that the Terehtaishii mountains may represent a fragment of a third arc. But, according to M. Klemenetz, in the greater part of the valley of the Tchuya a north-north-west to north-north-east strike prevails, and so far the mountains of lake Teletsk, which are the continuation of the Salair and the Alatau, maintain their direction.

Tschihatschew terms the Yik-tu the 'Chaîne des Monts Arhhyte'. He justly compares the long branches of the Altai with the Sierra Nevada of Spain, characterized by its broad monotonous ridge wholly composed of schists³.

¹ W. W. Sapodjnikow, *Izvest. Imp. ross. Geogr. Obsch.*, 1899, XXXV, p. 508.

² G. von Helmersen, *Reise nach dem Altai*, p. 179 et seq.

³ The differences in the nomenclature of the ranges are particularly great in the older works. The Russian ordnance map designates as Khrebet Saljugem, further north as Suilegem, the whole frontier range, from long. 88° E., round about the sources of the Tchuya and northwards as far as lat. 52° N. This view I have adopted. Gebler and Bunge confine this name to a narrower and probably to some extent different region; they confer the Mongolian name 'Sailughem' on a moderately high range striking from south-west to north-east, which embraces both the sources of the Tchuya and those of the Bashka-ussa. The more northerly range with the sources of the Tchulyshman is here called 'Altüm-tu.' Tschihatschew terms the bend of the range, which surrounds the sources of the Tchuya, 'Chaîne d'Irène Karagai,' and the continuation to the north-north-east, 'Chaîne de Moun-goun-taïga'; on the other hand, the name 'monts de Sailougème' is given to a short range north of the upper Tchuya.

Helmersen ascended the Katun range from Ujmon, near the union of the Koksus and the upper Katun; upon its western and south-western slope he travelled at a considerable height nearly as far as the sources of the Katun, and of the glacier of the Bielucha. On the ascent he met with chlorite schists and some serpentine, and then, at several localities, with granite, syenite, and gabbro; but the prevailing rocks on the whole were found to be schists, and the descent to the feeders of the Katun, as well as the crossing of the southern part of the Kholun range to the upper Bukhtarma, was made entirely in clay slates ¹.

Schtschurowski, accompanied by Gebler, crossed the heights of the north Kholun. Here also the range consists for the most part of clay slate. A mass of granite crops out from it between the White and Black Ulba and reaches the headwaters of the Turgussun. Dykes of porphyry traverse the slates in several places and towards the source of the upper or lesser Koksus porphyry sets in. The highest peak of the Kholun, which has yet been reached, consists of porphyry and amygdaloid lava surrounded by clay slate ².

If we leave the great ranges and proceed towards the north, in the direction of the steppe of Barnaul, or towards the west, in the direction of the Irtysh, we see that the isolated outcrops of granite still persist; the rocky columns on lake Kolyvan afford one of the best-known examples. At the same time Devonian and lower Carboniferous fossils appear in the stratified rocks. Towards the north there is a tendency to a northerly strike, while towards the Irtysh the north-westerly direction generally prevails.

Inostranzew met with a north and south strike in quartzite and chlorite schist on the north, close to the border of the steppe, near the village of Ruten, on the Loktevka, where Carboniferous beds are involved in the folding ³. There are numerous statements as to the occurrence of Devonian fossils on the west slope towards the Irtysh, in the tract from the lower Bukhtarma down to the Ulba and beyond ⁴.

Below the confluence of the Naryn the Irtysh for a long distance cuts the direction of the clay slates at so acute an angle that its course may be taken to mark a longitudinal valley. Here, on the Irtysh, a broad expanse of granite rests upon steeply upturned beds of clay slate. Hermann,

¹ Helmersen, *Reise nach dem Altai*, pp. 162-176; Gebler has performed the same journey.

² G. Schtschurowski, *Geological Journey into the Altai*, 8vo, Moscow, 1846, atlas, pp. 293-304.

³ Inostranzew, *Travaux de la Section géol.*, 1895, I, p. 30.

⁴ Tschernyschew, *Materialien zur Kenntniss der devonischen Fauna des Altai*, *Verh. russ. k. min. Ges.*, 1893, XXX, describes the lower Devonian of the Krjukowskii mine at Ridderskoje, and once more demonstrates the European character of the Devonian sediments of the Altai; the localities at which they occur are enumerated in von Peetz, *The Age of the clay slate of the outpost of Verkhne-Udinsk on the Altai*, *Trav. Soc. Nat. Saint-Petersb.*, 1897, XXVIII, pp. 82-89.

G. Rose, Humboldt, Helmersen, Cotta, and others have mentioned this remarkable phenomenon, and attempted to explain it, sometimes by dynamic overthrusting, sometimes by flow. Bogdanow describes in detail a tract, six versts long, between the rivers Bareshnikov and Koslovka, in which white granite rests on the uneven surface of the steeply upturned clay slates¹.

The same clay slates and chlorite schists, with a north-west strike, form the Kalbin range, west of the Irtish.

To the south-east, beyond the Narym range, lake *Marka-Kul* (1,407 meters), set deeply in the mountains, lies at the foot of the lofty *Sary-tau* and its offshoots. According to Struve and Potanin, the summit of the *Sary-tau* (3,268 meters) is a rounded granite mass, accessible on every side, with dykes of diorite. A series of valleys marks the boundary between this granite mass and the surrounding ranges, which consist of green schists. On the lake these schists strike north-west².

From this we may assume that the *Sary-tau* belongs to the Altai, possibly to the western part of its most southerly arc, which is very little known.

The Russian Altai is absolutely distinct from the ancient vertex. This is shown most clearly by the course of the Kusnetzkie Alatau, which runs at right angles to the main direction of the western half of the vertex, and also by the advance of independent foot-hills of the Kusnetzkie Alatau into the intermediate region of Minuzinsk.

The Russian Altai is distinguished from the Gobi-Altai by its deflexion and also by its composition. It presents us with thick masses of schists, in part of Palaeozoic age; the Gobi-Altai, on the other hand, is chiefly characterized by gneiss and Archaean rocks, and by long fault-troughs and

¹ B. F. Hermann (Beiträge zur Physik, Oekonomie, u.s.w. besonders der russischen und angrenzenden Länder, Berlin und Stettin, 1786-1788, III, p. 108) thought the granite was '*thrust up on to the schist.*' G. Rose (Mineralogisch-geognostische Reise nach dem Ural, dem Altai, und dem Kaspischen Meer, Berlin, 1837-1842, I, p. 611) first described the numerous intrusions of the granite into the schist, confirmed the superposition of the granite on the schist, and put forward two theories first conceived by A. von Humboldt. Humboldt stated that the granite had been *poured out* over a distance of more than 5,000 meters in almost horizontal sheets upon the steeply upturned clay slates (Fragmente zur Geologie und Klimatologie Asiens, p. 3). G. von Helmersen (Reise nach dem Altai im Jahre 1834 ausgeführt); Baer und Helmersen (Beitr. zur Kenntniss des russischen Reiches, XIV, 1848), regarded the granite as an effusive covering. Cotta (Der Altai, 1871, p. 40 et seq., Figs. 10-12) believed that the facts could be explained by the oblique ascent of the granite; a detailed description as well as a geological map of this part of the Irtish was furnished by D. P. Bogdanow, The mountains on the Irtish, Mater. Geol. Russia, published by the russ. k. min. Ges., 1883, XI, pp. 145-166.

² K. Struve and G. Potanin, Journey to Lake Saissan and in the basin of the Black Irtish as far as Lake Marka-kul and the mountain of *Sary-tau*, Zapiski Imp. ross. Geogr. Obsch., 1867, I, pp. 363-428; in particular p. 414.

horsts. Unfortunately the boundary of the two ranges is almost unknown. A tectonic continuation of the Kholsun or some other outer arc of the Russian Altai probably exists on the Mongolian frontier. It has been mentioned already that the transgression of the Devonian, coming from the Tannu-ola and Kharkira, probably encroaches on the basin of the upper Kobdo.

Plant-bearing beds of the Angara series occur on the upper Tchuya¹. Tertiary brown coal also appears on the Bukhtarma².

The Kirghiz steppe. The Kalbin range, which borders the left bank of the Irtish down nearly to Ust-Kamennogorsk, still belongs to the Altai, and the rocks of the Altai crop out in isolated hills still a long way further to the north-north-west. At the town of Semipalatinsk the Irtish exposes Devonian strata, and Wysotzki has indicated on both sides of the broad valley, to beyond lat. 51° 30' N., isolated outcrops of granite, porphyry, and diabase, Devonian, and Carboniferous limestone, which are visible beneath older marine Tertiary beds or beneath a still more recent covering. The range does not break off against a fault, but its denuded folds sink gradually beneath the plain³.

Further to the south-west, in the line of lake Saissan and beyond it, we see a long range, striking north-west, and represented by the heights of Kandygatai (north of the road from Kolpekty to Sergiopol), Aldjan, Arkat, and Urdatau; before coming to long. 78° E. this range reaches the mountain of Degelen (921 meters), formed of granite and porphyry, and with it the junction with the mountainous country of the *Kirghiz steppe*.

Still further to the south-west of lake Saissan there rises the long mountain range of Tarbagatai. With that gentle bend to the south which is characteristic of the branches of the Thian-shan, it trends to the north-west, continues beyond Sergiopol as the range of Tchingis, and then, on the other side of the watershed between the Irtish and the Balkhash, it becomes united, like the previous range, with the mountains of the Kirghiz steppe. The mountain of Kuu, formed, like Degelen, of granite and porphyry, appears to represent the true termination of the range of Tarbagatai-Tchingis. The mountains of Kuu and Degelen are connected by the Devonian ridge of Murdjik, which also strikes to the north-west.

Long ridges of lower Devonian quartzite, with broad synclines of upper Devonian and Carboniferous limestone lying between them, rounded bosses of granite, and rocky heights of porphyry, extend through the land; some of the ridges rise to a height of quite 1,000 meters above the surrounding

¹ Malewski, Gorn. Journ., 1870, II, p. 89.

² Schmalhausen, Tertiäre Pflanzen aus dem Thale der Buchtarma, *Palaeontographica*, XXXIII, pp. 181-216; whether this flora must be regarded as Pliocene or as the mountain flora of some other period of the Tertiary aera is left an open question.

³ Wysotzki, Djel. Dor., 1896, I, pp. 21-33, pl. I.

country. This region is described as a steppe on account of the character of its vegetation, particularly its poverty in forests.

Except for the junction, already mentioned, with the north-westerly trending spurs which radiate from the ranges of Central Asia, the contour of this mountain land is undetermined on all sides. It grows lower, breaks up into isolated hills, and disappears beneath the plains. Towards the north-east, it sinks in the direction of Pavlodar, under the low country. Krasnopolski has shown that in the bed of the river Seleta, between Omsk and Akmolinsk, the same rocks as those of the mountains may be recognized beneath the plain nearly as far as lat. 53° N.¹ Towards the north-west

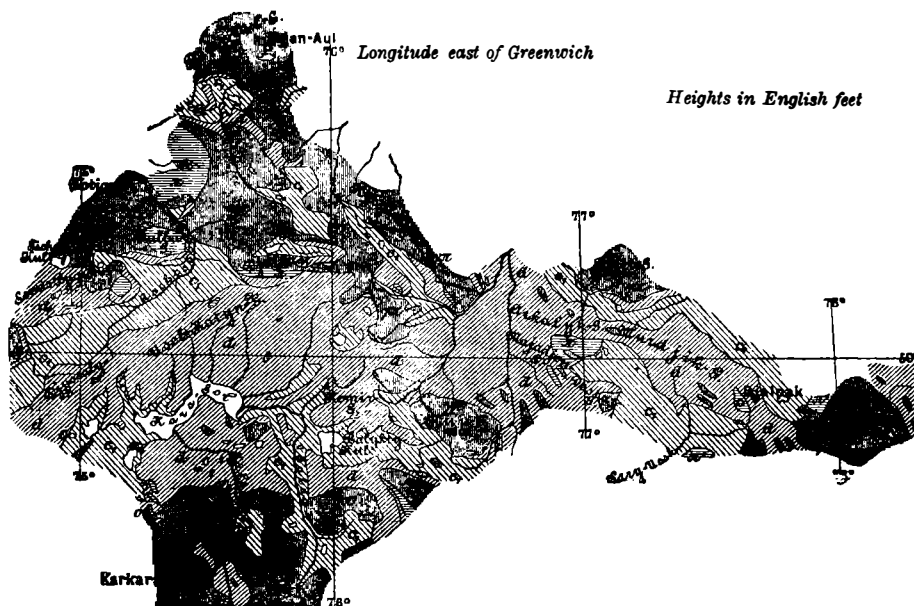


FIG. 8. Mountains of the Kirghiz Steppe, between Karkaralinsk and Bajan-aul. (After Wysotzki.)
 γ , π , granite and porphyry ; π' , porphyry tuff ; d, Devonian ; c, Lower Carboniferous.

lies Kokshetau, close to the border. Then the mountain land reaches the Ishim ; but in the south-west, towards Turgai and the sands of Kara-kum, and in the south, towards the Hunger steppe or Bedpak-dala, as well as towards the north shore of lake Balkhash, the boundary is quite indefinite and for the most part but little known.

The existence of ores and coal has brought many a mining expedition to this region, notably that led by Theophilatjew in 1814, and more recently, that undertaken by Antipow. The surveys made for the

¹ A. Krasnopolski, Geological investigations in west Siberia in 1896, Djel. Dor., 1898, IX, Seleta, pp. 73-81.

Siberian railway by Krasnopolski in the north-west and north, by Wysotzki in the east (Karkaralinsk, Baian-Aul), and by Meister in the west (Akmolinsk, Atbasar), afford us an insight into the general structure of the country¹. Meister has given a summary of the results, as well as a map of the region between longs. 66° and 76° E.²

The country is formed of granite, porphyry, and diabase, together with Devonian and Carboniferous strata. The coal measures, which occur in several localities, lie, according to Krasnopolski, sometimes on Carboniferous limestone, sometimes on granite³. Since *Asplenium Whitbyense* and *Phyllothea striata* are said to occur, it is evident that a part of the coal-bearing series must be more recent than the Carboniferous.

As regards the folds, some strike to the north-west and others to the north-east. In the south-east, as far as the region between Karkaralinsk and Baian-Aul, the north-westerly direction of the Tarbagatai prevails. Wysotzki's map of this region shows clearly how the Devonian range of Murdjik and its continuation, the Arkalyk, approach this region with a north-west strike, while the ridge of Ush-Katyn, which is also Devonian, advances with north-east strike; it shows also how, north of the town of Karkaralinsk, these two directions of folding encounter each other.

But towards the west the north-west direction soon disappears, and the north-east prevails, with very broad and open folding. A Devonian range of these folds forms the watershed between the Tchiderta and Ulenta, and a second range, the lofty Ermen-tau, separates the latter river from the Seleta. In the whole of the west the structure is clearly expressed in the configuration of the country. The folds, with a north-east strike, cross the Ishim towards the south; one of them gives rise to the sharp elbow of the Nura. Beyond Akmolinsk the country about the Ishim becomes flat, and towards the south broadens out into a wide plain scattered over with lakes. The Devonian sandstone is almost horizontal; the Carboniferous limestone with *Productus giganteus* lies in a very shallow basin. Still further west a more important anticline rises up with a north-east strike. It forms the ridge of *Djarkain Agatch*, which gives rise to the sharp elbow of the Ishim, near long. 66° E. The ridge is formed of granite, flanked on

¹ A. Krasnopolski, Coal beds near the Irtysh, Gorn. Journ., 1894, II, pp. 289 et seq.; Work of the mining section in west Siberia in 1893, Bull. Com. géol. Russie, 1894, XIII, pp. 89-203; Report on geological investigations in west Siberia in 1895, Djel. Dor., 1896, V, pp. 1-49. N. Wysotzki, Geological observations made in the year 1894 in the Kirghiz steppe and on the Irtysh, op. cit., 1896, I, pp. 1-45, with a geological map of the east part of the steppe. A. Meister, Geological observations made in the year 1895 in the Kirghiz steppe, op. cit., 1896, V, pp. 51-68; for the localities of ore deposits cf. in particular Antipow, Gorn. Journ., 1892. The distance from the mountain of Degelen to the Ishim, measured towards the west-north-west, amounts to about 850 versts.

² A. Meister, Geological observations in the Kirghiz steppe made in the years 1894-1896, Djel. Dor., 1899, XV, pp. 1-180, map; in particular p. 163 et seq.

³ Krasnopolski, Bull. Com. géol. Russie, 1894, XIII, p. 200.

both sides by Devonian sandstone, and it extends towards the north-east as far as the hill of Agatch Bel, in lat. 52° N.

In the same latitude another and similar anticline, the *Bektchentai*, crops out on the Ishim.

At the elbow of the Ishim all the observations at my disposal come to an end. The structure of the mountain land which rises further south, near the headwaters of the *Ssari-ssu*, is unknown to me.

Let us return to the east. Here, but somewhat further north, it certainly appears from existing accounts that the north-westerly folds are cut across by the north-easterly folds. In the coal-basin of *Eki-bass-tus* (lat. $51^{\circ} 40'$ N., not far from long. 76° E.) there is a north-west strike, and a slight overthrust of the north limb towards the south-west. In any case, it is certain that between the branches of the *Altai* and the *Thian-shan* on the one hand, and the *Ural* on the other, there exists an independent system of folds—some of them no doubt but faintly expressed—which strike to the north-east; these occupy the whole region between the *Ishim* and *Karkaralinsk* and encounter almost at right angles the folds of the *Tarbagatai*. We may name them the *Kirghiz folds*.

There is an undeniable resemblance between these folds and those of the *Kolyvan*, which also strike to the north-east, cross in front of the *Salaïr* at right angles to its trend, and then disappear on the banks of the *Obi* beneath the plain. We might assume with greater confidence some connexion between the folds of *Kolyvan* and *Kirghiz*, were it not that towards the west the latter appear to take a north-north-east direction. *Krasnopolski*, at any rate, marks the strike on the *Agatch* as $1-2$ [30° to 60° E. of N.]. Here, however, the saddles and folds flatten out to such an extent that it would be more appropriate to speak of undulations; out of the land formed by them the older rocks emerge in long ridges.

The first of the great ranges lying in front of the *Kalbin* mountains is the *Tarbagatai*; this is continued beyond *Sergiopol* in the *Tchingis-tau*, and forms the first of the arcs bent towards the south-west. We have seen already that it advances towards the mountain mass of *Saur* in the south, and that the disjunctive lines of *Dzungaria*, and a tendency to the formation of fault-troughs, make themselves felt as far as its east side, on the shores of lake *Saissan*. We have also explained how towards the north-west the *Tchingis* encounters the *Kirghiz* folds.

In the wide interval between the *Tarbagatai* and the first branch of the *Thian-Shan*, slant in like a straying wave, as it were, the *Urkatcher* and the *Alatau* of *Dzungaria*. The direction of this mountain segment is divergent, and it possibly represents only the eastern part of an arc, the north-westerly branch of which is aborted. It is cut through, however, in a characteristic manner by disjunctive lines which correspond precisely with this suppressed north-westerly direction and to the lie of the other

mountain folds. They produce the remarkable *trough of the Ebi-nor*, in which are alined in succession, starting from the marshes of Shicho, the lakes of Ebi-nor, Djalanesh, Ala-kul, Ujaly, and Ssassyk-kul; the trough declines in height till at Ebi-nor it is only 700 feet (213 meters), and at right angles to the mountains of Dzungaria it opens out towards the depression of lake Balkhash.

Now we have reached the *Boro-khoro*, one of the long branches of the virgation of the Thian-shan. As we have already introduced a description of this virgation, from the pen of the most competent authority on the subject, M. Muschketow (I, p. 264), no further discussion, apart from some remarks on the intermediate chains to follow later, will be necessary. In a work which has since appeared Muschketow has expressed his disbelief in the view formerly held that the several arcs follow two independent directions of elevation, with a trend to the west-north-west and north-east. These directions seem rather to represent fragments of arcs, the 'results, produced simultaneously, of one and the same geological process.' At the same time he asserted that 'the whole of the Thian-shan, from Barkul to the Hindu-kush and to the Karatau, represents an assemblage of very numerous arc-like folds, differing in size, but uniform in direction, which are all convex towards the south and concave towards the north'¹.

The virgation of the Thian-shan is not formed by the splitting up of a common stem. This common stem exists only in appearance, and is due to the close approach of the several virgae, which takes place in a more or less east-south-east direction. At the same time the several ranges, as well as the intervening depressions, like the valley of the Ili, are visible for long distances, and this would be the case to an even greater extent, were it not that here and there the north-east limb of one arc is overlain by the west-north-west limb of the next, and thus an imbricate structure like a tiled roof is produced. An image perhaps more apt would be that of very large and very flat drops clinging to the terrestrial sphere and overlapping one another.

This structure may also be recognized on the outermost edge of the south border.

In the region of the *Khan-tengri* (24,000 feet) the arcuate form of the south border is so strongly marked that, according to the descriptions of Ignatiew, the strike from lake Kokshal onwards is due north-east. Clay slates and white marble, accompanied by bands of Carboniferous limestone with *Productus giganteus*, and broken through by masses of granite and syenite, form this highest part of the Thian-shan. Gneiss, even in the moraines, is much more seldom observed than is usual in mountains of such height².

¹ J. W. Muschketow, *Turkestan*, 8vo, 1886, St. Petersburg., I, pp. 32, 34, map.

² J. W. Ignatiew, Report on the expedition to the mountain group of Khan-tengri, *Izvestija Imp. ross. Geogr. Obsch.*, St. Petersburg., 1887, XXIII, pp. 105 et seq., map. On

On the Khan-tengri itself, which represents the end of that branch of the Kokshal arc that strikes to the north-east, a re-entrant angle arises on the south border, and beyond it, north of the pass of Musart, the strike to the west-north-west sets in, and a new arc approaches the border.

This new arc is of very great length; it runs from the *Karatau*, along the south shore of the Issyk-kul to the Musart; reaching the south border of the Thian-shan, it bears the name of Khalyk-tau.

In long. 83° E. this is replaced by another arc, which is termed at the place of its emergence *Kok-tepe*; but this is simply a part of the long range of *Kuruk-tag*, which extends beyond the Thian-shan and forms the south border of the Bei-shan.

Let us turn our attention to the north shore of lake Issyk-kul.

The *Alexander range* extends along this shore in the Kungei-Alatau; the same branch, according to Muschketow, forms the Ish-kilik, and finally the pass of Narat (long. $84^{\circ} 15'$ E.) on the little Yulduss ¹.

Now follows the depression of the Ili and the Kungess, running towards the east-south-east. This is also the direction of the long range of *Boro-khoro* and its continuation, the Iren-khabirgan. The *Tshol-tag* belongs to the further continuation of this line, and forms the north border of the Bei-shan. I do not know the structure of the watershed between the Bagrash-kul and the river Algoi, and therefore cannot assert that the Boro-khoro and the Tshol-tag are actually parts of the same chain, but the Tshol-tag may certainly be recognized west of the meridian of Urumtchi, as already within the domain of the Thian-shan. The section from Kurlja to the subsidence of Ljuk-tshun, published by Bogdanowitsch, which intersects all the connecting links between the Thian-shan and Bei-shan, shows clearly how close are the relations between them ².

The *Bei-shan*, inserted between the Kuruk-tau and the Tshol-tag, consists solely of elongated branches of the Thian-shan.

the glacier of Djiparlyk, the steps of which hewn in ice form the most dangerous part of the Musart pass, a true kolk or Gryde lake is described (p. 127), like those which occur in Greenland below the Nunataks. South of the pass the strike to the north-east still seems to prevail in the foot-hills.

¹ The section which Muschketow drew after the earthquake of Vernoe (June 19, 1887), from this town to the south across the Sa-Ili-Alatau and the Kungei-Alatau to the Issyk-kul, shows that longitudinal faults are present in this part of the range, Mém. Com. géol. Russie, 1890, X, p. 132, pl. IV. Further east, south of Djarkent, the beds are overthrust to the south-east, according to Brusnitsyn, so that granite rests on Carboniferous limestone dipping to the north-west, Investigations in geology and mining in the province of Semiretschensk, Gorn. Journ., 1892, I, p. 459.

² K. Bogdanowitsch, Geological investigations in east Turkestan, Work of the expedition to Thibet directed by M. W. Piewtzow, II, published by the Russian Geographical Society, St. Petersburg, 1892, 4to, pl. V, fig. 8. The passage of the parallel folds of the Bei-shan into the Thian-shan, and the continuity of the two ranges, is emphasized by Obrutschew, Orography of Central Asia and its south-east border, Izviestija Imp. ross. Geogr. Obsch., 1894, XXXI, pp. 253-344, in particular pp. 277-278.

East of Urumtchi, a coulisse running to the east-south-east rises to a considerable height. Its summit, the *Bogdo-ola* (5,100–5,500 meters) lies close to Urumtchi, and north of Turfan the same chain reaches a height of 3,600–4,000 meters. The *Bogdo-ola* consists, according to existing descriptions, of metamorphic schists, quartzite, and black phyllites. But M. Klemenetz tells me, that though he reached greater heights on the *Bogdo-ola* than his predecessors, yet he found nothing but melaphyre, volcanic tuffs, and breccias.

It is the eastern part of this lofty chain which descends in steps towards Turfan and Ljuk-tshun and the north foot of Tshol-tag. This north foot, although penetrated by the coulisse of the Thian-shan, is distinguished by a deep horizontal fissure, which forms the south side of a long fault-trough.

The brothers Grum-Grimailo found, in the autumn of 1889, that at one locality, south of Turfan, the surface of the ground lies below the level of the sea. A few weeks later this unexpected discovery was confirmed by Piewtrow. Measurements give a difference of 102 meters. The place is covered by a salt marsh ¹.

We may observe at the outset that in this eastern region the strike of the Thian-shan has become east-and-west.

We have several exact descriptions of the depression of Ljuk-tshun. All agree that it is a typical fault-trough, let down along parallel longitudinal faults and flexures; and that not only the coal-bearing clays and variegated sandstones of the Angara series, but also the red conglomerates and friable sandstones of the Gobi series, are affected by the dislocation. Towards the north the border of the trough is formed by two ridges, the Djargess and the Tus-tag; along the latter alone the subsidence amounts to about 360 meters; the south border is formed by the north foot of the Tshol-tag.

The transverse section, drawn by Bogdanowitch from north-west to south-east as far as the bottom of the depression, shows the Djargess consisting of ancient folded schists, overlain by patches of the Angara series; then, at a lower level, the same deposits forming a downthrown step with very much disturbed bedding; and still lower and also very much disturbed, the Gobi beds ².

The brothers Grum-Grimailo have described the descent from the north-east and given a remarkable illustration of the unconformable superposition of the Gobi beds on the steeply inclined Angara series ³.

¹ This figure is given by Roborowski, C. R. Soc. géogr. de Paris, 1897, p. 207; see also Obrutschew, in Hettner's Geogr. Zeitschr., 1895, I, pp. 274–277 et passim.

² K. Bogdanowitsch, Geological investigations in east Turkestan, pl. V, fig. 9.

³ G. E. and M. E. Grum-Grimailo, Description of a journey in western China, publ. by the Russian Geographical Society, 4to, St. Petersburg, 1896, map; I, Along the Thian-shan mountains, p. 284 et seq.

The accompanying section, taken along the meridian of Turfan, I owe to the kindness of M. Obrutschew. It shows melaphyre and porphyry at the south foot of the Djargess, a broken anticline or flexure in the *Tus-tag*, and downthrown lower Carboniferous beds at the foot of the *Tshol-tag*. This sketch also indicates that the faults are not of the same age.

Towards the west this remarkable fault-trough seems to merge into the rapidly ascending valley of the river Algoi. Towards the east it is at first concealed by a thick accumulation of loose sand, the *Kum-tag* or Sand mountain, with a broad ridge which soon attains a height of 300 to 400 meters above sea-level. Obrutschew, as he proceeded from the south slopes of the *Syr-kyn-tag* to *Pit-shan* and the pass of *Tchiktim-tag*, observed on the north border of the Sand mountain, in the *Angara* beds and *Gobi* deposits, flexures and fractures which, judging from their position, correspond to the bendings and fractures of the *Tus-tag* (Fig. 9). At *Tchiktim*, where the Sand mountain ends, the bottom of the trough again becomes visible. From the lofty *Thian-shan*, which consists here of schists and diabase, the

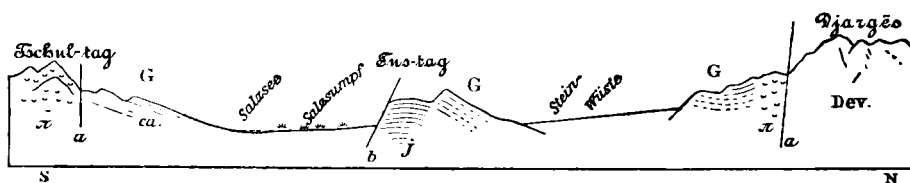


FIG. 9. The fault-trough of Ljuk-tshun.
Dev., Devonian; ca, Lower Carboniferous; π , Porphyry; j, Angara beds; G., Gobi deposits;
a, b, faults. (After a sketch communicated by W. Obrutschew.)

country sinks gradually towards the south, sometimes as a broad plain, sometimes in a series of steps. To the east of the Sand mountain, according to the descriptions of Roborowski and Koslow, there now appears along the foot of the *Tshol-tag* a desert tract, absolutely devoid of water, formed of *Gobi* deposits which are sculptured by the wind into fantastic forms. This is the 'devil's valley' (height about +300 meters). At one spot near the north foot of the *Tshol-tag* basalt is exposed. Finally the country sinks once again, along the north foot of the range, until it reaches a level of 36 meters, and according to some accounts, even lower. This is at a place close to long. 92° E., not far from the settlement of *Sulgassar*. The neighbouring lake *Shona-nor* (101 meters) receives the waters which flow down from the town of *Hami* (856 meters) ¹.

¹ W. Obrutschew, *Central Asia, North China and Nan-shan*, II, p. 536 et seq. I must here offer particular thanks to M. Obrutschew for his kindness in placing at my disposal abstracts of the several parts of his work on Central Asia, previous to publication. As I finish this page I have before me the abstracts as far as vol. II, p. 608. W. J. Roborowski and P. K. Koslow, *Preliminary account of a three years' journey in Central Asia* (report by Koslow), *Izvestija Imp. ross. Geogr. Obsch.*, 1897, XXXIII, pp. 121-163

In this region porphyry, porphyritic tuff, and melaphyre play an important part in the structure of the foot-hills or terraces at the base of the Thian-shan. In the coal-bearing beds of Tash-kese, between Lao-chin and Hami, Obrutschew found remains of *Phoenicopsis* and *Gingko*¹.

East of Hami, on the north border of the strip of desert, which may be regarded as the continuation of the fault-trough, there rises a series of foot-hills, dominated by a new and mighty coulisse of the Thian-shan, the *Karlyk-tag*. Roborowski and Koslow describe the magnificent view which it affords. For a distance of 50 versts its snowy peaks rise one behind the other to heights of 4,500 meters, and the glaciers descending between them present frightful precipices. Its continuation to the east is the *Emir-tag*; then the great range breaks up into isolated rocky ridges, and far to the east extends the desert².

These eastern parts of the Thian-shan present us with Angara beds, porphyry, schists, and bosses of granite and syenite; gneiss seems to be more widely distributed than in the west.

The river Khaya, flowing southwards from the ice-fields of the *Karlyk-tag* across the desert and the foot-hills, is discharged, according to Obrutschew, into a lake, close to the north border of the Bei-shan or rather of the chain of Yo-shui-shan. In this lake a valley coming from the east opens; on the maps it is marked as the *Protok-Yandunskii* or *river of Yandun*. The level is higher than in the west (777 meters), and the configuration of the ground is so suggestive that G. E. Grum-Grimailo is inclined to believe that a great river once actually flowed from east to west between the Thian-shan and the Bei-shan into the depression of *Ljuk-tshun*³.

Obrutschew gives a detailed description of that part of the depression which lies east of long. 95° E. A broad detrital tract extends southwards

Koslow travelled from the mountains west of Hami to the south, and found a similar depression of the desert to the south as far as the border of the *Tshol-tag*, loc. cit., p. 159.

¹ F. Krasser, *Die von W. A. Obrutschew in China und Central-Asien 1893-1894 gesammelten fossilen Pflanzen*, Denkschr. k. Akad. Wiss., Wien, 1900, LXX, p. 149. The beds with *Phoenicopsis* were also encountered in the *Tyrkyp-tag*, on the north border of the subsidence of *Ljuk-tshun* (loc. cit., p. 146). The plant-bearing beds of the *Tungshan*, a spur of the *Bogdo-ola* south of *Urumtsi*, are older and contain *Lepidodendron* (loc. cit., p. 143).

² Roborowski and Koslow, Preliminary account of a three years' journey in Central Asia, *Izvestija Imp. ross. Geogr. Obsch.*, 1897, XXXIII, p. 156. The brothers Grum-Grimailo remark a prevalent direction to north-east on the road which runs from Hami across the pass of *Ulan-ussu* to *Gusten*, as though the eastern end of the coulisse of *Bogdo-ola* were marked by a bend resembling that of the western coulisses of the Thian-shan; cf. Grum-Grimailo on the ridge of *Tshoglu-tshai* et passim, *Description of a journey in western Asia*, pp. 308, 428, 495 et passim.

³ Grum-Grimailo, *Description of a journey in western China*, I, pp. 313 et seq., pp. 495, 496.

from Karlyk-tag to this region; it is interrupted by rows of sombre foot-hills which consist of diorite, porphyry, granite, and black siliceous schists. South of the last foot-hills, the slope is continued to the hills about the spring of Utun-odsi (1,135 meters), which are formed of Gobi deposits, resting on the denuded edges of ancient rocks. South of Utun-odsi, near the spring of *Ya-dsi-tshuan* (1,350 meters), the ground sinks to a level of 490 meters. Here, indeed, the depression completely resembles an ancient river valley, running from the east towards the lake into which the Khaya flows. I have no information as to the level of this lake. At this point lies the eastern end of the great depression. Obrutschew regards the whole feature, from Toksum and Turfen to the spring of *Ya-dsi-tshuan*, as a tectonic trough, and terms it the *pre-Thian-shan* subsidence ¹.

Along the whole length of this trough, from long. 88° 30' E. to about long. 95° 30' E., the deeper part of the depression lies close to the southern side. In the extreme west it sinks to a level of -102 meters, but in the east it is partly filled up, though to what extent there is no means of judging, by the débris brought down from the high ranges. The sand blown from the Kun-tag is alone sufficient to form, near the deepest part of the depression, a broad ridge which rises to +300 to +400 meters.

Bei-shan. This range was first clearly distinguished from the other mountain groups by the brothers Grum-Grimailo; as regards its structure it appears to be a broad zone of folds which strike between east and east-south-east; these proceed from the Thian-shan; they are accompanied both on the north and south for their whole length, or at least for a considerable distance, by fractures and subsidence, after the fashion of a horst, and they strike across the Gobi to the Edsin-gol and beyond. At the same time the more northern folds make a bend at their eastern end towards the east-north-east or north-east.

The Bei-shan has been described as an 'intumescence,' but the manner in which its eastern end breaks up at the Edsin-gol into several folded ranges, reveals its true nature. We have already seen how the folded range to the north, the Tshol-tag, as also that to the south, the Kuruk-tag, show themselves to be true branches of the Thian-shan.

The depression of lake Bagrash-kul, which extends between these two ranges, interrupts the continuation of the inner folded ranges. At the same time the Bei-shan is much lower than the Thian-shan, and much poorer in water and vegetation; indeed for the greater part it is a true desert traversed by long, low rocky ridges. So far as its outer configuration is concerned, it has nothing in common with the glorious alpine landscapes which delight the traveller in the Boro-khoro; but it is, nevertheless,

¹ Obrutschew, *Central Asia*, II, p. 528 et seq.; also *Izviestija Imp. ross. Geogr. Obsch.*, 1894, XXX, p. 339, XXXI, pp. 294-301.

a part of the same tectonic system. Perhaps this apparent contradiction will one day find its solution in the discovery that the Bei-shan is a fragment of the ruins of an older structure modelled anew, after a plan developed on the ancient lines over the region of the existing Thian-shan.

Let us first consider a section in the west.

M. E. Grum-Grimailo proceeded from the trough of Ljuk-tshun between long. 90° and 89° E. towards the south. The ascent across the Tshol-tag was made first over clay slate and then over a weathered surface of granite and quartzite (901 meters). From this point we look over a mountainous land, broad and barren. Just below (815 meters) lies a salt region, and bright red carnelians lie scattered like spots of blood on the salt. The surface, which has been subjected to intense deflation by the winds and is covered with splinters of rock, reveals granite, granular limestone, and green phyllites. Then mica-schist forms trains of rocky crags, alined east and west. Two-thirds of the breadth of the Bei-shan has now been crossed; and before us the lofty granite mass of the *Tjuge-tau* (2,700 meters) dominates the landscape. The surrounding country has meanwhile reached a height of about 1,500 meters, and consists of diabase and marble. Beyond the diabase, vertical beds of sandstone and slate are exposed in a longitudinal valley. The north slope of the Kuruk-tag shows granite; its height appears to scarcely reach 1,200 meters; towards the south it slopes away to the hollow of the Lob-nor.

Gobi deposits have not yet been observed; the breadth of the Bei-shan amounts here to about 125 versts¹.

The next section traverses a region which lies much farther to the east; Obrutschew has taken it from Bulundsir, east of Ansi, along a line curving north-west to the spring of Ya-dsi-tshuan, at the eastern end of the pre-Thian-shan fault-trough. This section is distinguished by the predominance of Archaean rocks in the south and centre. The bordering range of the south (1,600 to 1,650 meters) is not known here as the Kuruk-tag, but receives the name of *Pustynni-Khreibet*, i.e. the desert mountain. It is formed of granite, gneiss, hornblende schists, and quartz-schists. A longitudinal valley containing Gobi deposits separates it from the *In-va-shan*; porphyry appears near the Archaean rocks; the heights exceed 2,000 meters. Coal measures are met with and a patch with divergent strike, which belongs perhaps to the supra-Carboniferous sandstone. Archaean rocks again follow, and in the *Dsi-ge-djin-dse* (clay slates, quartzite, green schists, 2,290 meters) we reach the highest part of the section. Gneiss again appears, and granite, which affords an illustration of the extremely destructive action of the wind. Hornblende-granite and syenite-porphyry follow, and extend as far as the neighbourhood of the *Yo-shui-shan*. This

¹ Grum-Grimailo, Description of a journey in western China, pp. 381-417.

chain, an anticline of mica-schists, clay slates, and quartzite, is the same as that which, in its continuation to the west-north-west or west, probably reaches the south border of the pre-Thian-shan trough.

Within this range, judging from the directions of the strike, a bend from west-north-west to east-north-east appears to occur. This bend makes itself manifest in the *Utun-shan*, which nevertheless consists of grey limestone and porphyry. Here we already see the snowy peaks of the Karlyk-tag, and a longitudinal valley appears to open out towards the north-east. Porphyry and porphyritic tuffs persist: then we reach the spring of Ya-dsi-tshuan and the eastern end of the trough¹.

Along a line from Sa-tshou to Kufi, the Bei-shan has been crossed by Prjewalski, Roborowski, and others, but the published accounts are brief. Here no considerable heights are reached, and the Bei-shan is divided lengthwise down the middle by a broad valley.

Important information, as regards the relations of the chains, is afforded by the journey made by Ladygin from Dalan-turu (south of the Zagan-nor, in the valley of the Lakes) in an almost southerly direction to Su-tshou².

South of the spurs of the Altain-nuru, which, as we have learnt, is the principal chain of the Gobi-Altai, Ladygin crossed the Burgustin-nuru, Ederyngin-nuru, and the desert of Narin-Khukhu-gobi, which is bounded towards the south by lofty mountains. It sinks to a level of 1,100 feet (335 meters); this is the lowest point met with on this journey.

The special value of Ladygin's journey lies in the fact that he followed the mountains on the south side of this desert for long distances both to the west and to the east. Towards the west he went far enough to see in the distance the white summits of the eastern outposts of the Karlyk-tag, and towards the east he saw the lofty peak of Noin-bogdo, east of the meridian of the Edsin-gol. There he was able to make out that the Adji-bogdo (about 5,800 feet) and the Baga-bogdo, which are both included among the foot-hills of the Gobi-Altai, are united with the ridge of Noin-bogdo by the long *Kökö-tymyrty*, which runs east of Ladygin's route towards the east-south-east and east, and extends into the desert.

Hence it is clear that a mountain range, standing out in bold relief, crosses the desert as a continuous arc, north of the lakes which lie at the mouth of the Edsin-gol (cf. p. 102).

South of the *Kökö-tymyrty* comes first the desert of Shjurten-

¹ Obrutschew, *Central Asia*, II, pp. 433-535.

² Roborowski and Koslow, *Izviestija Imp. ross. Geogr. Obsch.*, 1897, XXXIII, p. 155; W. F. Ladygin, Preliminary report on a section of the Gobi from Dalyn-turu to Su-tshou, *op. cit.*, 1900, XXXVI, pp. 169-197, map.

kholy-gobi (2,000 feet, 40 versts broad) and then the Boro-ula, the first chain of the Bei-shan.

In the west, the pre-Thian-shan trough may be regarded, if not as a tectonic, yet as a superficial limit between the Thian-shan and the Bei-shan, and we might even be inclined to regard the angle at which the Metchin-ola meets the Karlyk-tag at Barkul as the limit between the Thian-shan and the lines of Dzungaria, which rather resemble those of the Gobi-Altai; here in the east, on the other hand, such boundaries disappear, and the whole group of chains shows an increasing tendency to form a single arc.

The Boro-ula is formed of schists; the Khan-shui-nuru, which comes next, is the highest range of the Bei-shan, and is followed by two ranges of hills, which extend as far as the broad desert of Khunkyr-dsagyn-kholy. This stretches away to the west-north-west, and hills (Dsossytyn-nuru) rise out of it formed of red clay which probably belongs to the Gobi deposits. We then reach a low range of hills in which coal-measures occur, next the sands of Narin-khulussu, and finally the town of Su-tshou.

We are indebted to Obrutschew for a section of the Bei-shan, which crosses it from south to north, close to the Edsin-gol, at its eastern end¹.

In the south, a little north of Ting-tcha-hsi, we reach a belt of land along the river Lin-shui, which both to the east and west maintains the character of a desert plain. It is regarded by Obrutschew as a trough separating the Nan-shan from the Bei-shan, and it forms a continuation of the sands of Narin-khulussu previously mentioned. Then we reach the foot of the Bei-shan. Porphyry and porphyrite, and between them metamorphic limestone, are the prevailing rocks. At the same time granite also occurs. Somewhat further north comes a range of gneiss and ancient schist; the general strike is now directed to the west-north-west or north-west, but a curvature towards the east-north-east and north-east begins to appear and becomes increasingly evident towards the north. Porphyry and tuffs again succeed, then calc-schist, which includes a small laccolite of diorite. Conglomerates of the Gobi series border the mountains. The mighty central range of the chain has been named by Obrutschew the *Edsin-ula*. This presents first granite, porphyry, diorite, and crystalline limestone, then a wider belt of limestone containing lower Carboniferous fossils; the strike is already east-north-east and north-east. After an interruption of the range by the desert, we reach the most northerly branch of the Bei-shan, the *Boro-ola*, which is formed here of the same lower Carboniferous limestone. Already, further to the south, isolated ranges of hills are to be seen on the right bank of the Edsin-gol, which indicate the continuation

¹ Obrutschew, Central Mongolia, *Izviestija Imp. ross. Geogr. Obsch.*, 1894, XXX, pp. 239-244, and Central Asia, II, pp. 362-397.

of the Bei-shan and at the same time its curvature to the north-east. Two continuations of the Boro-ula now appear beyond the river, the mountain of Dserdjín-Vantshik, and the longer range of Koko-ula, directed to the east-north-east.

The brothers Grum-Grimailo, and Obrutschew also, agree in the view that the branches of the Bei-shan unite, beneath the sands of the Ala-shan, with the spurs of the ranges on the Hoang-ho, which advance to meet them. This junction is indicated both by the deflexion at the end of the Edsin-ula and the Boro-ula, and by the continuation of the latter to the north-east beyond the Edsin-gol. It receives confirmation in the north from Ladygin's discovery of an arc which starts from the Adji-bogdo of the Gobi-Altai and passes through the Kōkō-tymyrtý to the Noin-bogdo. But the ranges of the Thian-shan proper are no longer to be seen; at their origin in the west we found that the two chief ranges of the Bei-shan issue from the Thian-shan itself, but towards the east they are differently related. Looking at the angle which the ranges of the Gobi-Altai (Adji-bogdo, &c.) make with those of the Bei-shan (Boro-ula, &c.), that is the western expansion of the region of the Shjurten-kholy-gobi, it seems as though the several coulisses of the eastern Thian-shan (Emir-tag, with Karlyk-tag, then Bogdo-ula, &c), constantly driven towards the west-south-west, pass out from it, one after the other, in a slanting series.

San-sjan-tsy. This mountain fragment belongs to another chain of mountains, the arc of Yarkand; we will discuss it here for the sake of obtaining a clearer conception of the whole.

Koslow has given a description of his journey from the south-west along the south side of the Lob-nor. On the right lie the sands of Kum-tag, which form a broad zone bordering the foot of the Anembar-ula (Yarkand) mountains; on the left rise the outlines of the Kuruk-tag (Bei-shan) growing ever clearer and nearer. Between the settlement of Korot-bulak (about long. $91^{\circ} 25'$ E.) and Atchik-Khuduk, which lies about 150 versts away, the aspect of the desert undergoes a change. The salt marshes vanish and the vegetation which characterizes the neighbourhood of the Lob-nor reappears. Kuruk-tag presents steep declivities. At Atchik-khuduk the depression which corresponds to the prolongation of the Lob-nor becomes much narrower. Finally the tongue-shaped ridges of sand, which the Kuruk-tag sends out towards the north, reach the foot-hills of the Bei-shan and close the depression towards the east. This depression is called by Koslow the 'valley of the wild camels'¹.

From here Koslow crossed the sands towards the south-east and reached Sa-tshou. We will continue, however, to follow the route to the east. The sands, moving northwards to the Bei-shan, have built up a watershed,

¹ P. Koslow, Lob-nor, *Izvestija Imp. ross. Geogr. Obsch.*, 1898, XXXIV, pp. 60-116, maps, in particular p. 90 et seq.; Roborowski, *tom. cit.*, p. 15.

which cuts off the tributaries of the north-west Nan-shan from the Lob-nor and from the Yarkand-Darya. To the east, beyond the watershed, a series of smaller lakes soon appears; finally there follows a vast region of lakes and marshes, which is termed lake Khalatchi, and receives what were once the tributaries of the Lob-nor, now dammed up, the Dan-khe in the south, and the Su-lei-khe (Bulundsir) in the east. Here, in the low cliffs on the south shore of lake Khalatchi, hornblende granite crops out¹.

These are the first signs of a long range of Archaean rocks, which further to the north-east, where it forms a rocky ridge, is crossed obliquely above Ansi by the Su-lei-khe (Bulundsir). This ridge, far to the south-west, separates itself from the north side of the Anembar-ula as a series of rather short coulisses, and only appears to attain continuity in the elbow of the Dan-khe, above Sa-tshou. From there, however, it extends for a distance of more than 200 versts, running constantly to the east-north-east, parallel to the branches of the Anembar-ula, across the Su-lei-khe into the immediate neighbourhood of the south foot of the Bei-shan.

I know of no general name for this long rocky ridge; Lóczy calls the northern parts, as far as the Su-lei-khe, Ta-pan-shan and Lo-an-shan; the Russian map on the scale of 40 versts to the inch calls them the *San-sjan-tsy*. They were first visited by Michaelis, and the rocks have been described by Steuer².

According to Lóczy this range is formed of naked, broken rocks, and culminates above Sa-tshou at a height of 2,045 meters; on its north side it rises 300–400 meters above the surrounding wastes of débris, and on its south side sinks gradually beneath them. On the Su-lei-khe, above Ansi, it consists of grey gneiss, hornblende schists, mica-schists, and crystalline limestone, traversed by granite and quartz-diorite; the strike varies between due east and west, and N. 60°–70° E. Ancient sandstone rests against the east slope³.

The fragmentary ranges, which rise north of the Su-lei-khe, have been described by Obrutschew. They are formed of the same ancient schists and sandstones as those found by Lóczy on the east side. They strike N. 50°–60° E., in correspondence with the direction of the range itself. Then to the west of its north-east extremity we see a group of dark-coloured hills; they are cloaked in débris formed of hornblende-porphyrine. They

¹ According to Koslow's observation kindly communicated to me by M. Obrutschew.

² H. Michaelis, Von Hankou nach Su-tschou; Reisen im mittleren und westlichen China, 1879–1881, Peterm. Mitth., Ergänzungs-Heft 91, 1888, 58 pp., maps. A. Steuer described chloritic-mica-schist from these naked masses of rock; Mittheilungen über Gesteine aus den chinesischen Provinzen Kansu Schensi, Hupe und Honan, N. J. f. Min., 1895, Beilage-Band X, pp. 477–494, in particular p. 489.

³ Die wissenschaftlichen Ergebnisse der Reise des Grafen Bela Széchenyi in Ostasien, 1877–1880; Ger. Ed. (trans. by F. Schafarik), atlas, 4to, Wien, 1873; Geologische Beobachtungen von L. Lóczy, pp. 498–559 et passim.

do not lie far from the talus on the south border of the Bei-shan, that is of the Pustynii-Khreibet or desert mountain. Still farther west, and almost as close to the Bei-shan, there lies a broad worn-down Archaean mass, composed chiefly of gneiss and quartz-schist, in which the strike appears to vary between $N. 70^{\circ}$ to 100° E. This mass, precisely like its continuation to the south of the Su-lei-khe, forms an inclined platform sloping gently towards the south and sharply broken off on the north, as though it were separated from the Bei-shan by a broad rent, now covered by the desert. The south foot of the Bei-shan, in this part of its course, does not follow a straight line, but runs in and out in promontories and bays; two versts

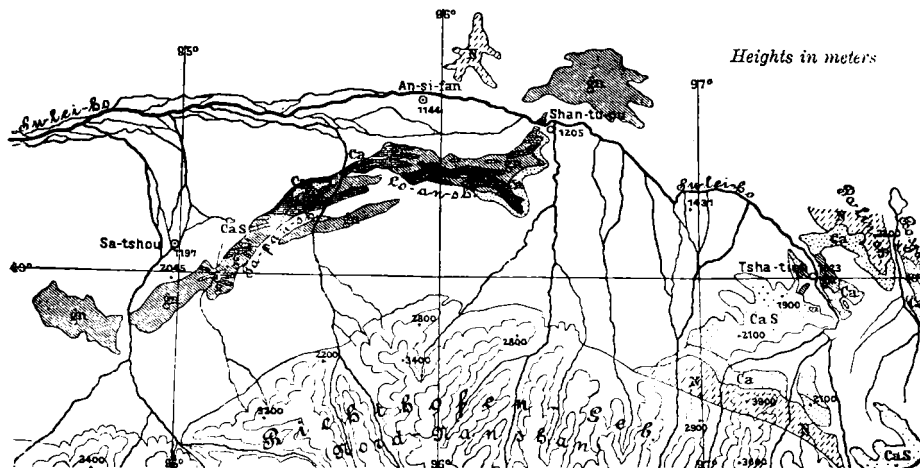


FIG. 10. The region of An-si-fan. (After Lóczy.)
g, granite, diabase; *N*, Sandstone of the Nan-shan; *gm*, gneiss, mica-schist;
Ca, Carboniferous; *CaS*, supra-Carboniferous sandstone¹.

from its foot, where its talus of débris begins to ascend, the height above the sea-level is 1,420 meters².

In this manner the most north-easterly coulisse of the Yarkand mountains, the range of the San-sjan-tsy, meets the Bei-shan. The depressions between its last heights are now occupied by salt marshes, but the ruins of frontier fortresses, and temples, and irrigation canals, now dried up, bear witness to a former state of prosperity. It is a region where the forces of nature compel man to retreat.

Lun-shan. Lying in front of the north foot of the Nan-shan is an elongated depression. It is separated from the sandy desert of Ala-shan on the north by a mountain chain. The rivers which descend from the snow

¹ This figure, as will be seen from the text, does not always agree with the results of recent observations; but it is the only geological sketch-map, so far as I am aware, of any part of the San-sjan-tsy.

² Obrutschew, Central Asia, I, pp. 598-613, journey no. 8.

fields and glaciers of the Nan-shan, and especially the tributaries of the Edsin-gol, water the depression before they cross the mountain chain to the north, and are then lost in the desert. This chain has received many names; by the people of the country it is generally called Bei-shan, i. e. the northern mountains, as opposed to the Nan-shan, or southern mountains; but it is not the direct continuation of the Bei-shan beyond the Edsin-gol, as was recognized long ago by F. von Richthofen. Some parts of it are called Pa-lin-shan, Bo-shan, Tsa-jui-guan-shan, &c.; the greater part of the eastern limb is known as the *Lun-shan*, i. e. the Dragon mountain, and we will use this name, following Obrutschew's suggestion, for the whole range. The depression between the Lun-shan and Nan-shan hardly reaches a breadth of 60 versts, and is generally much narrower; it forms the region of the *oases of Kansu*.

The Lun-shan exhibits two very striking stratigraphical features, each of which is met with again in the lofty Nan-shan.

The first, which was originally pointed out by Lóczy, is the very general and obvious unconformity at the base of the upper Carboniferous. This formation is represented by rich coal measures and marine beds, the latter containing an abundant fauna, which corresponds throughout with the upper Carboniferous of Europe (*Spirifer Mosquensis*, *Enteleles Lamarckii*, *Fusulina cylindrica*, &c.). Since its deposition, it has been subjected to violent movements; in the Lun-shan, as in the Nan-shan, many of the greatest lines of dislocation are marked by pinched-in bands of coal measures¹.

The second feature is the mantling round of the mountains by thick beds of red, yellow, or brown sandstone, marl, or conglomerate, which compose the Gobi series, here often over 1,000 feet thick. Obrutschew has shown that, though as a rule this rests horizontally against the mountains, yet it is often profoundly dislocated, not only by faults but also by folding. The sandstone beds sometimes resemble the supra-Carboniferous sandstone.

In the west, almost in the meridian of the town of Jui-myn, a broad independent ridge proceeds from the north foot of the Nan-shan; it is designated by Obrutschew the Pestraja Grjada, or mottled chain, and is formed by the many-coloured beds of the Gobi series². According to Obrutschew, these beds are strongly distorted close to the foot of the Nan-shan and then strike N. 65° E.—a direction alien to that of the great range—through the Pestraja Grjada towards Tsha-tien³. Near this

¹ Lóczy, Wissenschaftliche Ergebnisse der Reise des Grafen B. Sczéchényi, Band III: Beschreibung der fossilen Reste von Wirbelthieren und von Mollusken und die palaeontologisch-stratigraphischen Ergebnisse; in particular p. 207.

² In Fig. 10 these deposits are marked CaS (supra-Carboniferous sandstone) according to the earlier view.

³ Obrutschew, Central Asia, I, p. 581.

town gneiss is visible with a strike to N. 35°–40° E.; it evidently forms the foundation of the Pestrja Grjada and of the whole range which stretches across the depression. Lóczy thought it possible that this gneiss might represent an 'outpost' of the Archaean rocks of the Ta-pa-shan (San-sjan-ty). The direction actually corresponds with that of the western Kuen-luen, and not with that of the Nan-shan¹.

About 30–40 versts south-east of Tsha-tien, Obrutschew crossed the range east of the Palin-shan. Only traces of ancient rocks are visible; the thick masses of conglomerates and sandstones probably belong to the supra-Carboniferous sandstone. In the south-western part of the range the strike approaches an east-and-west direction, or even west-north-west, while in the north-eastern part it is N. 45°–80° E. About 25 versts further away we see metamorphic schists and sandstones, very sharply folded, sometimes, it would seem, overturned towards the north, and also traversed by dykes of syenite-porphyry. But here the strike has already turned to the west-north-west or north-west. The range becomes a small ridge; the Great Wall runs along its south side almost as far as the Lin-shui, which flows to the Edsin-gol. On the banks of this river we see crystalline limestone with flakes of graphite, dykes of aplite, and, further away from the water, granitic gneiss striking NW. 310°².

Thus, in this region the Lun-shan has assumed the prevailing direction of the Nan-shan; this it maintains for a long distance, while it forms the north border of the oasis tract of Kansu. Secondary chains join its south-west side; the range becomes broader and higher.

At Shan-dan-sjan, about 230 versts east-south-east of the Lin-shui, the main range of the Lun-shan consists of a sharp anticline of Carboniferous, which forms the highest and most northerly pass, and in front of this and to the south of it four parallel bands of green schist with isolated dykes of granite; these are separated from one another by bands of Carboniferous, and become lower towards the south. The range is closely folded, and it must remain an open question whether these parallel strips have been produced by step-faults with subsidence towards the south or by repeated overthrusting.

The general direction of the range is west-north-west or north-west, like that of the steep northern anticline, and of all the Carboniferous bands. We observe, however, that the Carboniferous rests unconformably on the green schists, which were folded before the Carboniferous was deposited; the strike of the green schists in the most northerly and most important band is directly opposed to that of the Carboniferous, being at first NE.

¹ Lóczy, *Die wissenschaftlichen Ergebnisse der Reise des Grafen B. Széchenyi in Ostasien*, I, pp. 554, 644, 662, Tung-hoan-hsien (= Sa-tshou).

² Obrutschew, *Central Asia*, I, p. 589 et seq. (for the section of the Lin-shui), I, p. 566 et seq.

45°; towards the south it approaches an east-and-west direction up to N. 87° E.; in the more southerly bands it varies between east to west and west-north-west.

From the north, as we proceed from the desert of Ala-shan, the Gobi deposits rise in flat-bedded and transgressive patches up the slopes of the Lun-shan; according to Obrutschew's observations they even reach a height which exceeds that of the pass of Lun-shan (2,320 meters)¹.

East of the region just discussed the parallel secondary ranges (Sin-khe-shan, Fin-shan, Bao-bu-dan-shan) on the south side of the Lun-shan increase in number; they all possess the same structure as the main range, and only in the most southerly of them—the Tei-chuan-shan, which extends furthest into the oasis tract of Kansu, and is also the highest—does granite-gneiss crop out, the oldest rock of the Lun-shan. In these foot-hills a strike from north-west to west-north-west everywhere prevails; the transgression of the upper Carboniferous is very striking.—

About 100 versts east-south-east from the section of Nan-dan-sjan, north of the town of Yuen-tshen-sjan, which lies about half-way from Ljan-tshou, the southern foot-hills of the Lun-shan have disappeared or else united with the main range. The Fin-shan runs north of Yuen-tshen-sjan, and is only separated from the Lun-shan by a narrow valley through which the Great Wall runs. The Fin-shan here consists of ancient sandstone with dykes of syenite-porphry and granite, the Lun-shan, however, chiefly of granite; it is not certain that it is of Archaean age. Here the strike of the rocks, as of the ranges, is directed from west-north-west to north-west².

Finally, it is possible, thanks to the sustained efforts of Obrutschew, to study the continuations of the Lun-shan along the course of the Da-khe, below Ljan-tshou, at a place about 80 versts east-south-east of Yuen-tshen-sjan, and more than 550 versts from that spot, where the ranges of the Lun-shan reach the northern foot of the Nan-shan in the Pestraja Grjada.

In this part of the Lun-shan, which lies furthest to the east-south-east, it appears, according to the map, as though the range has made a bend in the direction of the mountains of the Hoang-ho, similar to that made by the northern ranges of the Bei-shan on the Edsin-gol. Indeed in the conjectured normal continuation of the Fin-shan and Lun-shan in the east-south-east direction, Obrutschew encountered no mountains along the banks of the Da-khe, north of Ljan-tshou, and it was not till much further on, towards the town of Tshen-fan, that the spurs made their appearance as long débris-covered ridges surrounded by the 'barchans' of the sands of Ala-shan.

¹ Obrutschew, *Central Asia*, I, p. 526 et seq.; in particular p. 533, section of Shan-dan-sjan.

² Obrutschew, *Central Asia*, I, p. 512 et seq.

The first of these, the *Kun-nge-shan*, is formed of numerous ridges of various lengths, which extend to the west-north-west, and are continued east of the river; dark brown limestone is exposed; the stratigraphical position of the beds is uncertain, the strike perhaps east and west or east-north-east. In the débris there are some traces of Gobi deposits and doubtful Carboniferous fossils. The second and the last ridge towards the north, *Loje-shan*, with a relative height of 120 meters (valley floor, 1,430 meters), is also directed to the west-north-west¹.

To sum up, we may describe the Lun-shan as a mountain range, running to the west-north-west, or north-west, which is inserted as a parallel coulisse between the Bei-shan and the Nan-shan, but is distinguished from the Bei-shan by the fact that its western end beyond Tsha-tien and Pestraja Grjada, is bent in the direction of the arc of Yarkand i. e. to the south-west.

North foot of the Nan-shan. The mighty range of the Richthofen mountains, which forms the north border along the whole length of the Nan-shan, possesses no definite limit towards the north, i. e. towards the oases of Kansu. To the north of the Nan-shan there is nothing that can be compared with the zone of Flysch or Molasse of the northern Alps, the Carpathians or the Apennines, or with the Flysch mountains of Arakan in Burma, or the Siwalik mountains at the south foot of the Himálaya. Nor is anything to be seen which resembles the fractured inner border of a great mountain arc, but, on the contrary, we see here and there foot-hills which strike to west-north-west or north-west, parallel to the main range of the Richthofen mountains, and also to the foot-hills of the Lun-shan, which lie opposite them on the north. It was this which gave Lóczy the impression that the Ho-yen-shan (median part of the Lun-shan) was only one of the foot-hills of the Nan-shan².

East-south-east of At-sa-kou, i. e. of the junction of the west Lun-shan with the north foot of the Richthofen mountains, the latter are formed mainly of ancient schist and sandstone, which extend for a great distance, and strike west-north-west to north-west. At about 70 versts from the junction, the range of foot-hills called Tshin-tu-shan shows Carboniferous and supra-Carboniferous sandstone with the same strike, folded, but with the beds dipping uniformly to the south-west, i. e. towards the high mountains. Even far out on the margin of the plain, the Gobi beds themselves dip at an angle of as much as 60°-65° in the same direction. Obrutschew conjectures that the whole series is overturned towards the north-east³.

¹ It must be observed that the position of the town of Tshen-fan, as indicated on the maps, is incorrect.

² Lóczy, Die wissenschaftlichen Ergebnisse der Reise des Grafen B. Széchenyi in Ostasien, I, p. 637.

³ Obrutschew, Central Asia, II, p. 240.

A little more than 90 versts further to the east-south-east, near Tsin-fo-sy, where the Da-khe emerges from the Richthofen range, we see a broad granite mass, which rises rapidly from the border of the plain to a considerable height, and is separated from still higher chains on the south by an intervening band of coal measures¹.

About 100 versts further to the east-south-east, we reach a crowded group of foothills, the Din-in-pa-pan-shan, which, advancing towards Gao-tai, narrows the depression of the oases of Kansu to a breadth of about 25 versts. This group terminates towards the north in three distinct step-faults, which three times repeat the same series—ancient sandstone, Carboniferous limestone, coal measures, and porphyry with tuffs².

About 80 versts still further to the east-south-east, near Nan-kou-tshan, where the foot of the range has receded, and the depression has widened out again to a great breadth, the beds dip towards the interior of the chain; granite (or porphyry?) is exposed in the midst of an older Palaeozoic series, which is covered unconformably by upper Carboniferous³.

Not far east of this place a broad zone of melaphyre, with tuff and breccia, crops out at the foot of the range; it is likewise bounded on the south by coal-bearing Carboniferous rocks⁴. This extraordinary diversity no doubt suggests that the north border of the Richthofen range is not a simple and continuous tectonic line. At the same time it certainly follows the general strike of the Nan-shan; as do likewise its foothills, as well as those of the Lun-shan and the Lun-shan itself. Many of the existing features of the depression of the oases of Kansu, including its varying breadth, may have been produced by irregular trough-like subsidence along continuous longitudinal fractures.

Western boundary of the Nan-shan. This mighty range is bounded on the north-west by parts of the arc of Yarkand (western Kuen-luen), namely the Altyn-tag, Anembar-ula, and their secondary coulisses. This is the interpretation given by Lóczy and Bogdanowitsch, and it is confirmed by all that we have said above as to the direction and position of the gneiss ridge of San-sjan-tsy. On the north-east, towards the oases of Kansu, no continuous tectonic boundary exists, as we have seen from our study of the north slope of the Richthofen range. To the south-west we may draw the limit at will through lake Kuku-nor or from the Khaltyn-gol to the plain of Syrtyn, or along the north border of the Tsaidam; all these boundaries are equally arbitrary and only chosen for the sake of more easily obtaining a general idea of the configuration; none has

¹ Obrutschew, *Central Asia*, II, pp. 147, 151.

² Obrutschew, *Central Asia*, I, p. 545.

³ Lóczy, *Die wissenschaftlichen Ergebnisse der Reise . . . in Ostasien*, I, pp. 543, 544 (according to figs. 65 and 66).

⁴ Obrutschew, *Central Asia*, II, p. 144.

any basis in nature, for the direction of the folded ranges remains almost unchanged as far as the Prjewalski mountains, and the bend further to the south takes place very gradually. It is equally difficult to find a boundary on the south-east, and indeed, so far as I know, the attempt has never been made.

Sheet XXI of the Russian map on the scale of 40 versts to the inch, prepared by Colonel Bolschew, gives a good idea of the relative heights in the west of this region.

The Lob-nor lies at a height of 2,550 feet; then rapidly rising towards the south, the Altyn-tag culminates in peaks of 13,000 feet or over, but beyond the Altyn-tag the slope does not fall with the same rapidity; the plain of Tsaidam does not sink below 8,800 feet, and lies for the greater part above 9,200 feet; the plain of Syrtyn is over 9,400 feet, and south of Tsaidam the plain of the two lakes of Kum-kul lies at a level of over 13,000 feet.

Let us return to the level of 2,550 feet at the Lob-nor and follow the route taken by Koslow, already described, to the east-north-east on the south side of the Bei-shan. The country gradually rises to a height of 2,720 feet. Lake Khalatchi, beyond the watershed formed by the sand, lies at a height of 3,500 feet, but as soon as the San-sjan-tsy is crossed, beyond An-si, we find ourselves at a level of over 5,000 feet, and the whole surface, south of Sa-tshou, between the San-sjan-tsy and the prolongations of the Anembar-ula, as well as the whole region of the oases of Kansu on the other side, lie above 5,000 feet.

Above the oases of Kansu the crests and peaks of the Richthofen mountains rise to a height of quite 20,000 feet, but south of this range all the valleys of the Nan-shan remain very high; the surface of the Kuku-nor is at a level of 10,500 feet, and that of the Khara-nor, discovered by Roborowski, at about 12,000 feet. Beyond the Nan-shan we reach that elevated tract of the Thibetan chains where for great distances no point lies below 15,000 feet.

This mighty elevation of the ground, bounded on the south-west by the depression of the Yarkand-darya and the Lob-nor, constricted on the north-east by the depression of Ordos, is a sort of intumescence composed of a number of very crowded more or less parallel folds. These folds, with the exception of their outermost western border, follow a west-north-west direction from the oases of Kansu to Tsaidam. A broad valley, which includes the Kuku-nor together with the fluvial region of Bukhain-gol, and in its continuation further the Khara-nor, and lies, as we have just seen, at a considerable height, divides these chains lengthwise into a northern and a southern group. The separation, however, is not complete, since both to the north-west and south-east

of the great valley, the chains join together so completely that the valley between them has no outlet.

The breadth of the Nan-shan between the north border of the Tsaidam and the south border of the oases of Kansu may be compared with that of the Alps between Biella and Freiburg, and indeed there is a rough correspondence between the extension of the Swiss Alps as a whole and the region generally included under the name of Nan-shan. But though the absolute height of the chains of Nan-Shan is greater than that of the Alps, so is that of the valley bottoms also, and thus the contrast of relief within the chains is diminished; yet at the same time the observer is brought nearer to the limit of perpetual snow.

Many enterprising travellers, from Prjewalski to Roborowski, have attempted to determine the topography of this mountain land, but so far only two skilled geologists have taken part in its investigation and published their results. The first of these was Lóczy, whose work, apart from that on the north border, is of chief importance in relation to the line from Lan-tshou to Ljan-tshou, the valley of the Si-ning, and the regions in the south-east. He was followed by Obrutschew, who has drawn several sections across the northern chains. In the course of a lengthy expedition Obrutschew first crossed all the chains near their north-western end; then, following their trend, he reached the field of Lóczy's labours, on the south side of the Kuku-nor, and thence, travelling across the eastern part of the chains, again arrived at the oases of Kansu.

Important as these achievements are, yet, when we consider the nature and extent of the country, they cannot be regarded as more than a first step. The geology of the middle portion of the Nan-shan in particular, that is the districts around the Khara-nor and the fluvial region of the Bukhain-gol, is almost entirely unknown, with the single exception of the south border of the Kuku-nor. Since, however, Obrutschew has crossed the lofty chains in the west, and those of the east, thanks to the united efforts of several observers, have to some extent become known, it is possible to perceive that although the strike is affected by isolated, and sometimes very remarkable, local disturbances, to which we shall recur, yet on the whole the trend of the chains and the strike of the rocks are in fairly exact correspondence at both ends of the Nan-shan.

In the meridian of Su-tshou, four lofty chains, striking uniformly to the west-north-west, rise between the oases of Kansu and the longitudinal valley of the Kuku-nor. These are the Richthofen mountains, Tolai-shan, the range of Alexander III, and a fourth chain but little known, which is separated from the preceding by the upper valley of the Su-lei-khe. In the continuation of the Alexander range to the west-north-west or a little south of this direction, rises the Da-sjue-shan¹.

¹ W. Obrutschew, *Orographical sketch of the Nan-shan*; *Izviestija Imp. ross.*

The Richthofen mountains are here 50–60 versts broad and divided into several folded ranges, the first of which reaches a height well over 20,000 feet. At its northern foot, near Tsin-fo-sy, south-east of Su-tshou, a granite boss shows itself, but although the granite rapidly attains some elevation it does not extend far into the mountains. It is followed by a coal-bearing band of upper Carboniferous beds, dipping to the south-west, next by lower Carboniferous with *Productus striatus*, then by red and green Devonian sandstone; finally by quartzite and limestone, probably Silurian. Before reaching the first series of peaks we already find the folds dipping to the north, and all the remaining ranges of the Richthofen mountains may be regarded as closely crowded folds of similar Palaeozoic sediments, which either stand vertical or are overturned to the south. Imbricate structure also appears to occur. It is possible that one or other of the coal-bearing bands belongs to the Angara series. On the most southerly pass, the Tsin-nin-daban (4,220 meters), and even still higher up, the Gobi beds rest unconformably against the south border of the Richthofen mountains; they descend in places at a very steep angle to the valley of the Khun-shui, which forms the boundary next the Tolai-shan.

About 100 versts further to the west-north-west Obrutschew again encountered this zone of red Gobi deposits; they form a syncline, the beds of which dip towards each other on the two sides of the valley of Bei-jan-koi at an angle of 60° or over. This recent syncline must be regarded as the limit between the Richthofen mountains and the Tolai-shan. It shows that the Richthofen mountains become considerably narrower towards the west-north-west; possibly a number of their northern ridges disappear in this direction in the form of coulisses.

Still further to the west-north-west, towards the middle Su-lei-khe, red and green sandstones crop out in the Palaeozoic series of the Richthofen mountains, and in the partings middle Devonian fossils occur¹. On the south side the vast plain of the *Tshou-ma-er* oasis opens out. It is bounded on the south by the Tolai-shan, and is surrounded by red and yellow Gobi beds; in fact it is simply the broadened

Geogr. Obsch., 1894, XXX, pp. 42–112, map; Sketch of central Nan-shan, tom. cit., pp. 709–764, map; Orography of Central Asia and its south-east border, op. cit., 1895, XXXI, pp. 253–344 (in particular pp. 316–331), with a sketch map of the Nan-shan by Obrutschew and Roborowski. Further, Obrutschew, Central Asia, passim. The valley of Tatung-ho of Lóczy is the Chagryn-gol of Obrutschew. In the latter Roborowski distinguishes Mo-mo-shan from Ma-ling-shan; Chaji-shan L. (= Amasurgu) forms on Obrutschew's map, together with the granite and gneiss range which adjoins it on the west, the Lóczy mountains and Potanin mountains, the latter adjoining the south Kuku-nor; Maja-shan and Wu-so-ling L. = parts of Mo-mo-shan Obr. and Rob.; North-Tetung Prjew. = Tolai-shan Obr. and Rob.; South-Tetung Prjew. = Tshin-shi-ling Obr. and Rob.

¹ According to Tschernyschew *Rhynchonella alinensis*, in another locality *Spirifer elegans* and *Spirifer Anosoffi*; Obrutschew, Central Asia, II, pp. 9, 10.

termination of the great band of these deposits, in part bent into a syncline, which we have already traced from the Tsin-nin-daban pass, as the dividing line between the Richthofen range and the Tolai-shan. It is cut directly across by the middle Su-lei-khe.

Beyond this river the Richthofen mountains still further diminish in breadth, change their direction, describe a broad arc in the north and west of the oasis of Tshou-ma-er, and finally turn completely to the west-south-west. *This deflected mountain limb, bearing the name of the Shi-bao-shan, forms the first coulisse of the Anembar-ula.* This coulisse lies east of the oft-mentioned gneiss range of San-sjan-tsy, which borders the Anembar-ula as a sort of foot-hill.

It is easy to see that this bend made by the Richthofen mountains is similar to that made by the Lun-shan as it approaches the Pestraja Grjada. Furthermore, it completely surrounds the end of the Tolai-shan (the second range of the Nan-shan), which has broken up into low hills.

The *Tolai-shan* makes its appearance in the meridian of Su-tshou as a fairly narrow chain, but, like the Richthofen mountains, it rears its peaks high above the snow-line (here 4,400–4,600 meters). It is distinguished from the latter by a zone of gneiss, which crops out at its south foot. The disposition of the succeeding beds, however, is, according to Obrutschew's account, very peculiar. As we travel from the north we see, after crossing the intervening band of Gobi beds, violent folding of the thick Palaeozoic series. A local strike to the north-east and north-north-east comes in; then the rocks resume the prevailing direction to the west-north-west, and finally the most recent stage, coal-bearing Carboniferous and Fusulina limestone, is seen resting upon the gneiss. The section at this point suggests not so much a transgression of the upper Carboniferous as an overthrust of the whole Palaeozoic series, carrying it to the south over the gneiss.

A second section, drawn about 50 versts west-north-west of the first, shows that the gneiss zone of the south side has become much broader, and that even at a height of 4,530 meters the glaciers bring down gneiss from the summits. Thus gneiss contributes to the formation of the peaks; an exceptional occurrence in the northern Nan-shan.

If we follow this section from north to south, in accordance with Obrutschew's description, we first encounter, south of the dividing syncline of Gobi beds, two bands of melaphyre with tuffs and breccias, which rest on Palaeozoic rocks. They correspond to two step-faults. Then comes the series of great Palaeozoic folds seen in the first section. Close to its south border is the pass of Tye-daban (4,470 meters), which passes through supra-Carboniferous sandstone, and in the neighbourhood of the boundary, next the gneiss, upper and middle Carboniferous fossils

have been found. But while the normal west-north-west or north-west strike is dominant up to this point, yet before we actually reach the boundary great irregularity sets in, the strike sometimes running even to north-north-east or due north and south. The gneiss is accompanied by hornblende schists and by successive intercalations of banded limestone; the strike is north-west 295° ; and there is a steep dip to the north-east.

Beyond the gneiss zone, towards the south border of the Tolai-shan, upper Carboniferous again appears, here accompanied by porphyry tuff, (strike north-west, 290° – 300° , dip north-east, 40°) and apparently dipping beneath the gneiss.

The gneiss zone is thus restricted to the south of the Tolai-shan; on each side of it we find exposed not the lower but the highest part of the Palaeozoic series, that is the upper, and probably the middle, Carboniferous; and it remains for later investigations to determine whether this succession has been produced by an overlap of the Carboniferous, followed by posthumous folding, or whether a more profound and general movement of the whole Palaeozoic series, resulting in imbricate structure, has taken place.

The Tolai-shan is a shorter range than the Richthofen mountains, and breaks up towards the west-north-west, as we have seen, into low ridges, which, within the arc described by the north-west end of the Richthofen range, separate the oasis of Tshou-ma-er from the plain of Sua-dintse.

The chain of *Alexander III* rises south of the broad debris-choked valley of the Tolai-guan, and is formed, as is shown by two sections taken at a distance of about 20 versts apart, of steeply folded lower Palaeozoic beds passing towards the south into a great Carboniferous syncline, which includes a vast thickness of supra-Carboniferous sandstone. This syncline is so broad that the supra-Carboniferous sandstone rises within it in secondary anticlines, and so forms, in all probability, the peaks of U-ge-shan, the highest of the chain.

The *fourth chain* has not as yet been crossed completely from side to side: it is separated from the preceding by the upper valley of the Su-lei-khe, and, as we have seen, probably slopes away southwards to the longitudinal valley of the Bukhain-gol. It likewise is composed, at least in the part explored by Obrutschew, solely of Palaeozoic beds. It appears that the great syncline mentioned above, overturned towards the south and including all the Palaeozoic beds, is cut through obliquely by the valley of the Su-lei-khe, so that in the east-south-east the greater part of it belongs to the chain of Alexander III, while to the west-north-west it advances further and further beyond the valley of the Su-lei-khe into the fourth chain.

The structure of these four chains of the Nan-shan, from the oases of

Kansu down nearly to the valley of the Bukhain-gol, thus presents the following features: gneiss is visible on the south side of the Tolai-shan and nowhere else; all the rest of the range consists of closely folded Palaeozoic sediments. Near the north border there are indications of an overfolding to the north; in the interior of the range we observe a vertical position or a thrust to the south. The gneiss range is not accompanied, as we might suppose from the normal succession, by the lowest member of the Palaeozoic series, but by the upper Carboniferous.

We now follow the course of the upper Su-lei-khe and return to the north-western part of the Nan-shan.

The Da-sjue-shan is a lofty range, which is continued to the east-south-east, either directly into the mountains of Alexander III, or as an independent range between these mountains and the next succeeding, or fourth, range. It forms the south border of the plain of Sua-dintse. Its direction is first west-north-west, then due west, and finally west-south-west (265°). At the vertex of this gently curved arc it forms Obrutschew's Pik Poworotnii (Peak of the Bend), across which the river Da-kun-tse has cut its channel to the north-west. In the section thus afforded of the Peak of Poworotnii, Obrutschew found Carboniferous limestone, Devonian, and thick masses of clay slates, all overturned towards the north-west; and then, high up, traces of wedged-in coal-bearing Carboniferous and metamorphic schists.

On the right of the river the overturned series strikes west-north-west (290° – 315°), and on the left east-north-east (50° – 65°), so that *a sharp bend is made from the west-north-west direction of the Nan-shan into the east-north-east direction of the Anembar-ula*. Further west, in the bed of the Khai-khi-khe on the west side of the Pik Poworotnii, the west-north-west direction of the Nan-shan reappears. The structure of the Pik Poworotnii, which runs to the end of the Shi-bao-shan, is unknown to me.

On the south side of the Da-sjan-shan range diabase, porphyry, hornblende granite, and spotted schists occur. They form the Khrebet Besimani (the Unnamed mountains), and here ancient quartzite and hornblende schists crop out with a strike to east-north-east (75°), perhaps as the first indications of the structure exhibited by the next range, the Ye-ma-shan.

The *Ye-ma-shan* forms an exception among the chains of the Nan-shan. Even its outer form shows the divergent direction east-north-east (80°); the chain is shorter than the others, with rounded summits, which do not reach the snow-line. It consists throughout of Archaean or at any rate of very ancient rocks, gneiss and granite, chlorite and hornblende schists, and quartzite. The strike varies between north-east (52°) and east-north-east (80°). *The Ye-ma-shan is thus a coulisse of the Anembar-ula rising between the branches of the Nan-shan.*

The *Humboldt range* is much higher than the Ye-ma-shan. Not only

does it return, in its outer course and in the strike of its rocks, to the west-north-west or north-west direction of the Nan-shan, but it also swings round, even still more obviously than the northern chains, through a broad arc into the Altyn-tag, the longest and most important coulisse of which unites with the Humboldt range in the meridian of the Sa-tshou, i.e. in long. 95° E.

On the north-east the Humboldt range is bordered by the broad longitudinal valley of the Shara-gol. Towards the north-west the Shara-gol cuts through the range near Baigur, where a coulisse coming from the east-north-east joins the Altyn-tag, and thus perhaps represents a bend of the Da-sjue-shan; the Shara-gol then crosses the oft-mentioned gneiss range of San-sjan-tsy, and reaches the lake of Khalatchi. Its valley, north-east of the Humboldt mountains, is so broad, that Littledale, looking down on it from above, was filled with astonishment; from a distance, he wrote, it looks as though the Nan-shan were not connected at all with the Humboldt mountains; a broad plain lies between them, with a scarcely perceptible slope¹.

Obrutschew has crossed the Humboldt mountains by the Ulan-daban (long. 96° E.). From its northern foot there rises a parallel ridge of red gypsiferous Gobi-beds, dipping towards the range, i.e., towards the south-west, and comparable in colour and form to a great tiled roof. The north foot of the Humboldt range is formed of syenite-porphry, diorite, and probably granite also. These are soon followed by thick masses of grey schists with sandstone, described by Obrutschew as metamorphic, and for the most part phyllites. It is thrown into sharp folds, striking north-west (310° - 320°), and is covered unconformably by reddish-grey and red sandstone with shales, which belong to the supra-Carboniferous sandstone. This discordant series is also folded, with a similar strike, and forms first a patch at the north foot, then a broad syncline near the pass of Ulan-daban, and finally a second syncline within the southern slope. Thus, from a distance, says Obrutschew, we see steeply inclined red masses on a grey substratum, and from a still greater distance the chain appears to be wholly red.

At some places along this section gold placers occur; the metal is probably derived from dykes of quartz in the phyllites. Since similar deposits occur in the Humboldt range, fairly far to the east-south-east and also the west-north-west, up to the region where the range makes its bend to the Anembar-ula, we may suppose that these auriferous schists contribute to the formation of the range for a great distance.

On the south, precisely as on the north, the chain is accompanied by a

¹ St. G. Littledale, A journey across Central Asia, Geogr. Journ., 1894, III, pp. 445-475, map, in particular p. 462.

ridge of Gobi beds; and on this side also they dip, though very gently, towards the mountains, that is to the north-north-east.

The longitudinal valley of the Khaltyn-gol, which follows the Humboldt range on the south, is hemmed in by the foot-hills of the Tsagangolu ridge (also called Tsagan-Obotu); here the metamorphic schist is so rich in quartz that the talus slopes look as if they were covered with snow¹.

The lofty *Ritter range* is in the main formed by one of the parallel coulisses of the Nan-shan. Towards the west-north-west it is resolved into two hill ranges which flatten out towards the plain of Syrtyn. The first of these is the Tsagan-golu, mentioned above; the second and more considerable is called the Dakhyn-daban.

The metamorphic schist of the Tsagan-golu strikes to the east-north-east and reaches N. 65° E., so that the strike of the rocks deviates from the east-and-west direction of the range, and this branch of the Ritter mountains reveals in the direction of Syrtyn a bend towards the east-north-east. On its south side hornblende granite, with dykes of porphyry, crops out.

The Dakhyn-daban shows a strike to the north-west (295° to 340°); at its north foot Carboniferous limestone, dipping south, represents the beginning of a great syncline formed by the upper subdivisions of the Carboniferous; at the summit of the pass itself (4,360 meters) upper Carboniferous occurs with *Productus fasciatus*, *Aviculopecten*, and other fossils. The highest part of the range lying south of the pass is a steep anticline which brings up again the Carboniferous limestone; it is followed by a second syncline of the higher beds, which abuts against steeply inclined metamorphic schists.

With this we reach the side of a broad longitudinal valley which bounds the Ritter mountains on the south. Obrutschew calls it the *desert valley* (Pustynnaja dolina); it is one of those coulisse valleys which come from the east-south-east and open out from the Nan-shan into the plain of Syrkyn. South of the desert valley a range comes in, cut 'through by subordinate transverse valleys, which bears various names (Bomyn-ula, Tsaidamin-ula, Kaktyn-daban), but is designated by Obrutschew the Muschketow range. It is of great importance in a study of the Nan-shan. Towards the east-south-east it is united by the Airik-khetren-ula with the great south Kuku-nor mountains, and towards the west-north-west it is joined by several other coulisses, especially the Syrtyn-Makhain-ula; these, however, do not quite reach the chains of the west Kuen-luen. Thus the plain of Syrtyn is not completely separated from that of Tsaidam.

The Muschketow range is followed towards the south by a longitudinal valley formed by many fragments of coulisse valleys, and therefore varying considerably in breadth; it contains the lakes of Ikhe and Baga-Tsaidamin, and, towards the south, is partially separated from the Tsaidam

¹ The same fact is recorded at several localities at the foot of the San-san-tsy.

by a series of shorter oblique coulisces, which Obrutschew designates the *north Tsaidam chains*.

To the south of the Ritter mountains we thus recognize the Desert valley, then the Syrtyn-Makhain-ula, Muschketow, and Airik-khetren-ula as far as south Kuku-nor, then the coulisse valley with the Tsaidamin lakes; further on, the zone of the north Tsaidam coulisces; and lastly, the plain of Tsaidam. All these chains, south of the Ritter range, are distinguished from the northern chains by extensive outcrops of the most ancient rocks. The greater number and the most important of these chains are formed of gneiss accompanied by a broad or narrow border of Palaeozoic beds which are chiefly but not exclusively of Carboniferous age. Generally there is distinct overthrusting to the south-west, i. e. in the direction of the plain of Tsaidam. The Ulan-udsur, a coulisse which advances from the north Tsaidam zone and runs between the two lakes of Tsaidamin, is traversed by two thrust-planes and thus converted into two overthrust flakes.

Although important differences distinguish the chains separated to the north and south by the Desert valley—the southern chains predominantly gneissose, and, the northern mainly built up of Palaeozoic rocks and never presenting any large exposure of gneiss except at the south foot of the Tolai-shan and in the divergently trending Ye-ma-shan—yet, notwithstanding this, the Desert valley cannot be regarded as a true line of division. Indeed, according to the observations of Obrutschew, it seems much more probable, to judge by the pebbles brought down by the river, that the gneiss already begins to make its appearance north of the valley on the south slope of the Ritter mountains.

Syntaxis of the Nan-shan and the Yarkand range. Having now followed Obrutschew's description as far as the north-east border of the Tsaidam, we may attempt to discuss the relations of the western Nan-shan to the Anembar-ula, i. e. to the eastern part of the great arc which surrounds the basin of the Yarkand-darya.

With this object we will again commence our survey in the region of the Lob-nor and the Khalatchi.

On the south border of the Bei-shan, which runs here to west-north-west or due east and west, no indications of relationship between the Nan-shan and the Anembar-ula have as yet been recognized.

The gneiss range of San-sjan-tsy belongs, as Prjewalski has already observed, to the Anembar-ula. It reaches, east-north-east of An-si, the south foot of the Bei-shan, without assuming the direction of this range. The two ranges remain completely distinct. With the range which follows the case is different.

The Lun-shan, running west-north-west, parallel to the Nan-shan, separates the oases of Kansu from the desert of Ala-shan; it gradually bends from about Su-tshou onwards, away from the west-north-west, into

the west-south-west direction of the Anembar-ula, and, maintaining this direction, it reaches in the meridian of Yui-myn-sjan the north border of the Richthofen range, and at the same time bounds to the north-west the region of the oases of Kansu.

The much more important Richthofen range describes west of the middle Su-lei-khe the same curve from west-north-west to west-south-west, and under the name of Shi-bao-shan follows for a certain distance the direction of the Anembar-ula. The Tolai-shan flattens out before it accomplishes the bend; in this way the space situated within the bend of the Richthofen range comes to be divided into two parts, the oasis of Tshou-ma-er and the plain of Sua-dintse.

The Da-sjue-shan extends further to the west-north-west, and undergoes in the Peak of the Bend a sudden deflexion out of the direction of the Nan-shan into that of the Anembar-ula. Somewhat further west the strike returns in a sigmoidal curve to the direction of the Nan-shan; whether it is bent again before encountering the Shi-bao-shan is not known, but, judging by the course of the outer border of the Anembar-ula and the heights of Baigur, it seems likely.

The Ye-ma-shan is a coulisse of the Anembar-ula formed of ancient rocks and advancing to the east.

The Humboldt range makes a bend by which it passes completely into the main range of the Anembar-ula. But the bend is far gentler and more open than in the northern chains. For this reason the plain of Syrtyn, which it encloses, is broader and larger than the areas within the northern arcs.

Neither of the north-westerly branches of the Ritter range is long enough to accomplish the bend, and both disappear in the plain of Syrtyn, like the Tolai-shan on the south border of the Tshou-ma-er.

Even the elongated coulisse of Syrtyn-Makhain-ula, which continues the west-north-westerly direction of the south Kuku-nor and the Muschetow range, does not quite reach a junction with the Altyn-tag. The same is true of the northern coulisses of the Tsaidam. In this way the plain of Syrtyn is left in communication with that of Tsaidam.

A long and very remarkable coulisse valley, the *valley of the Winds*, discovered by Prjewalski, unites the Tsaidam with the depression of the Yarkand-darya and reaches the latter south of latitude 38° N. Although this valley traverses the whole range, the great traveller describes it as a longitudinal valley. In the west the Tchertchen Darya issues from it: then the valley bottom rises and reaches a height of 12,900 feet; towards lake Gass it again sinks to 9,300 feet ¹.

¹ Prjewalski, Fourth journey into Central Asia, from Kiakhta to the sources of the Yellow River. Exploration of the north border of Thibet and journey to the Lob-nor, publ. by the Imp. ross. Geogr. Obsch., St. Petersburg, passim; also Delmar Morgan, The Orography of Northern Tibet, Supplementary Papers, R. Geogr. Soc., London, 1890, III, Part I,

The trend-lines of the western Kuen-luen, as sketched by Bogdanowitsch, show, however, that here too the same relations exist between the eastern and western range as further north. This is clearly revealed by the angle formed in the direction of lake Gass, on the one hand by the Tshimen-tag, representing the western Kuen-luen, and on the other by the south Tsaidam, representing the Nan-shan; though these ranges do not come into contact with each other. But the chains corresponding to the Nan-shan describe an arc similar to that of the Humboldt range; thus the south Tsaidam (WNW.) turns towards the Dimnalik (WSW.), and the Columbus chain (Nargun-ulan) to the Ajalik-tag and the Tokus-dawan; thus it happens also that the valley of the Winds is completely enclosed by parallel coulisses directed to the west-south-west. Thus again the elevated

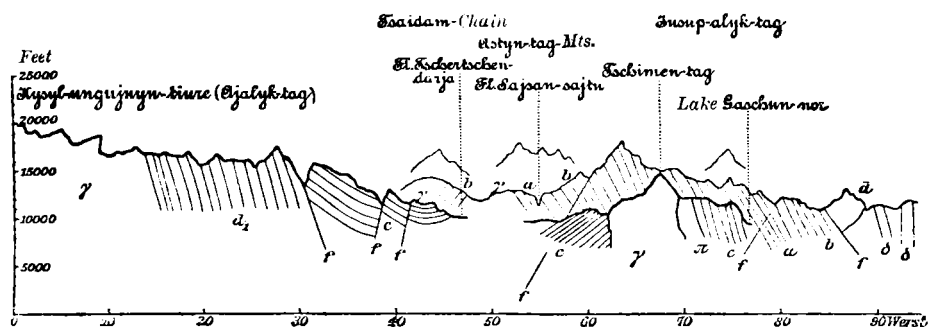


FIG. 11. *The Valley of the Winds.* (After Bogdanowitsch.)

a, b Gneiss and crystalline schists; *γ* granite; *δ* diabase, diorite, &c.; *π* porphyry;
d, d₁ Devonian; *c* Carboniferous; *f, f* faults.

region of lake Kum-kul is closed towards the north by an arcuate barrier.

One of the sections, drawn by Bogdanowitsch through the western Kuen-luen, crosses the valley of the Winds. Here the first and most northerly chain, the Altyn-tag, is formed of Devonian with intruded granite bosses, precisely like the Russian chain in the south-west. The second chain, the Yussup-alyk-tag, associated with Tshiman-tag, is a great range of gneiss. The valley of the Winds corresponds to a Carboniferous syncline. As the section is continued, a little further west, towards the south it meets first the opposite limb of the Carboniferous syncline, next steeply inclined Devonian, and then the great granite mountain of Kysyk-ungu-jun-tjure, with Devonian again on the further side. Beyond this mountain rises the Ajalik-tag, where Bogdanowitsch found middle Devonian corals at a great height, and then the range sinks to the basin of the Ajag-kum-kul, which

pp. 69-76; and C. Diener in *Peterm. Mitth.*, 1889, p. 34 et seq., map by C. Schmidt; and Bogdanowitsch, *Mitth. Geogr. Ges. Wien*, 1895, pp. 516-574.

lies at a height of 13,000 feet. Beyond this broad plain rises the lofty Prjewalski range (Akka-tag) trending east and west ¹.

Just as the Tshou-ma-er and Sua-dintse are a repetition of the space within the Pestrja Grjada, so the region south of the Da-sjue-shan, in the midst of which rises the Ye-ma-shan, is a repetition of the Tshou-ma-er and the Sua-dintse; the Syrtyn, lying within the arc of the Humboldt range, is a repetition of the Sua-dintse; the Tsaidam repeats the Syrtyn, and the elevated basin of lake Kum-kul repeats the Tsaidam.

As the western Kuen-luen and the Nan-shan become more remote from one another towards the south, so these interspaces advance further and further towards the south-west, and at the same time the arcs become less pronounced. The vertex of the arc of the Lun-shan lies between lat. 98° and 99° E., that of south Tsaidam between lat. 89° and 90° E., in the Prjewalski chain the arc is but slightly curved.

Many chains of the Nan-shan, such as the Tolai-shan, Ritter and north Tsaidam, do not reach the bend to the western Kuen-luen. But all these chains, trending to the north-west or west-north-west, belong to the Nan-shan and not to the western Kuen-luen. The chains of this range trend towards the border of the basin of the Yarkand-Darya and to the Mus-tag-ata, those of the Nan-shan to the east-south-east.

Every chain of the Nan-shan which approaches within a certain distance of the border of the depression of the Yarkand-Darya is deflected into the direction of the arc of the western Kuen-luen and becomes a part of this range. Bogdanowitsch speaks, not unfittingly, of the 'drawn-in ends' of certain chains of the western Nan-shan.

The relation of the two ranges to each other resembles that already described in the case of the ranges which meet on the Jhelam (I, p. 443, Pl. IV). There certain folds pass over from the region of the Himálaya into that of the Iranian chains, and a re-entrant angle marks the line of encounter between the two directions of movement; it is the same here, and the chief difference lies in the fact that the western part of these mountains is less developed, and that, owing to the divergence of the two parts, the syntaxis flattens out more rapidly towards the south.

To one accustomed to consider the continuity of the folds as the basis of classification, it would certainly seem unnatural to assign the two halves of a continuous folded range, such as the Anembar-ula and Humboldt mountains, to mountain groups so different from one another as the western Kuen-luen and Nan-shan; but this continuity only indicates a certain common dependence in the formation of the folds. Bogdanowitsch thinks it probable that the folding was contemporaneous in the two ranges. This

¹ Bogdanowitsch, Geological investigations in east Turkestan (Works of the expedition to Tibet directed by M. W. Piewtzow, II), publ. by the Imp. ross. Geogr. Obsch., 1892, 4to, pl. IV.

is certainly true of the most recent movements, but there are traces of a more profound influence exerted by the Kuen-luen which are not yet completely understood. Lóczy has already referred to 'directions of strike crossing each other lattice-like in the Nan-shan'¹; in this connexion, according to Obrutschew, should be mentioned the crook or sharp sigmoidal flexure in the Peak of the Bend of the Da-sjue-shan; as well as the divergent structure of the Ye-ma-shan, and of other chains remote from the region of syntaxis; in the Tolai-shan, for example, where in the midst of the Nan-shan the east-north-east or north-east direction of the western Kuen-luen makes an unexpected appearance. One very striking example given by Obrutschew is afforded by the region of the Da-khe in the Richthofen mountains, where supra-Carboniferous sandstone, with a north-west strike (290° to 305°) and steep dip to the south-west, makes an elbow-like bend into a north-east strike (40°) and steep dip to the north-west, and then returns soon after to its original strike and dip². This is a sigmoidal twist, in which the dip varies with the strike. In another case, in the eastern Richthofen range, deflexions from west-north-west to due west and north-east appear to occur in ancient Palaeozoic beds, but do not affect the supra-Carboniferous sandstone.

Let us now pass the facts in review.

All the mountain chains dealt with in this chapter fall into two groups. The first of these trends between west-north-west and north-west; the second, east-north-east. In many cases they are conjoined in arcs.

The first group includes the Lun-shan, and all the chains of the Nan-shan, with the exception of the Ye-ma-shan, next the south Tsaidam, Marco Polo, and others.

The second group includes the San-sjan-tsy, the gneiss chain of Tsha-tien with the Pestraja Grjada, the Shi-bao-shan, Ye-ma-shan, Anembar-ula, Altyn-tag, Tshimen-tag; further, the Dimnalik, Tokusdawan, Russian chain, and others.

The first group is connected by its disposition and direction with the Thian-shan and the Bei-shan.

The second group must be included in the western Kuen-luen, and forms part of the girdle around the basin of the Yarkand-darya.

The Altitudes. Directing our attention to any single mountain chain, such as the Caucasus, Carpathians, Pyrenees, or Appalachians, we may inquire whether its structure is symmetrical or asymmetrical, on which side its foreland lies, whether it is divided into several coulisses, and so on. But the several ranges of the ancient vertex do not lend themselves to such an inquiry. They owe their outer form, as well as their internal

¹ Lóczy, Die wissenschaftlichen Ergebnisse der Reise . . . in Ostasien, p. 662.

² Obrutschew, Central Asia, II, pp. 145 and 163. The place lies on the brook Kammenistoi, east of the meridian of Su-tshou.

structure, to a very general and extensive process of folding and subsequent disjunctive dislocation, and perhaps also in isolated cases to particularly long granite bands which reveal themselves in the relief of the country. In the east, as on the Gasimur, for example, where the discordant Devonian is folded, it is possible that posthumous folding may have taken place in addition.

As a rule the chains belonging to the first group provide us with long processes running with the strike, and the obstacles which have checked the development of the folds are obvious. But in the mountains of the vertex there is much less independence. There are signs of back-folding towards the amphitheatre, and we observe on a still larger scale the march of a common folding towards the exterior, namely towards the south-east, south and south-west.

The universality and the persistence of the folding movement are revealed not only by the horseshoe-shaped folds of the Angara series in the centre of the ancient vertex; the same feature is repeated in Minuzinsk; but even outside the vertex, in the basin of the upper Amur and in Manchuria, the plains themselves lying between the mountain chains everywhere present more or less obvious traces of folding. Such traces are to be met with extending upwards even as far as the Gobi deposits.

With so extensive a movement it only remains, in tracing out the trend-lines, to discover the region where this general movement originated. I use the term region because, little as we know of the detailed structure of the ancient vertex, yet it is now quite evident that the movement issued neither from a point nor from a straight line, but in all probability from a region bounded by an arc convex towards the south, such as would connect the directions of the Baikal and the Sayan.

But there exist in the interior of Asia other mountain chains, rising high into the region of eternal snow, which are more recent than the ancient vertex and different in direction. They are sometimes so closely crowded together that the bottoms of the valleys maintain over long distances an absolute height of 4,000 meters or even more, and they present stupendous and general elevations above which the relative height of the snow-peaks is comparatively trifling. The central Kuen-luen affords an example of this structure. But wherever these mighty mountain masses are cut into by deep transverse valleys, as between Min-tshou and the 'Red Basin,' we only observe crowded folds; and if the whole of the central Kuen-luen were worn down to the level of the sea, it would present on the whole an appearance similar to that of the ancient vertex, that is a great number of parallel folds, interrupted here and there by the enlarged base of a granite mass. It is the same with the eastern Gobi; this also is a sea of more or less denuded folds.

In these systems of crowded folds the separate chains do not possess

the same degree of individuality as is observed in the Caucasus and similar chains; and thus it happens, as in the Nan-shan, for example, that we find, one after another, chains formed sometimes of gneiss, sometimes of sedimentary formations, the Carboniferous in particular; this is intelligible, directly we regard these chains as waves belonging to a common movement; but considered separately, their diverse composition becomes incomprehensible. This unity of the movement accounts for the absence, within the chains, of a contrast, such as occurs in the Alps and the Himálaya, with an alien foreland of different structure. It is the difference which exists between the waves of the open sea and the breakers on the shore.

In a remarkable lecture delivered on the 3rd May, 1886, Tscherski made known his views on the structure of Inner Asia, views which were far in advance of the theories of his time ¹.

When he had fully recognized the convergence of the folded ranges of the Baikal and the Sayan towards the region of the southern Baikal, and had obtained a clear idea of the arc formed by these vast mountain tracts, he came to the conclusion that the western limit of this arc was to be found in about lat. 54° N., on the upper Kan, that is at the boundary between the east and west Sayan. From here onwards we again meet with a dominant direction opposed to that of the Sayan, or to the west-south-west and south-west. This direction is followed not only by the west Sayan but also by the western Altai almost down to lat. 50° N., especially by the Kusnetzki Alatau and Salaïr. On the Bukhtarma and on the Irtish, towards Semipalatinsk, the direction turns again to the west-north-west.

In a later passage Tscherski appears to distinguish not two, but three arcs concave to the north, namely the Baikal arc, the Sayan arc (by which we must understand west Sayan), and the arc of Altai.

Tscherski's keen glance penetrated yet further. He had heard of the recently discovered evidence that the chains of the Thian-shan are continued towards Europe, and he at once recognized that the Tarbagatai, Boro-Khoro, and all the other long ranges of the Thian-shan, follow the direction of the mountains on the Irtish. 'It would thus seem,' Tscherski adds in a note, 'as though the folding forces, *shifting gradually from east to west*, had successively affected increasingly younger deposits.'

We certainly perceive that towards the exterior, and consequently also towards the west, more and more recent marine deposits take part in the structure of the Eurasiatic folds. Correspondingly we recognize towards the interior indications of great antiquity. The folds of Archaean gneiss

¹ J. D. Tscherski, On the tectonics of the mountainous country forming part of the north-western region of central Asia, Trav. Soc. Nat. Saint-Pétersb., 1886, XVII, Heft 2, pp. 51-58.

on lake Baikal were formed and denuded in pre-Cambrian times, and towards the west the ancient vertex has arrested, like a horst, or, to use Tscherski's expression, like 'an immovable wall,' the further development of the eastern branches of the Altai. But that did not prevent the formation of posthumous folds within the space bounded by the pre-Cambrian folds and their ancient fracture, nor the plication, far out on the Gasimur and near to Urga, of the unconformable Devonian sediments, and some perhaps even still younger, which are thrown into great folds parallel to the ancient vertex.

In considering the relative age of these great unities of the earth's crust we will therefore use the terms 'old' or 'young' almost in the sense they bear when we compare the age of living persons.

Directly we adopt this point of view it becomes *more important to know when these various tectonic movements have commenced than when they have come to a close*. Considered thus, the displacement towards the west, conjectured by Tscherski, has actually taken place.

The hypothetical axis of the constriction of the Archaean folds within the overfolded syncline of Olkhon lies in the Primorskii Khrebet, near Buguldejka, and nearly coincides with the meridian of 106° .

The constriction of the posthumous folds of the Angara series within the amphitheatre may be said to coincide approximately with the meridian of 101° .

The bend of the horseshoe-shaped Devonian folds of Minuzinsk, on the Yenisei below the Tuba, follows the meridian of 91° .

If we include the bend of the Altai in the Bielukha in this comparison, then the centre of this bend is approximately marked by the meridian of 87° .

The Altai rises west of the ancient Baikalian vertex and of the intermediate region of Minuzinsk, as an independent and younger vertex. Towards the east and south its development has been checked. The most important of its eastern branches, the Kusnetzkii Alatau, probably proceeds from the region north of the upper Katunj: it passes lake Teletzk on the east and, describing a very gentle arc, reaches the plain east of the town of Tomsk. It is probable that south-east of this branch come other branches, slightly divergent from one another, which extend to the Saksar and the Izych, near the town of Minuzinsk. This quite exterior region of the Altai describes an arc to the south. In the middle of this arc stand the highest peaks. The western part presents on the Irtish a north-west strike, *but it is not possible to assign a boundary on the south-west to the younger vertex.*

In order to obtain an approximate idea of the configuration which is thus developed, let us imagine the whole of that part of Asia which lies to the south-west to be covered with water. Let an impulse originate from

the Irtish or the Tarbagatai and let us follow its effects towards the north-west. Numerous long mountain waves arise one behind the other ; at first they are more or less convex towards the south-west, as in the branches of the Thian-shan. They broaden out and elongate, or diverge from one another, where they find room enough, as on the Tchu and the Ili. They crowd together and rise, towering up, where the space grows narrower, as in the Nan-shan. Sometimes they sweep past obstacles, stiff and straight, as in the Tsin-ling-shan, continually seeking a lateral prolongation ; sometimes, on the contrary, they are impeded by these obstacles, bent and turned aside. At first the universally predominant direction is to the north-west or west-north-west. It is these folds or waves that we group together as the *Altaides*.

In Europe folded ranges have collapsed, and within the outer frame of horsts new folded ranges have arisen. In Asia we witness similar events, though on this continent it is not peripheral chains which collapse, but parts of an ancient vertex.

We will now inquire into the further effects of these processes.

CHAPTER VI

THE EASTERN ALTAIDES ¹

Ordos. The mountains on the Hoang-ho. Khar-narin-ula and Ala-shan. Bifurcation of eastern Nan-shan. Summary. Middle and eastern Kuen-luen. Separation of the Burman and Yunnan chains. Western branch. Mandalay. Mass of Cambodge. Southern branch. The Red River. Summary. The Malay Peninsula. Banda arc. Supposed fragments of New Guinea. Borneo. Celebes. Halmahera. Survey of the eastern Altaides.

FERDINAND VON RICHTHOFEN has shown that throughout the whole of northern China, from the lava-fields of Mongolia to the valley of the Wei, and even as far as the Hoang-ho near Hsi-ngan-fu, undisturbed Cambrian sediments rest unconformably upon folded Archaean rocks (II, p. 185). This region also comprises Shan-tung and Lian-tung, and, so far as existing observations extend, Korea as well.

This feature is so remarkable that, in spite of the divergent strike, which prevails from the spring of Ikhe-ude to the south-east of Mongolia, the question might be raised whether the ancient vertex does not reappear in this region. To this question the answer is furnished by F. von Richthofen. To the east, in Shan-tung and Lian-tung, the strike of the most ancient granites and primitive gneisses is constantly north-north-west, and is therefore not one of the directions of the vertex. On the other hand, in the regions off north Tshili and north Shansi, lying near the Gobi, where the most ancient rocks are represented by hornblendic gneiss and chloritic gneiss, gentle folding prevails with a strike to the east-north-east ².

With regard to the latter region we may certainly ask whether the Baikal wing of the vertex does not actually extend into it. It is certain in any case that the Sinian mole represents a rigid element in the later development of the structure of Asia.

F. von Richthofen, however, has also ascertained the following facts:—the grill of Peking, formed chiefly of ancient rocks, terminates towards the west in an area of subsidence. The western end of the Hsi-tshou-shan, near Hsin-tshou, proves this clearly, and the general relations show that the facts must be similar in the case of the Wutai-shan and Nan-tou-shan.

The beds lie fairly flat, both those of the ancient Sinian stage, resting on gneiss, and those of the supra-Carboniferous sandstone. But wherever

¹ Revised by R. D. Oldham, Esq., late Superintendent of the Geological Survey of India.

² F. von Richthofen, China, II, p. 706 et passim.

the Sinian stage is preserved it occupies a higher level than the supra-Carboniferous sandstone.

'This arrangement may be explained on the supposition that the plateau (of the supra-Carboniferous or plateau sandstone) marks the commencement of a deeply subsided area terminating in a straight line along that part of the primitive continent which has remained in place. How far it extends to the west, and in what way the structure of the mountains is modified towards the region of Ordos, are questions which must be left unanswered'¹.

This was written in 1882; we now know that the whole of Ordos belongs to this sunken platform, and that the Hoang-ho, in the easterly section of its course marks, approximately, the border of this region, the general outline of which is almost rectangular.

The series superposed on the Archaean foundation of the Sinian mole consists, as we have previously pointed out, of marine Cambrian (Sinian) sediments, then of marine sediments of upper Carboniferous age, then of coal measures, and the very thick plateau sandstone, or supra-Carboni-

N. Valley of the Hsin-tshou

Hsi-tshou-shan

S

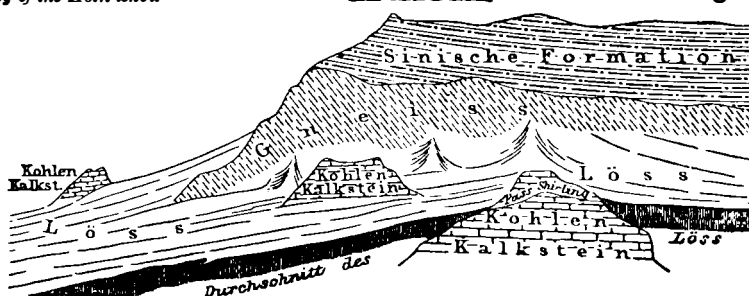


FIG. 12. West face of the Hsi-tshou-shan. (After F. v. Richthofen.)

ferous sandstone of Richthofen. With this we reach the period of those varied terrestrial floras which characterize the Angara series in Siberia, Mongolia, and Manchuria.

It is the younger members of this series which, as we have mentioned above, are to be seen let down near Hsin-tshou at the western end of the Hsi-tshou-shan. It is these also which form, further south, the tableland of Shansi (with the exception of the Ho-shan) and its step-like lines towards the east and south (II, p. 190). Towards the west, however, beyond that part of the Hoang-ho which flows to the south, this tableland slopes away gently through north Shansi and Kansu beneath the vast sheet of loess which extends from south Ordos towards the valley of the Wei.

Obrutschew has furnished detailed descriptions of Ordos. Stretching far and wide in the north are the sandy plains, and the sand is piled up

¹ F. von Richthofen, China, II, fig. 80, pp. 372, 390 et seq.

in vast masses on the north side of the Great Wall, south-east of Nin-sia-fu. South of the wall the loess spreads out over wide tracts towards the east; the supra-Carboniferous sandstone and the coal measures may still be traced beneath the mantle of loess and the gypsiferous deposits of the Gobi stage. The mountain ranges Lu-guan-lin and Bo-jui-shan which are marked on our maps have no existence, and towards the south the high plateaux of loess continually increase in breadth¹.

L. von Lóczy, who has travelled through the south of the country from Hsi-ngan-fu, i.e. from the south-east, in the direction of Lan-tshou, found the supra-Carboniferous sandstone and traces of Carboniferous underlying the loess. Near Ping-lean-fu he reached the ridge of *Lo-pan-shan* (long. 106° 45' E., lat. 35° 45' N.), 25 kilometers in breadth; it is an oblique syncline of intensely folded Carboniferous limestone and grey sandstone, with its axis dipping to the west. Elsewhere in Ordos the same rocks lie horizontal beneath the loess.

Somewhat west of the Lo-pan-shan, chloritic schists appear for the first time; they are again followed by loess for a distance of 280 kilometers, and then, a little to the south-east of the town of Lan-tshou, gneiss crops out in the rocky gorge of the Hoang-ho and strikes east-north-east (E. 30° N.)².

We may conclude, therefore, that a broad and level platform of supra-Carboniferous sandstone occupies the whole space within the bend of the Hoang-ho, extending to the Lo-pan-shan, where folding appears, and to the valley of the Wei. Measured in the meridian of 108° E., this gives more than seven degrees of latitude as the breadth of the platform.

The platform is not bounded merely by the bend of the river. Everywhere the Gobi lies higher than the Ordos, and the descent from one to the other is marked by a series of rocky chains, often steeply precipitous towards Ordos. These chains are mostly coulisses arranged one behind the other in echelon, and some of the coulisses cross over to the right bank of the Hoang-ho. To obtain a closer knowledge of them we will return to the north as far as the escarpment near Hsin-tshou, and then, turning to the north-north-west, we will proceed still further and cross the Mongolian frontier.

The mountains on the Hoang-ho. If, as we proceed from Peking to Kalgan, we abandon the road near Hsuen-hwa-fu to take a westerly course, and then follow the Yang-ho on the road to Kuku-Khoto, we shall reach

¹ Obrutschew, Orographical and geological sketch of central Mongolia, Ordos, east Kansu, and west Shansi, Izviestija Imp. ross. Geogr. Obsch., XXX, pp. 231-253; Central Asia, I, pp. 188-266.

² Lóczy, East Asia, p. 492 et seq. Subsequently Futterer crossed this isolated range; Futterer, Durch Asien, I. Geographische Charakter-Bilder, 8vo, Berlin, 1901, p. 471 et seq.

the edge of the basalt sheets of south Mongolia. We strike it near the Christian mission-station of Oerr-shi-san-hau, on the far side of the gneiss range of Kulu-shan, which runs to the north-east. From here onwards—more particularly from Kuku-khoto—long mountain ranges succeed each other, and border the north bank of the Hoang-ho up to its north-western bend. The most important accounts of these little-visited regions have been furnished by Armand David and Prjewalski¹.

A little west of Oerr-shi-san-hau (in about lat. 40° 47' N., long. 113° 18' E.) lies a sheet of water surrounded by lavas. David speaks of it as an 'etang'; Prjewalski names it 'Kirnor.' From amidst the lavas rises the chain of *Shara-khada*, probably so called from its yellow limestone. It runs to the south-west towards Kuku-khoto. Fifty kilometers further west follows the parallel chain of *Suma-khada*, higher than the preceding one, but, like it, rocky only along its borders, and formed almost entirely of granite: its foot lies at a level of 1600–1700 meters. North of Kuku-Khoto extends a long narrow range, perhaps a continuation of the *Shara-khada*; as it approaches the Hoang-ho it turns from a south-west to a west-south-west direction. On many maps it bears the name of *In-shan*. According to Prjewalski, this name applies to the whole of the mountains which border the west-to-east course of the Hoang-ho. North of the town of Bautu it runs like a high, steep wall along the Hoang-ho. David calls this range the Ouratau. It was crossed by this enterprising explorer as he travelled from Sertshi (a little east of Bautu) towards the north. After traversing a ridge of granite and porphyry he reached a fairly broad zone of coal measures and sandstone; beyond Tshe-kuen he crossed successively the gneiss and granite range of Ou-than-djo, the high plain of Ou-teuini-gol, the gneiss range Tshangini-ula (which runs parallel with the Ouratau), the arid plain of Mao-min-ngan; and once again a range of gneiss. After this fashion is the mountain land north of the Hoang-ho broken up along parallel lines².

The *In-shan* (Ouratau) after a course of 250 kilometers ends suddenly, according to Prjewalski, in the rocky range of Muni-ula (Wula-shan of Rockhill), which appears to present the same characters. The most westerly parts of the *In-shan*, Syrun-bulyk, and Muni-ula consist of granite, gneiss, granulite, and hornblende rocks, together with porphyry and comparatively recent eruptive rocks. Muni-ula attains a height of more than 8,000 feet;

¹ P. Armand David, *Journal d'un Voyage en Mongolie, fait en 1866*, *Nouv. Arch. Mus. Hist. nat.*, Paris, 1867, III^e Bullet., pp. 18–96, and 1868, IV^e Bullet., pp. 1–83, maps; N. von Prjewalski, *Reisen in der Mongolei, im Gebiete der Tungusen und den Wüsten Nord-Tibet's*, German trans. by A. Kohn, 8vo, Jena, 1877, pp. 120, 134, 217 et passim.

² On the other side of the last gneiss range mentioned above David marks in vol. IV, pl. 2 (*Journal d'un Voyage en Mongolie, &c.*), a broad plain with two bitter lakes, and a more remote granite chain to the north of these.

it forms a sharply defined strip 100 kilometers in length and about 25 kilometers in breadth, and terminates on the west just north of the Hoang-ho (long. $108^{\circ} 30' E.$). Its aspect is wild and alpine.

The oblique coulisse-like arrangement of the chains begins to be noticeable from the Kuku-khoto onwards, the eastern end of each chain overlapping the western end of the one lying next to it on the north; but as we proceed from the point we have now reached this arrangement becomes still more clearly pronounced.

On the north side of the western In-shan lies the short range of Shok-hoin-daban, i. e. limestone mountains, and north of this the Sheiten-ula forms another coulisse with a direction curving from west-south-west to east and west. Here begins the range of the 'Black mountains,' *Khara-narin-ula*, 370 kilometers in length; it curves from a west-south-west to a south-west direction, forming a vast arc, the concave side of which encircles the whole of the north-western elbow of the Hoang-ho. Prjewalski was acquainted with the steep descent of these mountains to the Hoang-ho and with their Archaean rocks; but here, as in so many other cases, Obrutschew's observations furnish a new and very peculiar representation of the facts¹.

The mission station of San-to-khu, on the banks of the Hoang-ho, lies at a height of 875 meters. A very broad alluvial plain, traversed by abandoned arms of the great river, separates it from the foot of the mountains (930 meters). The relative height of the *Khara-narin-ula* amounts here to 1,000 or 1,200 meters only; near by the chain is cut across by a long ravine, Gyr-obo-khundy, with a pass at a height of 1,580 meters. The mountains show gneiss and granite, ancient schists, and crystalline limestone; but the strike of these rocks is north-north-east, and thus does not correspond with the trend of the mountain arc. As a consequence, the chain is divided into a large number of ranges, crowded together, some of which, formed of granite and gneiss, possess rounded outlines, while others, formed of schist, weather into sharp peaks. Ravines running with the strike cut obliquely into the range, and the most important of these is the Gyr-obo-khundy.

The notion, therefore, that there is a single drop from the Gobi towards the Ala-shan along the line of the Hoang-ho does not correspond with the facts. On the other hand, the formation in oblique coulisses of the In-shan and other chains north of the Hoang-ho is probably continued into the *Khara-narin-ula*, and shows that this part of the Gobi has undergone a folding movement, directed obliquely against the border of the Ordos plateau; and to this the coulisses are due.

¹ Obrutschew, *Izviestija Imp. ross. Geogr. Obsch.*, 1894, XXX, pp. 239, 243; *Central Asia*, II, pp. 434-476.

This conjecture is confirmed as soon as we pass beyond the Khara-narin-ula to those parts of the Gobi which lie towards the north-west. All this region stretching far away up to the outrunners of the Gobi-Altai is a folded land. Obrutschew has accomplished the journey across the Khara-narin-ula to the north-west, but it is impossible to enumerate all the ranges which he crossed. Starting from the north-west side of the Khara-narin-ula, Archaean rocks prevail for about 90 versts to the north-west, and the mountains diminish in height, declining from 1,400 to 1,000 meters. Then comes a low-lying strip of desert (760 meters) running to the north-east, and thereupon porphyry, limestone, and supra-Carboniferous sandstone assume a larger share in the composition of the denuded folds. The strike is now east and west, and locally even west-north-west. The Mount Dsokhe (1,700 meters) shows intrusions of syenite; it is followed by many hills of porphyry; not far beyond these lies the Khurku, and the eastern end of the Gobi-Altai is reached¹.

The difference between the Gobi and Ordos could not be more complete. The contrast between the Alps and their foreland, of which, so far, the Altaides, regarded as folds of the vertex, have shown no sign, now makes its appearance. *We have reached the sharply defined border of the Altaides and their encounter with the foreland.*

The Khara-narin-ula is continued in the long ridge of Argalintai directed to the south-west. It departs further and further from the river, and, according to the earlier descriptions, was supposed to terminate at about lat. 38° 30' N. in the desert of Ala-shan. This, however, is not the case. Much further to the south-west, Kasnokow encountered the long ridge of Burguste-ula, which drops steeply in places, precipitously towards the south². Still further to the south-west rise the *Gori Yavarai*, which were crossed by Koslow. They are 100 versts long and 15 versts broad; the pass of Oboto-daban lies at a height of 5,400 feet. Its south side, says Koslow, presents chasms, separating mountains with steeply broken off sides arranged in a linear series. This recalls the structure of the principal chain³.

Thus the prolongations of the Khara-narin-ula extend far into the desert, almost in the direction of Kan-su and approaching to within 120 versts of this town.

As the Khara-narin-ula recedes from the Hoang-ho, new coulisses insert themselves in the interval.

On the right side of the river a long range of chains running to

¹ Obrutschew, *Central Asia*, II, p. 434; at Zalagai, *Palaeozoic corals*, p. 447.

² A. N. Kasnakow, Preliminary report on the journey across the desert of Gobi from the temple of Dsurachai-Dazan to that of Tshortynton (in Kansu), *Izviestija Imp. ross. geogr. Obsch.*, 1900, XXXVI, pp. 153-169, map, in particular p. 165.

³ Koslow, Report on the expedition, &c., *Izviestija Imp. ross. Geogr. Obsch.*, 1900, XXXV, p. 144.

the south rises in about lat. $40^{\circ} 15' N.$; in its northern part it is called *Arbis-ula*, and under various names (Oran-teshi, Kantageri, and others) it reaches Khara-khoto (lat. $39^{\circ} 15' N.$) ; but as it sinks lower, disappearing at last beneath the plain, the northern extremity of the lofty *Ala-shan* range, also directed to the south, makes its appearance on the left bank of the river.

The town of Nin-sia-fu on the Hoang-ho (lat. $38^{\circ} 30' N.$) lies at a height of 1,030 meters ; to the west of it the steep peaks of the *Ala-shan* mountains rise to a height of over 3,000 meters ; on the west flank of the mountains lie the sands of *Ala-shan* at a height of 1350–1500 meters.

In this region, opposite Nin-sia-fu, the chain is formed of two ranges, one on the north, which bears more to the east, and one on the south, which joins the other on the west. Where these two meet is a pass (2,540 meters) which leads to Fu-ma-fu, in the desert. Obrutschew ascended this pass and made the unexpected discovery that the whole southern range is an anticline of supra-Carboniferous sandstone, coal measures, and Carboniferous limestone, overturned towards the east, i. e. towards the Hoang-ho. The thickness of the beds no doubt exceeds 3,000 meters ; on the east side the whole series is inverted, on the west side it is normal. The masses of Sinian limestone which form the *débris* of the higher peaks lead us to suppose that an overthrust occurs near their summits, carrying the limestone over the coal measures¹.

Prjewalski ascended the summit of Bugutui (3,300 meters), which lies more to the south, and came on quartz-conglomerate².

We now approach another bend of the Hoang-ho between lats. 38° and $37^{\circ} 30' N.$ Although the river cuts through the north end of the Nju-tou-shan range a little south of lat. $38^{\circ} N.$, yet once more the bend is, on the whole, determined by the structure of the accompanying ranges. For data on this region we must rely almost entirely on Obrutschew's observations.

Near Nin-sia-fu, the mountain range of *Arshan-ula* begins on the right side of the Hoang-ho. It is probably an anticline of Sinian limestone partly converted into flow-breccia. In the above-mentioned range of Nju-tou-shan, which follows further up the river, the trend is south-south-west, and corresponds with the change in direction of the river.

Still more remarkable are the features on the left bank. Towards the south the *Ala-shan* mountains meet the broad and less lofty range of *Ye-tou-shan*, which Obrutschew describes as a horst ; it is bounded on the south by an almost east-and-west fracture, along which the range of *Nju-shai-shan* appears to be let down. Both this and the preceding range

¹ Obrutschew, *Central Asia*, I, p. 309 et seq., in particular p. 326, map.

² Prjewalski, *Reisen in der Mongolei*, 1877, &c., p. 232.

show beds dipping to the north of north-west; the general direction of the Nju-sha-shan is south-west; it consists of supra-Carboniferous sandstone. The latter also appears in isolated exposures on the Hoang-ho itself, which here flows nearly from east to west¹.

On the north side of the river the south slope of the Ye-tou-shan, and its apparently downthrown foot-hills, stretch far away to the west. Below Tshung-wei, near the river, we see an anticline with a strike to south-south-west (210°). This completes the bend.

Rockhill relates that he travelled still further to the west, as far as In-pan-shui (about long. 104° E.), along the south side of a range of hills called *Hsi-shan*, about 800 feet (relative) in height; coal occurs here, and red sandstone². South of this region lies the long range of *Da-tso-bei-shan* stretching to the west-south-west, with beds of supra-Carboniferous sandstone, dipping uniformly to the south-south-east.

Additional light may be obtained when the subject is studied in closer detail, but in any case it is certain that the broad bend which the Hoang-ho describes between lat. 37° 30' and 38° N. corresponds to a deflexion of the chain and of the coulisses bordering the river.

Lóczy had already conjectured that this bending round of the mountain ranges on the Hoang-ho stands in some relation to the eastern terminations of the Nan-shan, and Obrutschew believes that the two chains unite beneath the sands of Ala-shan. Indeed, a closer examination of the eastern Nan-shan renders it impossible to reject this view.

In the northern ranges of the eastern Nan-shan Palaeozoic deposits of great thickness are dominant, while the southern ranges consist chiefly of gneiss and ancient schistose rocks. On the north border of the Richthofen mountains a zone of melaphyre occurs in the meridian of the Kuku-nor³. On the line between Lan-tshou and Ljan-tshou, between lats. 36° 30' and 37° 30' N., two of the northern chains advance far to the east, covered with snow. The most northerly of these, the Mo-mo-shan, situated in the continuation of the Richthofen range, undergoes a slight diminution in height as it proceeds to the east, and then finds its further continuation in the lofty Shi-tshotse-shan. The next range which follows on the south is the Shi-shan; Obrutschew named its eastern continuation the Pin-fan-shan.

¹ Obrutschew, *Central Asia*, I, p. 337, fig. 88.

² W. Woodville Rockhill, *Diary of a Journey through Mongolia and Thibet*, 8vo, Washington (Smithsonian Institution), 1894, pp. 40, 45.

³ Somewhat further west, in the region of the Khyl-khe, at a locality which would correspond to the middle of the south side of the Richthofen range, Potanin long ago discovered lower Carboniferous fossils; P. Wenzukow, *The fauna of the lower Carboniferous of the river Bardun in south Mongolia*, *Verh. russ. k. min. Ges.*, 1889, 2nd ser., XXV, pp. 210-227.

In this way the Nan-shan advances eastwards across the meridian of Lan-tshou. At the same time the direction begins to bend towards the Ala-shan. The Mo-mo-shan, it is true, comes hither from the Nan-shan, with the prevailing east-south-east direction, but towards the east end of Shi-tshotse-shan, and especially close to the coal pits of the Ta-la-pu, the general direction has turned to the east-north-east. Here, however, we are already on the meridian of Rockhill's Hsi-shan, mentioned above, and close to that of the Da-tso-bei-shan¹.

The direction to the north-east or east-north-east is indeed visible even in the midst of the eastern Nan-shan, particularly in the Archaean rocks, which form the cliffs on the banks of the river Si-nin down to the mouth of the Da-tun². But we do not see any continuation of this direction in the adjacent chains; they follow the general strike to the west-north-west. It is not till we go far to the east, and enter the gorge of the Hoang-ho, below Lan-tshou, that we again encounter gneiss with a north-east strike. Whether or not this locality corresponds to a deflected continuation of the Potanin-Amasurgu range of the Nan-shan system must be left to later investigations to decide.

The south Kuku-nor chain, consisting of Archaean rocks, is one of the mightiest ranges of the Nan-shan, but towards the south-east it sinks rapidly to a trifling height. The Gobi deposits, which in the valley of the Si-nin, as in that of the Hoang-ho, are very thick and of wide extent, rest against the south side of the south Kuku-nor; they lie flat at its foot, but further up the slopes attain a steep inclination (70°–80°). They prove once again the existence of movements at a recent period³.

South of the town of Lan-tshou there rises, according to Obrutschew's account, the range of Guan-shan, which consists of Carboniferous and supra-Carboniferous sandstone. (Pass at a height of 2,690 meters.) The strike is variable, and, indeed, as often west-north-west as north-east. Beyond the Guan-shan, however, a broad plateau of Gobi beds, more than 60 versts across, extends to the south of the town of Di-dao and up to the foot of the Tshan-fan-shan mountains. It is more than 2,000 meters high; the river Tao and its tributaries have sunk their beds in it. Obrutschew considers the Tshan-fan-shan as the first of that group of chains which

¹ Obrutschew, *Central Asia*, I, p. 359 et seq., for Shi-tshotse-shan; on p. 364, an arc open to the north described by the strike of these beds is indicated south of Ta-la-pu, which possibly marks exactly the position of the bend; p. 418 et seq., for a section of the Pin-fan-shan; it consists (p. 400) of metamorphic schist, augite porphyry, and tuffs, and is only separated from the Shi-shan by erosion.

² Lóczy, *Die wissenschaftlichen Ergebnisse der Reise des Grafen Bela Széchenyi in Ostasien*, I, pp. 582 et seq., 605 et seq., 645; for the relations between the Potanin mountains and the Kuku-nor see the little map on p. 603.

³ Obrutschew, *Central Asia, North China and Nan-shan*, II, p. 97.

proceeds towards the Tsin-ling-shan¹. In any case, we have now reached a point south of the north-eastern deflexions to the Ala-shan. Possibly the plateau of Di-dao is continued towards the west into the plateau south-west of Bale-kun-gomi, which is bounded by the Koko-beili; but it does not extend further in that direction.

In all probability this plateau marks the bifurcation of the chains of the Nan-shan, that is, the separation of those folds which are arrested by the border of Ordos from those which maintain their direction undisturbed.

Summary.—Ordos has disclosed itself as a plateau of the foreland; the Gobi of the Ala-shan, on the other hand, as a part of the folded region of the Altaides: the Hoang-ho, in its course from south to north and then from west to east, thus occupies a position similar to that of the Guadalquivir in front of the Betic cordillera, or the Ganges in front of the Himálaya. The isolated coulisses, such as the Arbis-ula, which occur on the right side of the river, recall those fragments of Persian foot-hills which crop out at Rôri and Hyderabad, on the left side of the Indus.

To the north-west and the west of this elbow of the Hoang-ho we may recognize, then, concordantly with what those explorers best acquainted with the country have supposed, an arcuate structure which belongs, indeed, to the Altaides, but in which the distinction between the ancient and more recent vertex disappears in a peculiar manner, or, in other words, in which the Sayanides and Altaides merge into one another.

Starting in the west from the Adji-bogdo of the Gobi-Altai, and therefore from the ancient vertex, a long arc advances into the desert; it runs through Baga-bogdo, Kôkô-tymyrtý, and a number of bare ridges of rock, to Tostu and Noin-bogdo, thus crossing the whole desert.

South of this arc, in the Shjurten-kholy-gobi, we ought to see the coulisses of the Thian-shan; but they have dwindled away in the form of a wedge, along with the Karlyk-tag and Emir-tag.

In consequence of this disappearance the Bei-shan attains, on the whole, the east and west direction; but its northern branches show, on the Edsin-gol, the characteristic bend to the east-north-east and north-east; it is seen, for instance, in the Boro-ola, which crosses the Edsin-gol to become the Kôkô-ula, and in like manner in the Edsin-ula.

Now a long range advances from the north-east into the desert. It comes from the elbow of the Hoang-ho itself, that is, from the spot where the crowding of the folds is at a maximum. It is composed of the coulisses of Khara-narin-ula, the Argalintai, the Burguste-ula, and the mountains of Yavarai; it runs in the direction of the town of Kansu.

Next the mighty chains of the Nan-shan approach from the west. The most northerly of these equally adapt themselves to the great system, and

¹ Obrutschew, *Central Asia, North China and Nan-shan*, II, pp. 352, 357.

accomplish the same bend as the northern chains of the Bei-shan, though somewhat further to the east, on the other side of the meridian of Ljan-tshou. The first bend is effected in the line of the Richthofen—Mo-mo-shan—Shi-tshotse-shan mountains, on to the coal pits of Ta-la-pu; the second bend in the Shi-shan and Pin-fan-shan.

It is impossible to say precisely how far this inflexion of the folds towards Ordos extends to the south; possibly indications of it may still be observed in the gneiss of the Hoang-ho valley near Lan-tshou. But while on the east these chains have been bent back, on the west they remain closely crowded, and from the termination of the inflexion they pursue their course undisturbed to the west-north-west. This is also true of the chains south of the plateau of Di-dao, which probably marks the bifurcation.

Thus the whole of the central Gobi, together with the desert of Ala-shan, may be regarded as the site of a system of folds, dammed up to the east against the foreland of Ordos; continued towards the south in the homologous folds of the central Kuen-luen; extending far towards the west, up to the syntaxis of the western Nan-shan with the Altyn-tag and Anembar-ula, and opening out towards the north-west beyond the Shjurten-kholy-gobi to make way for the vast virgation of the Thian-shan.

Let us now cast a glance over the coulisses on the Hoang-ho, from the Khara-narin-ula through the chains of In-shan down to the north-easterly trending Shara-khada, east of Kuku-khoto. As regards position and direction these chains seem to associate themselves harmoniously with the great ranges of the grill of Peking up to the Hōng-shan and beyond, where the Cambrian strata are disposed in a platform. They are bounded by lines resembling flexures, and their beds show a general dip towards the north-north-west, i. e. towards Mongolia. Richthofen has suggested that these lines are bent near Kai-ping and continued on the west side of the valley of Mukden; if this should prove to be the case then the resemblance would be yet greater, and there would be a transition to the direction of the Great Khingan. But I will not gainsay that comparison of these facts with what we know of the structure of the chains near the Hoang-ho raises the question whether we are dealing with true flexures produced by subsidence, or with lines of simple folding, as seems to be indicated by the prevailing dip of the beds to the north-north-west¹.

¹ F. von Richthofen, *Über Gestalt und Gliederung einer Grundlinie in der Morphologie Ost-Asiens*, Sitzb. k. preuss. Akad. Wiss., Berlin, 1900, XL, p. 17 et seq. The sections at Kalgan, which are known in great detail, afford no information on this point; the Chinese mountains are here much higher than in the Gobi, which lies at a height of about 1,400 meters, is deeply abraded and covered by more recent volcanic flows. The best definition of the word 'flexure' appears to me to be furnished by the expression employed by Heim, *Tafelabbiegung* (E. de Margerie et A. Heim, *Les Dislocations de l'écorce terrestre*, 8vo, Zürich, 1888, p. 26). Since the tendency to overthrust subsidences appears in many localities, as we have already shown by examples and will illustrate further on a later

The bearing of these observations is no less important as regards our interpretation of the structure of the Great Khingan.

The distance from Yehol in the south to the Argun in the north amounts to nine degrees of latitude. It is true that over the whole of this distance the country west of the Great Khingan is in general higher than that on the east.

Unfortunately there is a dearth of trustworthy accounts from the south. Fritsche, travelling to the north, crossed the watershed between the Lan-ho and Lian-ho (1,237 meters) in long. $117^{\circ} 52' E.$, lat. $41^{\circ} 48' N.$, and reached a series of parallel chains which run from north-north-west to south-south-east; then crossing the Barin-dao (1,230 meters), formed of three dome-like heights, he found himself at the end of the mountainous country through which he had travelled since leaving Peking, and in a region of plateau-like character. Here his map gives heights of 846 meters, 1,080 meters, 1,630 meters, 1,208 meters, and so on¹.

From Kalgan to Föng-ning-hien (long. $117^{\circ} 10' E.$; lat. $41^{\circ} 13' N.$, 604 meters) the direction of the mountains is mainly east-north-east, then rather north-north-east and north, and finally, in the south part of the Khingan proper, north-north-west. The observations of Fritsche accord fairly well with the hypothetical inflexion near Kai-ping mentioned above, but from this we can hardly conclude that the Great Khingan itself is a flexure. We know that it sometimes presents a steep scarp on its east side, but we also know that in the north it is certainly a very broad folded zone; that there even the Angara-beds in the neighbouring plain of the Amur are affected by posthumous folding; that the Gobi west of the great Khingan is a folded region; and that rhyolite and basalts occur on both sides of it, but, strange to say, do not enter the grill of Peking.

Thus the hypothesis most in harmony with the existing state of observation is that the Great Khingan is a folded range, similar to the Aldan

page, an *overthrust flexure* may easily be produced, and it is quite possible that it is precisely this local combination of subsidence and tangential movement which has given rise to some of the greatest overthrusts. The difficulties are due to the outward resemblance of the simple oblique fold resulting from tangential movement and the flexure produced by subsidence, and this is doubtless the origin of the objections raised by Bittner (Jahrb. k. k. geol. Reichsanst., 1887, XXXVII, pp. 404 et seq.). In this case the complicated processes which, according to Willis, should lead to an increased deflexion in the bend of the 'stepfold,' are entirely disregarded (U. S. Geol. Surv., XIII, Report, part II, p. 273). In the case of long lines of this kind succeeding each other uniformly, I should be inclined to decide in favour of a *flexure*, and therefore for a predominance of subsidence wherever the subsidences take place progressively in a given direction; and for *folding* where this progressive subsidence does not take place, and consequently the gentler inclination of the longer limb compensates for the steeper inclination of the shorter.

¹ H. Fritsche, Ein Beitrag zur Geographie und Lehre vom Erdmagnetismus Asien's und Europa's, Peterm. Mitth., 1885, Ergänzungsheft No. 78, maps, p. 10.

range and *Sikhota-Alin*, which are also bordered by downthrows—incomparably greater ones—on their east side, and follow a perfectly similar course.

The *Khara-narin-ula* and *Ala-shan* face the tableland of *Ordos*, and represent the dammed-back outer border of the *Altai*es. The *Great Khingan*, in front of which lies the equally folded land of *Manchuria*, may be regarded as the final expression of this folding, which, coming from the *Altai* and embracing the whole south of the ancient vertex, now manifests itself in the peripheral chains of the east.

Kuen-luen. This name, as *F. von Richthofen* has shown, appears in the book of *Yü-kung*, which dates from the twenty-third century before our aera. It claims the veneration due to age. But there is a difficulty in deciding where the mountainous country lay which was known to antiquity as the *Kuen-luen*. The majority of Chinese scholars, so *Richthofen* informs us, place the mountains of *Kuen-luen* in the region of the 'Sea of Stars,' near the sources of the *Hoang-ho*. To this we must conform¹.

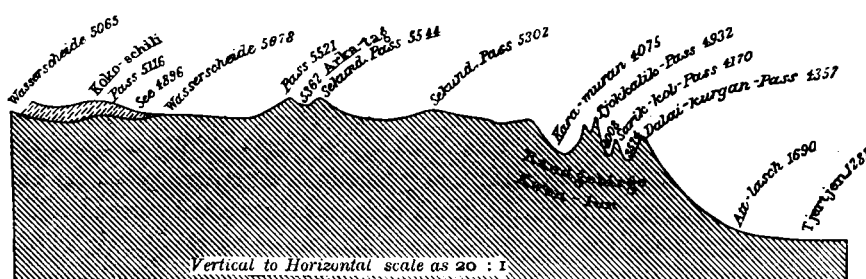
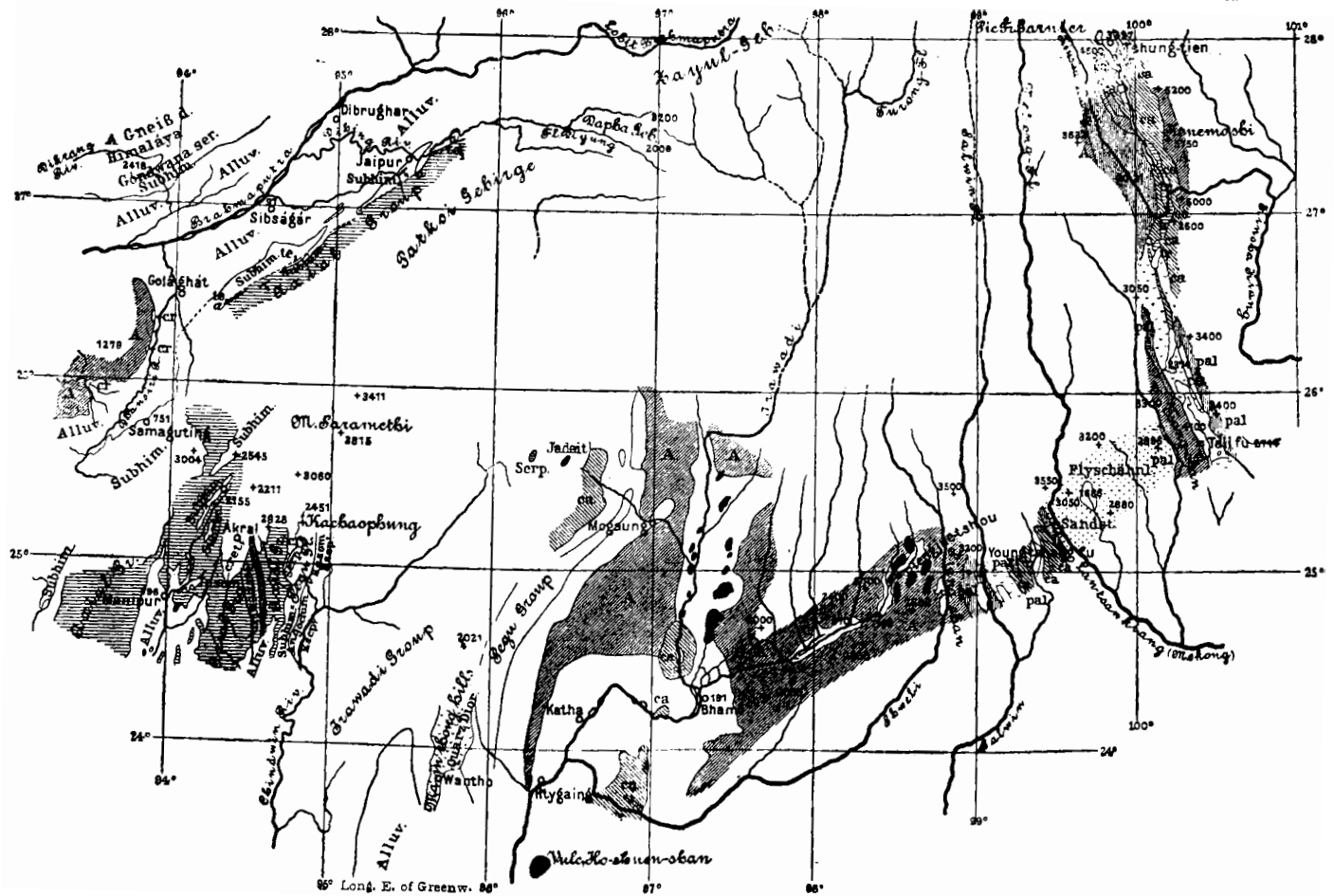


FIG. 13. Section from *Koko-shili* to the plain of the *Tjertjen-Darya*. (After *Sven-Hedin*.)
The part marked *Randgebirge Kwen-lun* corresponds with the arc of *Yarkand*.

Accordingly, there can be no doubt that the mighty chains extending far to the west-north-west and east-south-east across the meridian of the *Sea of Stars* from the *Arka-tag* (*Prjewalski* chain) to the *Tsin-ling-shan*, and termed by *F. von Richthofen* the middle and eastern *Kuen-luen*, have also a claim to this name. *Richthofen* places the western limit of the central *Kuen-luen* in about long. 89° E. Our present knowledge of the western part of the *Arka-tag* would lead us to shift the limit to 87° or $86^{\circ} 30'$. But as regards the range which lies west of $86^{\circ} 30'$ later observations seem to justify a different interpretation, which involves the separation of the western from the central *Kuen-luen*.

Bogdanowitsch has laid emphasis on the continuity of the arc-like frame which surrounds the basin of the *Yarkand-darya*. This arc extends from the *Mustag-ata* mountains in the north-west to the gneiss range of

¹ *F. von Richthofen*, *China*, I, p. 225 et seq.



The mountains between the Brahmaputra and Yang-tse-kiang

(After Medicott, Mallet, R. Oldham, Noetling, and Lóczy)

San-sjan-tsy, near An-si, in the north-east. In the absence of a special name we will designate it the western Kuen-luen or *Yarkand arc* ¹.

To the north-west this arc is broad and formed of several lofty ranges; its central part is high, but narrow, and cut through by transverse valleys; towards the north-east it breaks up into long and high overlapping coulisses between which the rivers find room to escape. These coulisses, especially the Altyn-tag, Anembar-ula, and San-sjan-tsy, maintain the east-north-east and north-east direction of the arc itself, and all the several chains of the Nan-shan are sharply deflected on meeting them, as has been stated previously. Thus, as we have said, spaces arise, such as the Syrtyn, Tsai-dam, and that of the lakes of Kum-kul; the angle of syntaxis becomes more obtuse, and almost vanishes as the Prjewalski chain finally attains a nearly rectilinear course. This lofty and imposing mass now reaches the south side of the arc in long. $86^{\circ} 30'$ E., and probably merges with it for a certain distance to form a single morphological whole. But an examination of the sections of Bogdanowitsch suffices to show that on the meridian of Kopa there is only one principal chain, the Russian chain or Akkar-tshelik-tag ².

We regard the Arka-tag or the Prjewalski chain as that part of the central Kuen-luen which advances furthest to the west (between long. 86° and 87° E.). It is characterized in a remarkable manner by the presence of recent volcanic rocks. The earliest trustworthy record is furnished by Dutreuil de Rhins, who obtained vesicular basaltic scoriae from the range of the Atchit-nor ³. Henri d'Orléans and Bonvalot mention volcanos and fields of scoriae at several places, but give no details. The same is true of Littledale's statements. On the other hand, Sven Hedin saw tuff and lava-flows close to the west end of the Arka-tag in lat. 86° , and at several places on the south side of this range. According to Bäckström,

¹ Richthofen has compared the Ta-pa-shan with the inflexion of the Dinaric arc against the south Alps; Bogdanowitsch cites as parallel the relations of the central Kuen-luen with the arc of Yarkand and the Ta-pa-shan, Mittl. k. k. geogr. Ges. Wien, 1895, XXXVIII, p. 518; cf. also Wegener, Entschleierung der unbekanntesten Theile von Tibet; Festschrift für Freiherrn von Richthofen, Berlin, 1893, p. 414. It is with reluctance that I employ the terms *Tarim* range and depression of the Tarim, since, according to Prjewalski, Tarim as the name of a river is altogether unknown to the inhabitants of the country. Tarim means tilled or arable land, and since the Chinese officials levy taxes according to the amount of water used in irrigation the term has been transferred to the river.

² In this connexion I should like to refer to the beautiful map by Hassenstein which accompanies Sven Hedin's report in Peterm. Mitth., Ergänzungsheft No. 131, 1900; cf. also M. Friedrichsen, Morphologie des Tien-shan, Zeitschr. Ges. f. Erdk. Berlin, 1889, XXXIV, 191 pp., map.

³ St. Meunier, Note géologique in J. L. Dutreuil de Rhins, Mission scientifique dans la Haute Asie, 1890-1895, 4to, Paris, 1898, III, p. 295. It is true that we have data concerning volcanos in the south of the Prjewalski chain, but proofs other than those based on the form of the mountains are wanting.

the rock from a locality in long. $87^{\circ} 30'$ E. is a bronzite andesite, and evidently recent¹.

Numerous chains, all running more or less to the east-south-east, join the Prjewalski chain, follow the south border of Tsaidam, and, bearing the names Sjan-si-bei, Ugutu, &c., reach the Hoang-ho south of the plateau of Balekun-gomi. Prjewalski was aware that the chain of Djupar, east of the Hoang-ho, must be regarded as their continuation. Futterer journeyed from the range of south Kuku-nor across the Dabasun-Gobi and those eastern parts of the coulisses of the north Tsaidam which Obrutschew calls the Semenow range, and then southwards to the Hoang-ho. He found that the Semenow range, like the other coulisses, consists of ancient rocks, in front of which lies Carboniferous, and that it is continued in an east-south-east direction or towards Balekun-gomi. Further south he reached the Djupar-range, east of the Hoang-ho, and encountered, not only here, but as far as the watershed of the Tao, the same strike to the east-south-east. Thus these observations link on in a most satisfactory manner with those made in the valley of the Tao².

Among the many additions which Obrutschew has made to our knowledge of the structure of Inner Asia one of the most important appears to me the transverse section which he has drawn from Lan-tshou to the Red basin, extending through nearly four degrees of latitude; this has rendered it far easier to form an opinion as to the connexion of the western range with the Tsin-ling-shan³.

The northern part of this section has already come before our notice; it consists of the lofty plateau of Di-dao, formed of Gobi beds, and the Tshan-fan-shan, which is regarded as the most northerly of the chains running to the Tsin-ling-shan. The Gobi beds are upturned on its north slope, precisely as on the south slope of the south Kuku-nor. On the same slope (according to the line of march, in about long. $103^{\circ} 50'$ E., lat. $35^{\circ} 9'$ N.) basalt appears, perhaps as a continuation of the recent volcanic outflows which are so characteristic of the Prjewalski chain⁴. The Tshan-fan-shan

¹ Sven Hedin, *Die geographisch-wissenschaftlichen Ergebnisse meiner Reisen in Central-Asien, 1894-1897*, Peterm. Mitth., *Ergänzungsheft* No. 131, 1900; in particular H. Bäckström, *Ueber jungvulkanische Eruptivgesteine aus Tibet*, op. cit., pp. 375-378.

² K. Futterer und Holderer, *Dritter Bericht über die Reise durch Central-Asien und China*, Verh. Ges. f. Erdk. Berlin, 1899, pp. 142, 144. The appearance of the country is very clearly described by Futterer, *Durch Asien*, I, p. 318 et seq.

³ Obrutschew, *Central-Asien*, II, pp. 304-361. This line is also remarkable in other respects; the contrast between the valleys of the Tsin-ling, which are chiefly transverse, and the longitudinal valleys of the platform of Thibet has often been pointed out; this line marks the boundary of the meridional transverse valleys, and already in some of the affluents of the upper Hoang-ho the characteristic direction to the north-west appears, e.g. in the Ri-tshju and Rka-tshju on Potanin's map of Amdo, *Izviestija Imp. ross. Geogr. Obsch.*, 1877, XXIII.

⁴ Obrutschew, *Central Asia, North China and the Nan-shan*, II, p. 352.

consists of folded Palaeozoic beds, strike west-north-west (280° – 300°); on the south side the beds have yielded *Knorria* and *Lepidodendron*.

In the chains which follow to the south the rocks present the same west-north-west or north-west strike for a distance of 200 versts, or till they reach the neighbourhood of the confluence of the river Djorni with the Pei-shui (about lat. $33^{\circ} 25' N.$). This is the region in which the western mountains cross over to the Tsin-ling-shan. Nowhere along this line does Obrutschew mention any important band of gneiss or granite; here and there ancient schists occur, but in general we have simply a series of closely crowded Palaeozoic folds, in which traces of Devonian and Carboniferous fossils have been found. These folds form, one after another, the ranges of Tshan-fan-shan, Sjao-shan (3,400–3,600 meters), the watershed of Ya-lin (2,810 meters) between Tao and Pei-shui, up to and over which the red Gobi deposits on the slopes of the Ya-lin-shan appear to ascend, and then the rocky chain of Min-shan (4,000 meters), which on the line of the section shows a syncline of supra-Carboniferous sandstone overturned to the south-west.

From the exact data furnished by Obrutschew we may also infer that a little south of the above-mentioned confluence of the Djorni, and near the town of Tsy-tshou, a change occurs in the strike of the folds. Even above this locality, ancient chloritic and tourmaline-bearing schists become more frequent. Where the Pei-shui cuts through the range of Lin-jan-shan while making a bend, the direction of the folds becomes for a while east and west, with overfolding towards the south; then the strike turns to north-east (60° – 80°), returning to east and west in the Pa-nan-shan, and finally assumes in the Pi-shan a direction to north-east (60°), which persists for 50–60 versts up to the border of the Red basin.

This north-easterly trending southern range is united by intermediate folds with the folds striking to west-north-west. It consists in the north of ancient schist, especially chlorite schist and phyllite; further south, in the Dali-shan, of Palaeozoic sediments, in fact upper Silurian or Devonian and *Fusulina* limestone. Here overfolding occurs to the south-east. Now follow in transgression the thick marginal conglomerates of the Red basin. The plant-bearing beds of this basin present signs of slight posthumous movement.

The town of Lan-tshou lies west of long. $104^{\circ} E.$; the section we have just described, across the north-easterly trending range, together with the Pi-shan and Dali-shan, lies between long. 105° and $105^{\circ} 45' E.$ The transverse sections taken across the Tsin-ling-shan by Richthofen, Lóczy, and Obrutschew all lie between long. $106^{\circ} 30'$ and $107^{\circ} 30' E.$

We have already learnt from Richthofen's works (ii, p. 189) that this great range, although fairly regular in outward form, yet consists of two ranges running in different directions. The northern chain, the *Tsin-ling-*

shan proper, extends from the valley of the Wei to the granite mass of Lju-pa-ting, and presents the structure of a normal unilateral range; it consists of a zone of gneiss, a second zone of ancient schist unconformably overlain by upper Carboniferous, and a Palaeozoic zone from which rises the granite mass of Lju-pa-ting, surrounded by a zone of contact. The Tsin-ling-shan runs west by north (282°). This direction corresponds precisely with that taken in the west by the folds which strike west-north-west from the Tshan-fan-shan to the confluence of the Djorni, and this group of chains must doubtless be regarded as the continuation of the Tsin-ling-shan.

South of the Tsin-ling-shan and the granite mass of Lju-pa-ting there follows on the east a narrow zone, perhaps Carboniferous, which is wedged in and displaced by contact with other chains.

Richthofen compares the Tsin-ling-shan to a heavy bar, laid on a cloth thrown into parallel folds; it crosses them obliquely, and is pushed against them in a direction perpendicular to its axis, until they bend themselves round into complete adaptation to it¹. This displaced zone might be compared with that much broader zone of the western section which extends, with a strike varying between west-north-west, due west, and north-east, from the confluence of the Djorni to the Pi-shan.

Finally there follows on this eastern side the second range of *Ta-pa-shan*, striking to the east-north-east and formed of a zone of ancient gneiss-like schists, generally with a vertical dip, followed by Palaeozoic beds which are overthrust to the south, and driven into overriding flakes; resting on the older rocks are the plant-bearing beds of the Red basin. The Pi-shan and Dali-shan of the western section are the direct continuation of this range. But in those mountains the strike has passed from east-north-east to north-east, in consequence of contact with the ranges running to Yünnan.

Let us leave aside for the present the range of *Ta-pa-shan* with its divergence to the south-west, and confine our attention to the Tsin-ling-shan proper. Although it represents a simple chain, asymmetrical towards the south, and elevated anterior to the upper Carboniferous epoch, yet towards the west-north-west we have a whole series of chains which correspond to it—the Tshan-fan-shan, Sjao-shan, and Min-shan, and still further to the west-north-west, the Djupar, San-si-bei, Ugutu, Amnje-matchin, besides Rockhill's Caroline range and the Burkhan-buddha, all of them bordering the Tsaidam on the south; then the Marco Polo mountains, and perhaps also the Columbus and the chains of south-west Tsaidam; south of these the Koko-shili, and finally the Arka-tag (Prjewalski range). These are in fact a mighty and almost rectilinear series of ranges running to the west-north-west across central Asia, and are entitled to bear the

¹ F. von Richthofen, China, II, p. 638.

ancient name of Kuen-luen; as was recognized by Richthofen, a true pioneer, many years ago.

A close examination shows that the terrestrial folds attain their supreme development in the centre and towards the west of this series. *Here the valley-bottoms attain a much greater altitude, even where they sink lowest, than the peaks of the Tsin-ling-shan*, and this range, in spite of its length and height, is only an outrunner from that flood of chains which follow one after the other in the meridian of Tsaidam and Kuku-nor. 'The highland of Thibet,' says Bogdanowitsch, 'merges, in the central Kuen-luen, into the mountain region of the Nan-shan, and yet further on into the Bei-shan. Thus we pass through an almost continuous series of mountain chains, from the Kuen-luen system to the Thian-shan¹'.

We see, in fact, *that all these mighty chains follow the same direction, between west-north-west and north-west, as the chains of the Nan-shan*. The latter, however, like the Richthofen range, Tolai-shan, Alexander III, and others, are sometimes represented by bands of folded sediments; sometimes they include gneiss, which is exposed on one of their slopes, or sometimes again they are formed, as in the south Kuku-nor, mainly of gneiss. Each of these chains may be regarded as a morphological unit; yet not one possesses tectonic independence: they are all the transverse waves of a swelling tide of folding movement, which forces its way between the plateau of Ordos in the east and the arc of Anembar-ula (Yarkand arc) in the west. Some of the folds, dammed up by Ordos, have swerved back towards the Ala-shan. *But as soon as the defile is passed the transverse waves elongate themselves in opposite directions*. It is thus that the Kuen-luen proceeds from the Nan-shan. In this way the Tsin-ling-shan, folded towards the south, arises on the south border of the Sinian mass, and so, too, the mighty Arka-tag, on the north border of the Yarkand arc.

The emergence of the western branches. Space would fail me were I to attempt to describe all the devoted efforts which have been made to determine the course of the Thibetan chains. Potanin, H. Bower, Littledale, Bonvalot, Henri d'Orléans, Dutreuil de Rhins, Rockhill, and many other daring explorers, have in turn thrown light on various parts of the great coulisses which are deflected in the direction of the meridian. From the mass of data thus provided, naturally relating for the most part merely to the configuration of the surface, a master trend-line may be educed; it is given by the band of limestone which, with a constant east-south-east strike, accompanied Rockhill on his way for many a day's journey. This band, which, according to Rockhill's map, may well exceed 500 kilometers in length, proceeds from the south side of the Dang-la, and reaches the road to Dshamdo, near the river Nashe-dshu (long. 93° E., lat. 32° N.); it probably forms, as it continues to the east-south-east, part of the mighty

¹ Bogdanowitsch, Mitth. geogr. Ges. Wien, 1895, XXXVIII, p. 525.

mountain of Ramnon-gang-ri, beyond which it proceeds still further in the same direction¹. Then a south-east, instead of an east-south-east, direction sets in; it is seen in the mountain ranges, and betrays itself also in the deflexion of the river valleys. Even near Draya, Rockhill still met with limestone mountains. Some $1\frac{1}{2}$ degrees of latitude further south, near Yarkala on the Me-kong (about lat. 29° N.), we reach the locality where Desgodins found upper Carboniferous (or Permian) fossils. Here a south-south-east strike prevails, and Lóczy has succeeded in showing that the fossiliferous upper Carboniferous (horizon of Loping) of the ridge of Dengu-la (lat. $29^{\circ} 10'$ N.), which is most probably connected with the upper Carboniferous of Yarkala, follows the Yang-tse-kiang with the same strike through more than three degrees of latitude. Near Tshung-tjen (lat. 28°) it is overlain by segments of Trias; near I-yang-tang (lat. $26^{\circ} 25'$) it contains *Schwagerina craticulifera*, and Lóczy has traced this remarkable band to a point south of lat. 26° N., north of Ta-li-fu.

Precisely as in the oases of Kansu and in so many other mountainous regions of Eurasia, the upper Carboniferous rests unconformably upon an older folded Palaeozoic series; it has itself been subsequently folded².

We now enter completely within the region of the bordering arc of Burma, and cross its several zones in a south-westerly direction. The band of Palaeozoic, and in particular of upper Carboniferous rocks, which we have just traced from Batang nearly down to Ta-li-fu, is bounded on the west by the range of Tsang-shan, which consists of crystalline schist. Beyond it there lies a broad zone of flysch-like sandstone, and this is again followed, between the Me-kong and the Salwin, by a folded Palaeozoic zone. In this zone Lóczy found upper Carboniferous fossils at a locality east of Yung-tshang-fu, and between this place and the Salwin, near Pu-pjao, he came upon Silurian with traces of Trilobites and great plates of a Cystoid (*Hemicosmites*? spec.). The strike is here no longer south-south-east but north and south³.

The Siang-shan, which now follows, forms the watershed between the Salwin and Irawadi; it runs from north to south, consists of gneiss and phyllite, and forms the commencement of an extensive zone of older, chiefly

¹ W. W. Rockhill, *Diary of a Journey through Mongolia and Tibet*, pp. 260, 267, 277, 280, and also 294 for the general strike. In 1895 Littledale travelled from Tchertchen towards the south across the strike of the chains, to the Garing-tso (long. 89° E., lat. 32° to $31^{\circ} 30'$ N.) and to the Tengri-nor, and mentions some volcanic outcrops with regard to which I have no further information; from the Garing-tso to the neighbourhood of Leh, i. e. through eleven degrees of longitude, the map shows chains and valleys in the direction of the Himálaya: St. George R. Littledale, *A Journey across Tibet, from North to South, and West to Ladak*, *Geogr. Journ.*, 1896, VII, pp. 453-483, maps.

² Lóczy, *Die wissenschaftlichen Ergebnisse der Reise des Grafen Bela Széchenyi in Ostasien*, p. 692 et seq., in particular pp. 731, 736, 746, sections, figs. 142, 144, &c.

³ Lóczy, *Ostasien*, p. 767, and III, p. 21.

granitic rocks, which extends from here down towards Bhamo. West of this zone there again occur, east and west of the meridian of 97° E., indications of a Palaeozoic zone, believed by Noetling to be Carboniferous, and beyond it, according to the observations of Noetling and Griesbach, another zone of gneiss and similar rocks which extends to Mogaung and in the south to Htygaing (Tu-gaung)¹.

A glance at Plate I, however, shows that these numerous zones or coulisses are not quite parallel. In particular, there is an obvious deflexion to the south-south-east between Tshung-tjen and Tali-fu, while the western ranges run from north to south. Somewhat further south, between the Salwin and Irawadi, the divergence of the trend-lines becomes still more marked.

The work done by the Geological Survey of India, particularly the investigations of La Touche and Datta in the north part of the Shan states, and those of Middlemiss in the south part as far down as Karenni, have rendered it possible to form a general idea of this region².

La Touche and Datta have traversed the district between lats. 23° and 22° N. and longs. 96° and 98° E. The general strike varies here between north-north-east and east-north-east. The railway and road, which have been recently constructed from Mandalay to the north-east, through Thibau to the Kunlon ferry on the Salwin, run for long distances with the strike of the rocks. The oldest rocks lie to the west; near Mandalay the lowest beds appear, possibly Cambrian, then lower Silurian, upper Silurian, and infolded red sandstone, and finally the recent plain of the Salwin, with slightly disturbed sediments possibly of Siwalik age.

The Silurian, thrown into folds, presents a great diversity of character. Cystoid plates, found by Lóczy at Pu-pjao, lie in a yellowish-brown crinoidal limestone, and are striking objects on account of their great size. On first entering the limestone range in the east, Noetling likewise found his attention arrested by a gigantic Cystoid in red crinoidal limestone, and he named it *Echinospaerites Kingi*. He correlated the deposits with the

¹ Noetling, Report on the Coalfields in the Northern Shan States, Rec. Geol. Surv. India, 1891, XXIV, pp. 99-119; C. L. Griesbach, Geological Sketch of the Country North of Bhamo, op. cit., 1892, XXV, pp. 127-130. Among the publications of F. Noetling, the Geological map of north-east Upper Burma deserves special mention; this appeared in conjunction with the treatise, Ueber das Vorkommen von Jadeit in Ober-Birma, N. J. f. Min., 1896, I, pl. 1. This sketch map, in spite of certain deviations in topography, may be used as a supplement to Lóczy's maps.

² T. D. La Touche, Preliminary Report on the Geology of the Northern Shan States, Gen. Rep. Geol. Surv. India, 1899-1900, pp. 74-95; P. N. Datta, Notes on the Geology of the Country along the Mandalay-Kunlon-Ferry Railway Route, Upper Burma, tom. cit., pp. 96-122; C. S. Middlemiss, Report on a Geological Reconnaissance in parts of the Southern Shan States and Karenni, tom. cit., pp. 122-153; and Griesbach, tom. cit., 32-37.

Echinosphaerites limestone of the lower Silurian of the Baltic¹. La Touche has discovered Graptolite shales also in the overlying beds.

From the general strike of the beds between Mandalay and Kunlon, I think we must conclude that the Palaeozoic zone, which is cut through by the Salwin west of Yung-tshang-fu, strikes from here to the south-west and reaches the Irawadi near Mandalay, thereby diverging from the direction followed by the mountains of Tali-fu. *The trend-lines diverge from one another, probably in the region of the flysch-like sandstone, which Lóczy crossed between lats. 26° and 25° N., between Tali-fu and Yung-tshang-fu; and through which the Mekong flows in this region.*

South of Mandalay, Middlemiss acquaints us with the following facts: The general strike to the south-west can no longer be recognized; the prevailing direction is again north and south. East of the Irawadi gneiss again crops out in a range of imposing length, but of inconsiderable breadth. It rises steeply out of the alluvial plain, is not bordered by foothills, and is cut off on the west by a long north-and-south fault. Towards the east the gneiss is followed by a zone of crystalline schist, then comes a very broad limestone plateau, without water on the surface, but drained by subterranean rivers, and attaining in some places a height of 4,000 feet, in the Loi-sampu of about 5,000 feet. This is the *Shan plateau* proper. The limestone is folded, and the folds are worn down. The Silurian fossils of the northern Shan states have not yet been found in it. All the fossils yet discovered belong to the middle Productus limestone (Permian). Griesbach supposes that it is a continuation of the limestones of Moulmein, which are of the same age. Still further east we again meet with the red sandstone of the north in folded-in bands; Middlemiss regards it as Tertiary.

The range of gneiss which bounds the alluvial plain of the Irawadi in Karenni is evidently the same as that which reaches the vicinity of the sea at the mouth of the Sittaung. I think we must conclude that the Palaeozoic zone of Yung-tshan-fu is the same as that which runs east of Mandalay, that it is continued into the great plateau of the south Shan states and reaches the sea near the mouth of the Salwin. With this also may be associated the outcrops of Carboniferous which Noetling has described at Therabwin, near Tenasserim, and possibly even those of east Sumatra².

A few years ago only insignificant traces of these occurrences were known (I, p. 456). We now see that the gneiss ranges marked on Plate I, between longs. 96° and 99° E., do not come down into the neighbourhood

¹ F. Noetling, Field Notes from the Shan Hills, Upper Burma, Rec. Geol. Surv. India, 1890, XXIII, pp. 2, 78, 79. One specimen attained 160 mm.

² F. Noetling, Carboniferous Fossils from Tenasserim, Rec. Geol. Surv. India, 1893, XXVI, pp. 96-100.

of the sea except along the Sittaung, and that the coulisses of ancient rocks which, placed obliquely one behind the other, form the Malay peninsula, belong to a more interior region of the collective structure; and in the north, on the fork between Tali-fu and Yung-tshang-fu, they do not occur.

Lóczy, when he had crossed the upper Schweli, was surprised to find at Teng-jueh-tshou, while still in the midst of the ancient rocks, that he was surrounded by recent andesite. Noetling records two series of recent basalts in the valley of the Irawadi, which extend from the north of Bhamo up to about lat. $25^{\circ} 30' N.$, and, further towards the north-west, basalt likewise appears near the nephrite mines of Sanka. Perhaps the basalts of Bhamo should be regarded as precursors of the long line of volcanos (I, p. 455), of which the northernmost, Ho-shuen-shan (lat. $23^{\circ} 20' N.$), has been described by Lóczy¹.

Let us now attempt to obtain a general view of the region represented on Plate I.

In the north-west of this sketch we see the eastern part of the highest *gneiss summits of the Himálaya* (6,939 meters); towards the south the peaks become lower (3,679 meters), and where the river Dikrang leaves the mountains, deposits of the Gondwána series dip, according to Godwin-Austen (I, p. 450), beneath the gneiss, while below these deposits there disappear in turn the Tertiary beds of the sub-Himálayan group, which terminate towards the alluvium of the Brahmaputra in an escarpment 900 meters in height. Near Sibsagar the surface of the alluvium lies only 95 meters above the sea.

South of this region, beyond the Brahmaputra, comes the east border of the *Shillong-plateau* (I, p. 410), which on June 12, 1897, was the starting-point of the mightiest earthquake of the nineteenth century. Its south and south-east border are formed, according to Medlicott and F. H. Smith, by a great flexure². Here it consists of gneiss sloping gently away to the north, with superposed horizontal sheets of middle Cretaceous. Isolated domes of this mass of gneiss are visible north of the Brahmaputra, a little beyond the western limit of our map, and extend even into the Tertiary foot-hills of the Himálaya.

We now reach the outer border overfolded to the north-west of the *Nága* mountains, which are the northern continuation of the folded range of Arakan; the Brahmaputra separates them from the Himálaya, and the Dhansiri from the plateau of Shillong. Their north-eastern part has been described by Mallet (I, p. 411). What is known here as the 'Axial Group' is probably Cretaceous Flysch, or perhaps in part lower Tertiary sediments

¹ F. Noetling, N. J. f. Min., 1896, I, p. 13; Bauer, *ibid.*; Lóczy, *Reise des Grafen Bela Széchenyi in Ostasien*, p. 771.

² F. H. Smith, *The Geology of the Mikir Hills in Assam*, Mem. Geol. Surv. India, 1897, XXVIII, pp. 71-95, map; in particular p. 73.

highly altered by pressure¹; on the map (Pl. I) *te* indicates an Eocene lignitiferous series; *aaa* is a strike fault on the outer border.

Those parts of the range lying to the south in the direction of *Manipur* have been investigated by R. D. Oldham (I, p. 452). In the north of this region the Axial group presents a north-and-south strike, and, as far as it has been traced, a vertical dip; in the south, where this zone is much broader, we see as we come from the west a dip to the east or east-south-east, which is maintained throughout its whole breadth, across the plain of Manipur and Tusom; this would seem to suggest the existence of a series of overthrust flakes. From Tusom to beyond the band of serpentine the dip is in the opposite direction, namely west or west-north-west, so that the whole appears to form an asymmetric fan. The structure of the lofty chain which runs from the east wing of the fan to the north-north-east (Saramethi, 3,815 meters) is unknown.

The upper Tertiary beds (*sub-lim* Pl. I) rest unconformably on the Axial group, but are carried up to great heights towards the centre and east of the range. Near Samaguting and Yemi bivalves have been found in the sandstone; elsewhere plant-remains occur, and amber as well. In the east towards the Chindwin, where they form the Kachaophung (2,451 meters), these beds terminate, with a dip of about 20° E., in the lofty escarpments of the Angokhim and the Kasom.

We have now reached the field of Noetling's labours in *Upper Burma*.

The Irawadi group is a deltaic Tertiary formation in which remains of the Siwalik fauna are imbedded². The next oldest series is the marine Pegu group, of Miocene, or possibly, as is indicated by the presence of *Anthracotherium*, of Aquitanian age. It rests on Eocene beds with Nummulites, and *Velates Schmideliana*. From the Tertiary lowlands the range of the Mainthong hills, formed of quartz diorite, emerges near Wuntho³; and near the Hty-gaing on the Irawadi, north of the volcano Ho-shue-shan, we reach the border of the great westernmost range of the ancient rocks of the Burman arc.

It is from this range that the Irawadi, bordered by recent eruptive rocks, emerges near Bhamo.

From this point onwards Lóczy becomes our guide, and we reach the long coulisses of gneiss, separated by closely folded-in Palaeozoic bands, and distinguished by the transgression of the upper Carboniferous⁴. We

¹ The older statement that fossils of the Trias period occur in this range rests on an error: R. D. Oldham, *Manual of the Geology of India*, 2nd ed., 1893, p. 144.

² F. Noetling, *The Development and Subdivision of the Tertiary System in Burma*, *Rec. Geol. Surv. India*, 1895, XXVIII, pp. 59-86.

³ F. Noetling, *Note on the Geology of Wuntho in Upper Burma*, *Rec. Geol. Surv. India*, 1894, XXVII, pp. 115-124.

⁴ On Pl. I it was necessary on account of the small scale to unite under the

cross the Mekong and the region where the Ta-li chains diverge from one another. We reach the Yang-tse-kiang, then the lake of Ta-li with its Paludinas of Levantine type, and the Trias deposits of Tshung-tjen. Coulisses of similar structure are repeated from Ba-tang up towards Ya-tshou-fu, and bend as a whole towards the west-north-west, in the direction of Dang-la, Dumbure, and the other Thibetan chains.

It is difficult to piece together the observations in these regions, owing to the fact that the geographical data on which they are based are somewhat divergent. If in spite of this we attempt to insert in this sketch the results obtained by Prince Henri d'Orléans on his arduous journey from Yunnan to Assam we obtain the following outline¹.

The François Garnier peak, in about lat. $28^{\circ} 15' N.$, rises west of the Mekong, in the chain which separates this river from the Salwin. From here towards the west it was shown that the most easterly and at the same time the longest affluent of the upper Irawadi, the Turong, scarcely extends beyond lat. $28^{\circ} 30' N.$; and that the river-basin of the Irawadi is bounded on the north by the lofty and snow-covered chain of Zayul which runs west-south-west from the source of the Turong, and gives rise, to streams flowing southwards to the Irawadi and northwards to the Zayul Tshu (Lohit Brahmaputra). The Zayul chain has been supposed to form a continuation of the chains of the Himálaya, a conjecture which its direction seems to justify. But the structure of the valley of the Brahmaputra near Dibrugarh renders this view improbable, and I should rather be inclined to regard the Zayul as a continuation, beyond the upper course of the Dihang river, of that chain, which includes the above-mentioned Saramethi, and probably belongs to the Patkoi arcs.

The Irawadi would thus lie entirely within the coulisses of the Burman arc, and the deflexion of these coulisses caused by the eastern Himálaya, as well as the direction to the east-north-east, would already make themselves felt in long. $98^{\circ} 30' E.$

The separation of the chains. We have already become acquainted with the divergence of the mountain ranges which occurs west of Ta-li-fu. A broad zone of sandstone, described by Lóczy as resembling Flysch, is inserted in this region. The Mekong flows along its western

abbreviation *pal.* limestones, which are probably of Silurian age, and phyllites, and under *ca* the marine upper Carboniferous and the associated sandstones; in like manner granite, gneiss, and ancient crystalline schists are placed together. For divergent opinions on the stratigraphical position of certain occurrences (Permian or upper Carboniferous), see F. Frech, *Lethaea geognostica*, 1. Theil, *Lethaea palaeozoica*, 2. Band, 1899, p. 384 et seq.; for the influence of these different opinions on our idea of the nature of a discordance, we may refer to what is said later (chapter VIII) in connexion with the peri-Adriatic region.

¹ The most detailed co-ordination of the facts may be found on the little map of the *Geogr. Journ.*, 1896, VII, p. 303; cf. also op. cit., 1896, VIII, pp. 566-585.

border and turns towards the south-east. Near Meng-huating, south of Ta-li-fu, near the head waters of the Red river, Colquhoun observed a vast plain; this is the same plain as that which Prince Henri d'Orléans struck south of lat. 25° N. on the Mekong, and it may extend as far as lat. 24° N.¹ Further to the south-south-east lies the plain of Semao; Carey thinks it continues in the same direction to the plains of the French Laos, and these regions probably belong to the eastern branch of the chains, since west of Semao, Carey found the Mekong (672 meters) enclosed between mountain ranges 1,500 meters in height².

To understand the further course of the Mekong we must bestow some attention on that of the Nam-hu, which descends from the French Laos, and enters the Mekong at Luang-Prabang. The Mekong may, in fact, be divided into several parts. The upper Mekong, as far as Kjang-sen, on the boundary of Siam, follows the same direction as the other great rivers which descend from the Burman chains towards the south. The Nam-hu, with that part of the Mekong which extends as far as Muang-kan-tao, forms a second similar part. These two are united by the transverse channel from Kjang-sen to Luang-Prabang. A second transverse channel extends into the region of Patshum. Here begins the lower course of the river, at first following the direction of the cordillera of Annam, which borders the coast. It afterwards splits up into several branches and flows at large over an extensive plain.

Near Lakon (lat. $17^{\circ} 20'$ N.), according to Joubert, ranges of steeply dipping limestone strike N. 47° W., that is, fairly parallel to the river itself and to the cordillera on the east: they probably represent the foot-hills of the cordillera. Further up stream, above Patshum, a complete change takes place. Near Vienshang Joubert found the river hemmed in by steeply plunging, sometimes vertical, beds of sandstone and arkose and violently crushed shales, with traces of anthracite. Folded schists and quartz porphyry now border the Mekong; talc schists predominate, and all strike to the north-east. The higher mountains consist of limestone. The banks maintain the same character as far up as Luang-Prabang³.

Counillon has described the district in the elbow of Luang-Prabang. Here, too, a north-east strike prevails, corresponding to one branch of the bend. North of the town we first see grey limestone, almost horizontal, with *Spiriferina*, *Rhynchonella*, *Lima*, and *Avicula*. Then follows, after a strip of alluvial land, red clay dipping first south-east, then north-west; it contains plant-remains and bones of great reptiles, and is correlated with

¹ H. d'Orléans, *Geogr. Journ.*, 1896, VIII, p. 571.

² F. W. Carey, *A Trip to the Chinese Shan States*, *Geogr. Journ.*, 1899, XIV, pp. 378-394.

³ Joubert in Garnier, *Voyage d'Exploration en Indo-Chine*, 4to, Paris, 1873, II, p. 95 et seq.

the upper part of the Indian Raniganj group. Then follows limestone and greywacke, dipping north-west, with plant-remains and small Productides; finally violet clay, with a conglomerate at its base containing limestone pebbles with Schwagerina, while its highest beds afford remains of Dicynodon. Further on, after some interruption of the section, hard grey limestone is met with ¹.

With regard to the upper parts of the Mekong accounts are less detailed, but we know from Joubert's journey that sandstone and shale, and in the higher mountains limestone, continue nearly up to Lim (lat. 20° 45' N.), where navigation finally becomes impracticable owing to reefs. A continuous mountain land of greater height lies towards the west.

We have seen that the Burman chains, elsewhere of such regular structure, are deflected in upper Burma, passing from Kunlon on the Salwin, across Thibau towards Mandalay in a south-westerly direction, and then continuing their course to the south.

It is a very remarkable fact that the same bend finds expression in the course of the Mekong between Kjang-lun and Kjang-sen, and the prevailing north-east strike which has been observed down to the Vien-shan is in harmony with this circumstance. It shows us that the transverse sections of the course of the Mekong mentioned above are true transverse valleys; that the upper Mekong as far as Kjang-sen, and the Nam-hu, together with that reach of the Mekong running in the same direction as the Nam-hu to Muang-kan-tao, do in fact, like the Burman rivers, correspond approximately, if not exactly, to the structure of the mountains. *The folds on the Mekong run in the same direction between Kjang-sen and Vien-shan as between the Salwin and the Irawadi; but instead of resuming a southerly course after the deflexion to the south-west, they gradually sink down and finally disappear beneath the plain of Siam.* A large number of the chains which rise above Kjang-sen may be continued through the teak forests into the mountains east of Moulmein. This connexion may be recognized on Black's map of Siam ².

The structure of the heights north-east of Bangkok between lats. 14° and 15° N. is unfortunately unknown to me. Nor am I acquainted with the age and relations of the sapphire and ruby mines of the province of Battambang and the heights of Khantabun. But an important question arises in this connexion. From what has been said above it cannot be doubted that the whole basin of the Menam lies within the region of the folded ranges of Burma, here hidden from view. But the extensive

¹ Counillon, Documents pour servir à l'étude géologique des environs de Luang-Prabang, Cochinchine, C. R. Acad. Sci. Paris, 1896, II, pp. 1330-1333, small map. The wandering solfataras described by Joubert (p. 102) from the region west-south-west of Luang-Prabang are believed by Lóczy to be burning coal measures.

² J. S. Black, Journey round Siam, Geogr. Journ., 1896, VII, pp. 429-452, map.

occurrence of certain outcrops of granulite and granite, with which we have already made acquaintance in the plain of the lower Mekong (II, p. 168), indicates a structure different from that of the folded *ranges*. *They are traces of an older mass which we will call the mass of Cambodia.* The plains of Further India are therefore of two kinds. A more exact knowledge of the mountains mentioned as occurring to the north-east and south-east of Bangkok might throw light on the respective boundaries of these two kinds of plain.

Accounts of the geology of the valley of the Mekong are, as we have seen, disconnected and few in number, but they seem to be fairly harmonious. A separation of the chains, such as occurs west of Ta-li-fu, may also be observed much further south on the Mekong, between long. 103° and 104° E. about, in the neighbourhood of Patshum. The deflexion to the north-north-east, and even north-east, which we perceive to the north-west on the outer border of the Nága hills, where they slope away to the Brahmaputra, resembles that which occurs between Mandalay on the Irawadi and Kunlong on the Salwin; and it is probably continued, though in a feebleness degree, towards Patshum, in the region of the Mekong.

In the region of the separation lies the mass of Cambodia.

The advance of the eastern branches. In lat. 30° N., Lóczy crossed very high mountains between Ta-tsien-lu and Batang. The Gambu, west of long. 100° E., attains a height of 7,400 meters, and the peak of Dsara in Ta-tsien-lu is believed to be still higher. These mountains strike almost north and south, and consist of Archaean rocks, separated by strips of flysch-like sandstone¹. Towards the south their height decreases, and they are cut through by the Yang-tse-kiang in a course which presents several sharp bends, and consists of successive reaches of longitudinal and transverse valleys. Amundsen found that the river returns from the snow-covered mountains of Likang to flow much further towards the north than is shown on our maps².

From Tai-ping-tshang, on the boundary of Yunnan and Sztshwan, east of Yung-peí-ting, and thus from the eastern part of this range, Leclère obtained plant-remains which Zeiller correlates with those of the upper Gondwána of India³. The bend east of the confluence of the Ya-long consists of leptynite. Melaphyre with labradorite appears on the Yang-tse-kiang. In north Yunnan flows of porphyritic andesite are intercalated beneath the Carboniferous, and similar rocks occur also in the south. The observations made by MM. Lévy and Lacroix on the rocks brought back by Leclère

¹ Lóczy, *Reise . . . in Ostasien*, I, pp. 692-726.

² F. Amundsen, *A Journey through south-west Sechuan*, *Geogr. Journ.*, 1900, XV, pp. 620-625, and XVI, pp. 531-537, maps; in particular p. 532.

³ R. Zeiller, *Sur quelques plantes fossiles de la Chine méridionale*, *C. R. Acad. Sci. Paris*, 1900, CXXX, pp. 186-188.

show that Archaean schists form the basis of a Palaeozoic series in the valley of the Red river from the north down to Yenbai (lat. $21^{\circ} 30' N.$)¹. A coal-field, probably of Tertiary age, then occupies the river valley for a distance of 30 to 40 kilometers².

In the district of Sao-bang, in north-east Tongking (about lat. $22^{\circ} 15'$ to lat. $23^{\circ} N.$), it appears from Billet's description that the south-easterly direction makes itself everywhere evident, both in the hilly ranges and the valleys. The south-west part consists of ancient schist and quartzite; here the heights are gentle and rounded. In the north-east part limestone predominates, often rich in corals; it is characterized by steep cliffs and crags, caves, and great caldrons³. Here we reach the border of the great limestone plateau of Yunnan, to be described later.

Let us now turn to the west side of the Red river.

Douvillé and Diener have shown that the Julian stage of the Trias occurs on the upper course of the Black river⁴. Joubert states that he first met with the border of the limestone plateau of Yunnan, on the upper Black river (Nam-lé-Papien). In coming from the west he crossed near the town of Pu-erh, still west of the Black river, first steeply dipping beds of anthracite, then sandstone and limestone with a fairly east-and-west strike. This chain is marked on Garnier's map as the *Ho-liem*, and there appears as the deflected continuation of a longer chain coming from the north, which runs as the *Ho-liem* to the east-south-east, and then proceeds much further to the south-east. On the road from Pu-erh to Lin-gan Joubert saw a lofty range on the south which he believed to be at least 4,000 meters in height. Judging from its position this could only be a continuation of the *Ho-liem*, but I have no further information regarding it⁵.

Beyond Pu-erh, near Semaio (Szu-mao-ting) there lies, according to Bons d'Anty, open country, above which rise isolated masses of limestone full of caves. This is the plain on the west of which, as we have already mentioned, the Mekong is bordered by south-easterly trending chains.

¹ Michel-Lévy, A. Lacroix, et Leclère, Note sur les roches cristallines et éruptives de la Chine méridionale, C. R. Acad. Sci. Paris, 1900, CXXX, pp. 211-213.

² R. Zeiller, Sur des empreintes végétales du bassin de Yen-Baï au Tonkin, Bull. soc. géol. de France, Dec. 4, 1893, p. cxxxv.

³ A. Billet, Deux ans dans le Haut-Tonkin, Région de Cao-Bang, Bull. sci. de la France et de la Belgique, éd. par A. Giard, 1896-1898, 4^e sér., VIII, pp. 1-358, maps; in particular pp. 48-54. On the railway running from Phu-lang-thuong to Lang-son, which probably cuts through the south-easterly continuation of the heights of Sao-bang, remains of Ammonites are known in black shale which probably belong to the lower Trias; Douvillé, Bull. Soc. géol. de Fr., 1896, 3^e sér., XXIV, p. 154.

⁴ C. Diener, Note sur deux espèces d'Ammonites triasiques du Tonkin, Bull. Soc. géol. de Fr., tom. cit. pp. 882-886; *Juvavites Tonkinensis*, Diener.

⁵ F. Garnier, Voyage d'Exploration en Indo-Chine, 4to, Paris, 1873, atlas, I, pp. 442 et seq. A little map of the sources of the Red river is given by C. E. Bonin, Note sur les sources du fleuve Rouge, Bull. Soc. géogr. Paris, 1897, pp. 202-206.

Thus we have approached the western border of the eastern folds and the zone of bifurcation¹.

The connexion between these observations may be slight, but they lend support to the view advanced many years ago by Lóczy, and recently advocated by Leclère; to the effect that a part of the lofty chains of Yunnan, deflected from south to south-south-east, and then to south-east, runs down through Tongking, with decreasing height, parallel to the valleys of the Black river and the Red river. Of the high chains between Ta-tsien-lu and Batang it is chiefly those lying to the west which attain so great a length. In the east the conditions become more complicated.

Let us first return to the north.

The Ta-pa-shan, which adapts itself to the south side of the Tsin-ling-shan, consists, according to Richthofen, of Silurian, Devonian, and lower Carboniferous rocks, overfolded towards the south and overthrust into imbricated flakes. On their abraded edges rests a transgressive series, coming from the south. This series begins with a limestone, some 360 meters in thickness, believed by Richthofen to belong to the Permian or Trias, and above this follow the mighty red, yellow, and green coal-bearing sandstones which fill the 'Red basin.' The sandstones are cut up by step-faults, which hade towards the north-west, i. e. towards the great mountains (II, p. 191).

Lóczy observed similar conditions in the west. At the foot of the Nju-tu-shan (5,800 meters) lies the plain of Tshing-tu-fu, 120 kilometers in length, and only 480 meters high. At the same time the thick limestone disappears beneath the sandstone. Lóczy regards the plain as an area of subsidence².

The high mountains trend more and more to the south-west, and then to the south, surrounding the town of Ya-tshu-fu (531 meters) in an arc. At the same time they sink in the Tauong-tin to 4,000 meters, and in the first range turned to the south to 3,200 meters. On the east border of this range, south-west of Ya-tshu-fu, are three parallel anticlines, in which the plant-bearing series is folded along with its Palaeozoic basement; the higher mountains are formed of granite, traversed obliquely by a syncline which rises to a height of 2,500 meters, and includes middle Devonian with *Spirifer undiferus*, and plant-bearing sandstone. Lóczy calls this first southerly trending range the *Ta-shian-ling*; it is a part of the eastern border of the eastern branches.

Thus from the Ta-pa-shan across the Nju-tu-shan to the Ta-shian-ling

¹ P. Bons d'Anty, Relation d'un voyage dans la région située au Sud de Semaou, Ann. de Géogr., 1899, VIII, pp. 49-61, map; in particular p. 57.

² Kreitner, Die wissenschaftlichen Ergebnisse der Reise des Grafen Széchenyi in Ostasien, I, p. 214; Lóczy, op. cit., I, p. 690. Rosthorn's journey was made in the same neighbourhood, Mitth. geogr. Ges. Wien, 1895, XXXVIII, pp. 285-320, map.

there lies a mountain arc concave to the south-east, which in its disposition somewhat resembles the Khara-narin-ula.

F. von Richthofen has shown that the structure of the Ta-pa-shan again makes its appearance far to the south-east, near I-tshan on the Yang-tse-kiang. A great plateau of limestone, Cambrian below and Carboniferous at the summit, forms west of I-tshan a low broad arch with an east-north-east strike; within it metamorphic rocks and granite are exposed. The south-south-east limb dips very gently out of sight, the north-north-west limb is thrown into simple folds slightly overturned to the south-south-east; towards Sztshwan the Mesozoic plant-bearing beds are included in the folding. This broad zone, cut through by the Yang-tse-kiang, runs west-south-west, directly into the lofty mass of Kuei-tshou and Yunnan¹.

In this manner indications are given of a second range, which would correspond to the Ta-pa-shan; the 'Red basin' lies between these two ranges, or, perhaps more correctly, is carried by the southern range. In the south-west of this region, Bourne travelled from Lu on the Yang-tse-kiang, first towards the south, across the frontier of the Kuei-tshou province, then towards the south-west, across Yunnan-fu into the region of the Mekong. The boundary of the Red sandstone is reached near Yung-ning (330 meters, lat. 28° 10' N.); here we arrive at a long and continuous scarp which corresponds approximately with the boundary defining Sztshwan from Yunnan and Kuei-tshou; it marks the commencement of an extensive region of limestone which is often weathered into the most extraordinary forms. A little south of this boundary the limestone rises to a height of 1,650 or 1,700 meters; south-west of Wei-ning, in west Kuei-tshou, it reaches 2,350 meters, and it extends to Yunnan-fu with a height of 1,956 meters. Both in the sandstone of the Red basin and in the limestone, the beds are steeply inclined and folded. About half-way between the south side of the lake of Yunnan-fu and the Red river we encounter granite (1,652 meters). At this place we have already crossed the western boundary of the limestone².

We owe the most important contribution to our knowledge of the limestone region to Leclère. His route led from Hanoi in a north-westerly direction to Mong-tse—where a future railway will have to ascend from 100 meters to 1,700 meters—from here to Yunnan-fu and Tali-fu, then eastwards to Kuei-yang, Kuei-lin, and across Nan-ning back to Hanoi. Not only Yunnan-fu, but Lin-gan and Mong-tse as well, belong to the limestone region. It is traversed, according to Leclère, by great flexures, striking

¹ F. von Richthofen, *Ueber Gestalt und Gliederung einer Leitlinie in der Morphologie Ostasiens*, Sitzb. k. preuss. Akad. Wiss. Berlin, XL, 1900, p. 893 et seq.

² F. S. A. Bourne, *Report of a Journey to North Ssu-Chuan in South-Western China*, Blue Book for 1883, China, no. I, Fol., 92 pp., maps. S. L. Litton also penetrated as far as Sungpan in the north-west; *Report of a Journey to North Ssu-Chuan*, Blue Book for 1898, *Miscellaneous Series*, no. 457, 48 pp., maps.

to the north-north-east, which bring the whole region down, in a series of steps sinking to the east-south-east, from the mean height of 2,200 meters to 400 or even 100 meters.

The results of this journey, and the works of Douvillé and Zeiller, based on Leclère's collections, show how great is the stratigraphical diversity of this region. Middle and upper Devonian appear in the neighbourhood of Lu-nan, east of Yunnan-fu, and various subdivisions of the Carboniferous and Permian have been met with as far as Kuei-lin, where upper Carboniferous occurs. A species allied to *Lecanites psilogyrus* of the Salt range was found not far from Kuei-yang. In the west, near Mong-tse, grey coral limestone occurs with *Naticopsis declivis*, *Delphinulopsis Cainali*, and other forms characteristic of Esino and the Marmolata, in Tyrol. The presence of Lias is doubtful; on the other hand, plant-bearing beds, which Zeiller assigns to the Rhaetic stage, occur at many localities¹.

This great limestone plateau, together with the repetition of the Ta-pa-shan which appears near I-tshang on the Yang-tse-kiang, is cut off, in its northern and larger part, so Richthofen and Leclère concordantly affirm, by a fault or flexure which strikes to the north-north-east; some difference of opinion exists as to the eastern end of the southern part. Richthofen emphasizes the very remarkable fact that the fracture at I-tshang corresponds in position and direction with the flexure of Tai-hang-shan in Shansi, and also with the eastern scarp of the Tsin-ling-shan. Further south Leclère mentions a north-north-easterly trending ridge of prae-Cambrian rocks which rises along this line, near Hoai-juen, south-west of Kuen-luen, and a granite mass to the west, on the Si-kiang, accompanied by prae-Cambrian rocks.

The relations of these ancient rocks cannot be determined from the accounts so far at our disposal. We are hardly in a position to decide whether they form the foundation of the limestone platform, as at I-tshang, or whether they are parts of an ancient mass, which exists probably in the south-east of China as an independent foreland of the Altaides.

The little which we know, through Madrolle, of the island of *Hainan* shows us in the centre the mountain of *Sai*, formed of granite and schist, from which ranges extend in different directions. An argillaceous sandy

¹ Leclère, Sur la géologie de la Chine méridionale, C. R. Acad. Sci. Paris, 1900, CXXX, pp. 184, 185, and Sur la continuité tectonique du Tonkin avec la Chine, op. cit., CXXXI, pp. 966-969, map; and Géographie générale des provinces chinoises voisines du Tonkin; La Géographie, 1900, pp. 267-288, map. H. Douvillé, Examen des fossiles rapportés de la Chine par la mission Leclère; C. R., 1900, CXXX, pp. 592-595. *Lecanites psilogyrus* belongs to the lowest horizon of the lower Trias of the Salt range. A more definite determination has been made which would extend the limit of the Mesozoic Tethys to beyond long. 107° E. and north of lat. 26° N. This genus, however, was also found by Diener in the Permian Bellerophon beds of the South Alps. From a locality in Kuei-tshou, not definitely named, E. Koken has described a Trias fauna of the type of St. Cassian; N. J. f. Min., 1900, I, pp. 186-215.

formation, red in the north and yellow in the east, surrounds this mountainous region¹.

The delta of the Red river and the coast of Tongking have been already discussed (II, p. 170). I must confess with regret that I have not arrived at any opinion as to the connexion between the outcrops of the plain and those of the ranges of the Red river. From subsequent observations of Jourdy's it seems as though above the delta, somewhere near Phu-lang-thuong, this connexion is established by a bend in the strike².

The cordillera of Annam, which borders the east coast, is shown very clearly on the geological map of Indo-China drawn up many years ago by E. Fuchs³. Bel, starting from the Mesozoic coal-measures of Tourane on the east coast (lat. 16° 10' N.), crossed the whole breadth of the cordillera.

It consists there of several coulisses, 600–900 meters high, formed of granitic and dioritic rocks, and then of gneiss and crystalline schists. It is bordered, but only on the western side, by more recent stratified rocks. It is extremely probable that the small mountain tract already mentioned as occurring near Lakon on the Mekong (lat. 17° 20') forms part of the cordillera⁴.

Beyond Attopeu (south of lat. 15° N.) is an independent mountain mass in which Joubert observed an extensive development of basalt. It lies west of the cordillera towards the Mekong, and probably belongs to the mass of Cambodia (II, p. 169).

Summary. Having once overcome the damming back caused by the Sinian mole (Ordos) in the east, and the constriction due to the Yarkand-arc (Altyn-tag, Anembar-ula) in the west, the mighty branches of the middle and eastern Kuen-luen extend themselves from the Arka-tag in a straight east-south-east line on the south side of the Sinian mole, as through the Tsin-ling-shan. Soon, however, a fresh constriction of the coulisses appears, caused on the west by the Himálaya, on the east perhaps by the action from afar of an older mass in south-east China, of which as yet but little is known; as the chains advance towards the south they become parted by the intervening mass of Cambodia. It cannot be determined whether this mass really makes its influence felt towards the north, or whether the mere widening of the space is itself sufficient to determine the separation of the chains.

The western group runs through Burma down to the Malay peninsula, and the eastern group through Yunnan and Tongking. The divergence of

¹ C. Madrolle, *Étude sur l'isle d'Hainan*, Bull. Soc. géogr. Paris, 1898, 7^e sér., XIX, pp. 187–228, map.

² J. E. Jourdy, *Note complémentaire sur la Géologie de l'Est du Tonkin*, Bull. Soc. géol. de Fr., 1885–1886, 3^e sér., XIV, p. 445, map.

³ E. Fuchs and E. Saladin, *Ann. des Mines*, 1882, 8^e sér., Mémoires, II, pl. VI.

⁴ J. M. Bel, *Mission au Laos et en Annam*, Bull. Soc. géogr. Paris, 1898, 7^e sér. XIX, pp. 261–290.

the chains is already obvious between Ta-li-fu and Young-tshen-fu, and it can be traced onwards in the region of the Mekong. At the same time the chains decline in height as they proceed towards the south.

The damming back caused by the eastern end of the Himálaya finds expression in the arcuate advance of the Patkoi and Nága hills, as well as in the curve described by the mountains of Arakan. Further towards the interior this course is represented by the south-westerly direction which can be traced from Kunlon through Thibau to Mandalay. Then, in the Shan states of Burma, several of the coulisses which approach from the north and north-east disappear beneath a karst-like plateau of Palaeozoic limestone, which is folded and owes its tabular form to denudation. Fresh coulisses make their appearance in the south and form the Malay peninsula. A very long and extremely regular zone of disjunction runs down from the volcano of Ho-shue-shan between the coulisses of the Altaides, and in all probability extends to the Banda islands.

The configuration of the eastern group is completely different.

The Ta-pa-shan, driven in overthrust flakes to the south, adapts itself to the south side of the Tsin-ling-shan; it is part of an arc concave towards the south-east, the western limb of which merges into the north and south coulisses of Yunnan. A fragment of a second similar range occurs west of I-tshan on the Yang-tse-kiang. The western part of the high coulisses of Yunnan is continued in the direction of the Red and the Black rivers; and the cordillera of Annam is, to all appearance, a member of this group. The eastern part sinks beneath the great limestone plateau of Kuei-tshou, south-east of Yunnan and west Kuang-si, in the same way as the coulisses of north-east Burma sink beneath the limestone plateau of the Shan states. In this case, as in that, the limestone is folded, and the plateau owes its form to abrasion. This was observed by Middlemiss in Burma and by Bourne in Kuei-tshou. Elsewhere, too, we perceive this cave-eaten limestone between the spurs of the range, e.g. in the plain of Sei-mao. *Generally speaking, both the high-lying karst-land of the Shan states in Burma, and the great limestone region of south-western China, appear to represent a mantle of folded sediments which has been worn away from the high chains, but remains preserved in the less elevated parts as abraded plateaux, beneath which the chains sink gradually out of sight*¹.

In this way the mighty swell of the Altaides in Thibet subsides and is dispersed. The whole continent becomes lower. Many coulisses disappear. Only a few long branches are continued: on the east into the cordillera of Annam; on the west, always giving rise to fresh coulisses, through the Malay peninsula, and still further, to Java and beyond.

The Malay Archipelago. We have now arrived at one of the most instructive parts of the earth's surface. Four elements combine to form it:

¹ This has also been conjectured by Lóczy; Ostasien, p. 760.

the end of the Burman arc, the southern branches of the virgation of the Philippines, the spurs of the great cordillera of New Guinea, and finally the continent of Australia, with the cordillera which marks its eastern border and crosses Torres strait.

Let us consider the first of these elements in connexion with the preceding paragraph.

The coulisses of this branch of the Altaides, in their furthest extension to the south-east, break up first into peninsulas and then into islands. The distance between the visible parts of the folded ranges continually increases, a feature often observed when a folded range reaches the sea. The islands and reefs become less numerous as their distance from the peninsula increases, until at last it becomes impossible to discover the trend-lines by which they are governed. But this does not always hold true for the volcanos. Very often we find that as a cordillera becomes concealed beneath the sea the volcanos increase in number; and it may happen that the cordillera almost completely disappears, while curves of volcanos remain visible, and reveal the plan of the vanished structure. It is so in the case of the Aleutian islands, the Kuriles, the Liu-kiu islands, the Philippines, the Lesser Antilles, and, to some extent, in the Malay archipelago; for this reason, it is always of particular interest to take note in such cases of the nature of the connexion between the volcanic lines and the coulisses of the cordillera as they advance from the peninsulas into the sea.

The Cretaceous and lower Tertiary zone of the Nága hills and the coast of Arakan, with its long bands of serpentine, dips beneath the sea at cape Negrais and reappears in the Andaman and Nicobar islands¹ (I, p. 451), and the series of islands which lies west of Sumatra, from Pulo Nias to Engaño (I, p. 457), may be regarded as its further continuation.

Then follows the broad depression between this range and the Sit-taung, to which the basin of the Irawadi and the Tertiary ridge of Pegu Yomah belong. The gulf of Martaban also corresponds to this elongated subsidence.

It is as a continuation, not of one of the long folded ranges, but of this subsidence and the gulf of Martaban, that the long range of volcanos appears which extends from the Ho-shue-shan (lat. 23° 30' N.) through Puppa-doung (lat. 21°), the little trachyte rock of Chouk-talon (lat. 16° 22' N.) to Narcondam (lat. 13° 24' N.) and Barren island (lat. 12° 17' N.)² (I, p. 455; II, p. 164).

¹ R. D. Oldham, *Geology of the Andaman Islands*, Rec. Geol. Surv. India, 1885, XVIII, pp. 135-145, map. Here the correspondence with the rocks of Arakan is again confirmed.

² A. Carpenter, *Barren Island and Narcondam*, Rec. Geol. Surv. India, 1887, XX, p. 46 et seq.; also Prain, *Flora of Narcondam*, Journ. Asiat. Soc. Bengal, 1893, LXII, part 2, p. 39.

To the east, beyond the fracture on the Sit-taung, lie a number of coulisses, which are continued into the *Malay peninsula* (I, p. 456).

Warrington Smyth gives an excellent description of the extreme regularity and great length of these zones. West of the patches of upper Carboniferous which are known as far as Tenasserim, lies the first range of granite, which terminates at Jung Ceylan (lat. $7^{\circ} 50' N.$). It affords tin at several localities. Then comes a limestone zone on the east; at Champawn, on the east coast, (lat. $10^{\circ} 30' N.$) are isolated mountain bluffs which belong to it. They are continued in the rocky promontory of Sam Roi Yawt (about lat. $12^{\circ} 6' N.$; 619 meters); south of Langsuan the limestone cliffs reappear. The island of Antarang consists of folded limestone, and the limestone band as a whole corresponds to the basin of the river Bandon, which cuts through the peninsula obliquely in a broad coulisse valley.

East of this valley rises the second granite coulisse, likewise tin-bearing. It emerges from the sea in the island of Koh tau (about lat. $10^{\circ} 6' N.$; 375 meters), forms the hilly islands, Koh Pungum and Koh Samul (lat. $9^{\circ} 45' N.$; 676 meters and 691 meters), and entering the peninsula, becomes the Lakawn range, which thence onwards represents the axis of the peninsula¹.

Still further south this long granite range breaks up into isolated ridges and, associated with ancient sediments, reaches the sea near Singapore². A series of cliffs and smaller islands reveals its continuity with the tin-producing islands of Banka and Billiton.

Thanks to Verbeek's detailed investigations the islands east of Sumatra, from Kaljan-gan in the west-north-west to Nangka in the east-south-east, i.e. for a distance of about 400 kilometers, belong to that part of the archipelago which is most exactly known. The whole region is formed of very steeply upturned ancient sediments and intervening granite masses. The sediments include quartzite and slates, also Radiolarian rocks, and are believed to be identical with the ancient schistose series of Sumatra, which

¹ H. Warrington Smyth, *Journeys in the Siamese East Coast States*, Geogr. Journ., 1898, XI, pp. 465-489, map. North of Singora (lat. $7^{\circ} 6'$) traces of another limestone band appear to be present in the east around the so-called 'inland lake' (p. 482). At the same time compare the older works of Low, *Notes on the Geological features of Singapore and some of the adjacent Islands*, Journal of the Indian Archipelago, Singapore, 1847, I, pp. 83-100; J. R. Logan, *Sketch of the Physical Geography and Geology of the Malay Peninsula*, op. cit., 1848, II, pp. 83-138, and *Geology of the Straits of Singapore*, op. cit., 1852, VI, pp. 179-217 (also Q. J. G. S., 1854, VII, pp. 310-344, map); Logan, *Notices of the Geology of the East Coast of Johore*, Journal of the Indian Archipelago, Singapore, 1848, II, pp. 625-631.

² H. Lake, *Johore*, Geogr. Journ., 1894, III, pp. 281-297, map; also Louis, *On the River Telubin*, tom. cit., pp. 228 et seq., map. Some Mesozoic fossils of undetermined character were brought from 'Pahang trunk road on the Lipis river.' Pahang lies on the south-east coast of the peninsula; cf. R. Bullen Newton, *On Marine Triassic Lamellibranchs discovered in the Malay Peninsula*, Proc. Malacol. Soc., London, 1900, IV, pp. 130-135.

is overlain by upper Carboniferous. Their vertical dip is not dependent on the granite, which, according to Verbeek, is rather the consequence than the cause of the folding in the ancient sediments. In certain localities dykes of granite invade the sediments, and the contact phenomena show that much of the granite was intruded after the folding.

The direction of the ancient sediments in the islands is not quite rectilinear. Even at Singapore we see clay-slates striking south-south-east (165°). In the little islands between Banka and Billiton we meet with a due east-and-west strike, and even east-by-north (75°); then at Nangka (lat. $2^\circ 30' S.$, E. of long. $108^\circ 30' E.$) the strike is again south-south-east (165°). In spite of these deviations the series of islands maintains on the whole a direction to the east-south-east, and it is also along this line that the zone of ancient rocks exhibits its last outcrop in the little island group of Karimoen djawa, north of Java¹.

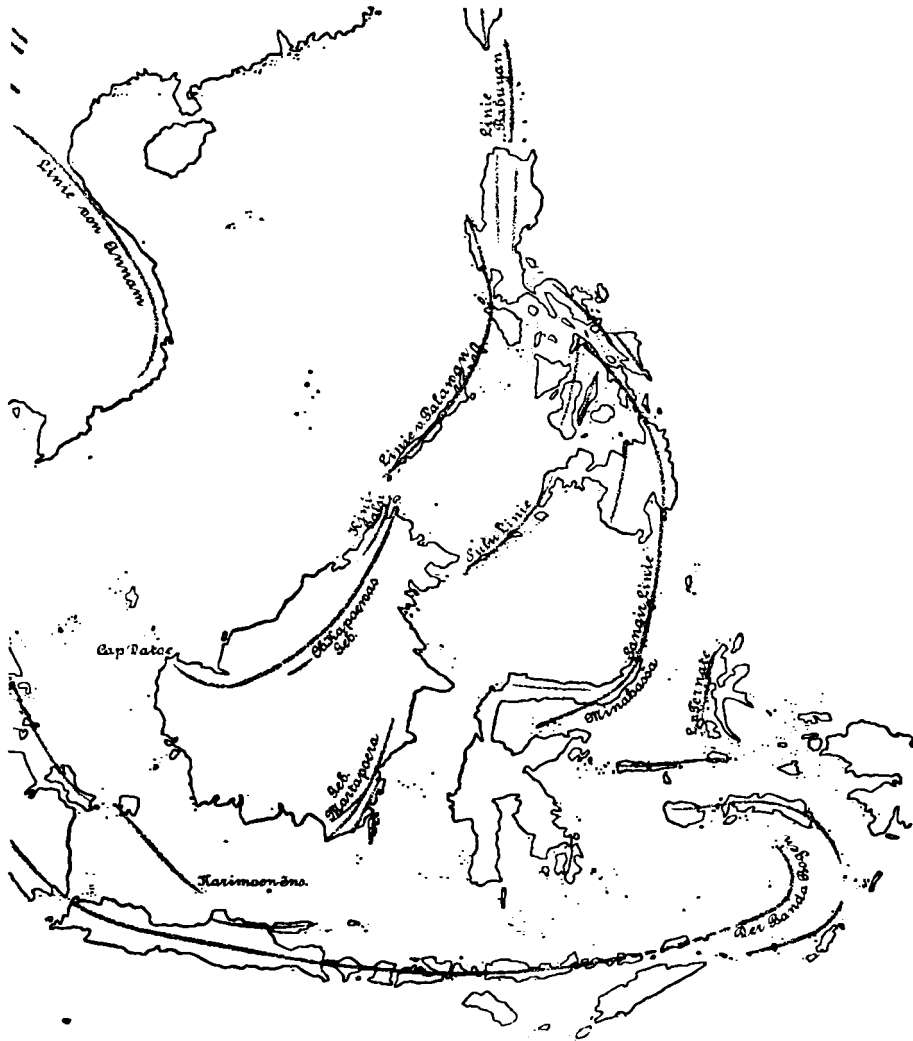
The structure of *Sumatra* has been discussed on an earlier page (I, p. 457). Ancient schists and gneiss-like rocks form its foundation; their direction corresponds to the form of the island; they are covered unconformably by a schistose mass of unknown age, but probably Carboniferous, then by the upper Carboniferous, richly fossiliferous, and by patches of Trias and Tertiary. Here two disjunctive lines occur: along the west coast a line of andesite eruptions, which is of Tertiary age, and further east the long line of active volcanos. The latter runs along the east side of the Barisan range, which is formed of ancient schists, and extends through the whole length of the island. The east side of the island is low and flat. We might fairly regard it as the continuation of the depression on the Irawadi and the gulf of Martaban. A very slight rise of the sea-level would render this continuity apparent. Long after the upper Carboniferous had been known on the west side Volz found it on the east also, and discovered in addition the patches of Trias mentioned above².

Thus it looks very much as if the ancient schist range of Sumatra, cut through or cut off by these two disjunctive lines, formed part of an independent coulisse which is not visible in Burma.

The whole region of the archipelago, as far as the continent of Australia—this, in contrast to the archipelago, is only affected by isolated transgressions—formed part of the Tethys, which extended from the

¹ R. D. M. Verbeek, *Geologische Beschrijving van Bangka en Billiton*, Jahrb. Mijnw. Ned. O.-Ind., XXVI, 1897, XXI, and atlas. The tin occurs as an impregnation completely independent of the hornstone in the zone of contact of the granite: it is associated with quartz veins, and is situated, in no small part, outside the granite in the region of the ancient sediments.

² W. Volz, *Beiträge zur geologischen Kenntniss von Nord-Sumatra*, Zeitschr. deutsch. geol. Ges., 1898, LI, pp. 1-61, map; L. Milch, *Ueber Gesteine von der Battack-Hochfläche (Central Sumatra)*, tom. cit., pp. 62-74; for a general survey, J. F. Hoekstra, *Die Oro- und Hydrographie Sumatras*, 8vo, Gröningen, 1893, 127 pp., map.



The Philippines and the Sunda Archipelago

After Drasche, Molengraaff, Hooze, Verbeek, Wichmann, Martin, Koto, and others)

continent of Asia across Yunnan, and the marine series deposited over this area does not appear to present any important gap, from the time of the upper Carboniferous to the present day. The Mesozoic sediments exhibit a striking resemblance to those of southern Europe, as is the case throughout the Tethys; in particular the abundant presence of igneous rocks rich in magnesium silicates is characteristic of the Cretaceous formation and of many Flysch ranges both in this region and Europe. The great bands of Flysch in Arakan, which are at least in part Cretaceous, do not end with the Andaman and Nicobar islands (I, p. 455); even in the Mentawai islands peridotite and serpentine occur, as described by Traverso, who mentions amphibolite also¹. After Martin had succeeded in showing that *Orbitulina concava* occurs in most intimate association with serpentine on the island of Java, Verbeek assigned to the Cretaceous formation not only the serpentines of the whole archipelago, but also the gabbro and diabase, as well as certain rocks hitherto regarded as amphibolite, and the green felspathic schists of the whole of this region².

It is not until the Tertiary period, during or shortly before the beginning of the first Mediterranean stage (Depéret's Burdigalien) of south Europe, that the marine faunas lose their affinities with Europe and acquire an Indian character which renders a direct comparison with the European series more difficult. The limestone characterized by *Lepidocyclina* (*Orbitoides*), attains considerable thickness; Martin has termed certain of its subdivisions the Java stage; it is certainly more recent than the Nummulitic limestone of the Eocene, and older than the continental formation containing the Siwalik fauna. In the southern Alps *Lepidocyclina* is found in the beds of Schio³.

The active volcanos of the principal zone of Sumatra and Java continue eastwards to the island of Pantar. From there onwards through Alor and Kamping to Romang (Roma) only ancient craters are known, clearly forming, however, part of the same line, and beyond Romang active volcanos again begin. At the same time, proceeding from Flores onwards, the arc-like trend of the whole range becomes more and more pronounced.

The case is so clear that the connexion between the volcanos beyond Romang, Damma, Teun, Nila, and Serua was recognized many years ago. The further continuation of the arc was sought, in accordance with what

¹ St. Traverso, Rocce di Sipora (Isole Mentavei), Atti Soc. Ligustica di Sc. nat. e Geogr. Genova, 1895, VI, p. 3.

² R. D. M. Verbeek, Voorloopig Verslag over eene geologische Reis door het Oostelijk Gedeelte van den Indischen Archipel in 1899, 8vo, Batavia, 1900, p. 15; also Verbeek et Fennema, Description géologique de Java et Madoura, 8vo, 1896, II, p. 928 et passim.

³ K. Martin, Eintheilung der Tertiärschichten auf der Insel Java, Zeitschr. deutsch. geol. Ges., 1900, LII, Protokolle, pp., 2-8. With reference to Douvillé's work on *Orbitoides* in Bull. Soc. géol. de Fr., 1898, 3^e sér., XXVI, p. 595 et seq., Martin places the genus *Lepidocyclina* in the Oligocene.

was known of the facts at the time, in the island of Tuur, but erroneously; the true continuation lies in Manuk and in the Banda group. Nevertheless its similarity in structure with the Lesser Antilles was even then recognized. Outside the volcanos in question an arc of non-volcanic islands was distinguished; and the Banda sea was compared with the Caribbean sea; the Arafura sea, on the other hand, with the gulf of Mexico, i. e. the fore-land (II, p. 167).

Almost at the same time Wichmann described the arc from Romang to the Banda islands. Martin and Kotô have also dealt with this question, and notwithstanding differences of opinion on points of detail, they agree that the Banda sea presents an arc of volcanos, which is open towards the west and surrounded on the south-east and north by a girdle of islands, formed either of ancient rocks or of Tertiary sediments¹.

This arrangement is shown very clearly on a map published by Wichmann in 1899. A line of fracture is represented as surrounding the Banda sea and running from Wetar, through Romang and the volcanos already mentioned, to the south coast of Nusalaut and Amboina. The sunken side lies towards the interior, i. e. towards the Banda sea. A second fracture fairly concentric with the first is marked as running from Kisser, Moa, west of the Tenimber islands through Tuur, to the south side of Ceram and Buru, also with subsidence towards the interior. A third concentric fracture would seem to run in an arc east of the Tenimber and Kei islands to the north side of Ceram and Buru, with subsidence on the outside. Thus represented, we might regard the whole zone of the Tenimber, Kei, and Watubele islands, together with Ceram and Buru, as resting upon an arc-shaped horst, and this would be separated on the north by a trough subsidence from New Guinea, Misul, and Obi².

A somewhat divergent description is furnished by Verbeek, one of the most distinguished authorities on these regions. According to his conception, a connexion between the principal chain running through Java-Sumbawa-Flores and the Banda arc of active volcanos is not admissible, on account of the greater age of the volcanos between Pantar and Romang. He regards the Banda arc as the border of an independent subsidence, and traces it through Damna, Teun, Nila, Serua, Manuk, the Banda group, and

¹ A. Wichmann, *Gesteine von Kisser*, Samml. geol. R. Mus. Leiden, 1887, II, pp. 183-201, pl. V; also the sketch in *Tijdschr. Ned. Aardr. Gen.*, 1892, 2nd ser., IX, tab. XIII, fig. 4. K. Martin, *Die Kei-Inseln und ihr Verhältniss zur Australisch-Asiatischen Grenzlinie*, *Tijdschr. Ned. Aardr. Gen.*, 1890, pp. 240-280; in particular p. 260 et seq. B. Kotô, *On the Geological Structure of the Malay Archipelago*, *Journ. Coll. Sci. Tokyo*, 1899, XI, part 2, pp. 85-120, map.

² A. Wichmann, *Der Wawani auf Amboina und seine angeblichen Ausbrüche*, *Tijdschr. Ned. Aardr. Gen.*, 1899, No. III, 109-142, map; also K. Martin, *Einige Worte über den Wawani, sowie über Spaltenbildungen und Strandverschiebungen in den Molukken*, tom. cit., pp. 709-742.

then much further still, west of the Tortoise and Lucipara islands, formed of limestone, to the volcano of Api, north of Wetar, and finally back to Damna, so that it describes a closed ellipse¹.

We must first consider the configuration of the sea bottom.

It has long been known that the Banda sea, in contrast to the open Ocean, possesses an equable temperature below a depth of 1,600 meters of about 3° C., and that the sea of Celebes, below a depth of 1,300 meters, down to the deepest parts of its basin, maintains a temperature of 3.7° C. From this it has been concluded that the lower and colder waters of the Ocean do not enter the deeper parts of these two seas. Weber's report on the soundings carried out by the Dutch ship *Siboga* shows that ridges actually occur bounding these greater depths².

The thousand-meter line unites Australia in a broad arc with New Guinea and Halmahera. South of Halmahera the Obi islands form a long band, lying above the thousand-meter line, and only separated by a narrow interval from a further band which unites at a common level Bossi, Mangola, and Taliabo with the Peling islands and the adjacent parts of Celebes.

If, making use of Weber's data, we draw a section from the bottom of the Banda sea to east or south-east across the island arcs which here come into question, we obtain the following: (a) The Banda sea is here very deep and reaches 5,684 meters. (b) The recent volcanos, from Damna to the Banda group, stand upon a common ridge. (c) This ridge is succeeded towards the exterior by an arc-like furrow which presents depths of 3,000 and even 4,000 meters. (d) Finally, we reach the line of the outer island arc, and with it the fragment of the cordillera.

From this I think we may fairly infer that the principal fracture lies on the inner side of (d) and that the ridge (b) which separates the subsidences (a) and (c) consists of volcanic ejectamenta.

In addition, an independent elevation, the *Siboga* ridge, extends from the volcano of Api towards the north-east, and embraces the Lucipara and Tortoise islands. Beyond it, towards the north-east, the sea bottom again sinks below 4,000 meters.

If we could withdraw the veil which the Ocean extends over the abyss of the Banda sea, and thence to Sumatra over all the prolongations of the Burman arc, a most magnificent spectacle would present itself to our gaze.

¹ R. D. M. Verbeek et R. Fennema, *Description géologique de Java et Madoera*, 2 vols., 8vo, et Atlas, Amsterdam, 1896, pl. I et passim; Verbeek, *Voorloopig Verslag over eene geologische Reis door het Oostelijk Gedeelte van den Indischen Archipel in 1899*, *Extra-Bijvoegs. d. Javash. Courant*, No. 6, Batavia, 1900, 48 pp., map.

² M. Weber, *Die niederländische Siboga-Expedition zur Untersuchung der marinen Fauna und Flora des Indischen Archipels und einige ihrer Resultate*, *Peterm. Mitth.*, 1900, XLVI, pp. 182-191, map.

The very steep slope, descending rapidly to depths of 3,000 and 3,500 meters, which borders the west side of the Nicobar and Mentawai islands, draws close to the south coast of Java, and it is not till it has proceeded far to the east, and is approaching Sumba, that the sea bottom begins again to ascend; here the great slope turns to the south-east. At a still greater distance from Java the sea descends to below 7,000 meters in the Maclear deep, and beyond this subsidence, about 280 kilometers south of Java, rises a great isolated mountain, Christmas island (+ 356 meters); its flat summit rises as high above the floor of the sea as the peaks between Ta-tsien-lu and Batang above the surface; if laid dry, it would surpass them in grandeur.

For a great distance around the depths vary between 4,500 and 6,000 meters.

Thus Sumatra and Java reveal themselves as the highest parts of a mighty mountain slope which forms the boundary between the lesser depths in the direction of Borneo and the region of the Burman folds, on the one hand, and the Ocean on the other; a slope incomparably more important than the boundaries of the same kind which are visible on the continent of Asia. It is true that the levelling action of subaerial denudation does not here play so great a part, and that volcanic ejectamenta have also to be taken into account. Nevertheless a question may be raised as to how far the absolute or relative height should be considered, besides the breadth, in determining the importance of a folded range; a question which involves many others extremely difficult to answer. We will disregard them for the present and turn our attention to *Christmas island*, of which Andrews has furnished an instructive description¹.

Christmas island is one of an increasing number of islands which were formerly regarded as raised coral reefs, and are now known to consist of normal sediments of the Tertiary aera. In this case the mountain crowned by these sediments is no doubt an ancient volcano, and its slopes are so steep and uniform that depths of over 5,000 meters are met with at distances of about 30 kilometers in every direction. All around the volcano is covered by a mantle of Tertiary beds, once of much greater extent, and now cut off on all sides by cliffs; an intercalation of trachyte occurs, and two later intercalations of basalt. An Eocene or Oligocene limestone extends up to a height of 250 or 300 feet (76-91 meters), and above it, up to at least 550 feet (167 meters) the same middle Tertiary limestone with *Orbitoides* (*Lepidocyclina*), which is so widely distributed in Java, as well as further to the north and east. The upper parts of the island are covered with dense vegetation and deep soil formed by the decomposition

¹ C. W. Andrews, A Monograph of Christmas Island (Indian Ocean), 8vo, London, 1900. (publ. by British Museum), in particular pp. 269-298. map.

of volcanic ash. Near the summit disconnected masses of limestone appear, containing indistinct organic remains, and to a great extent converted into dolomite.

On the summit itself (356 meters) the hard yellowish-white rock contains 40.02 per cent. of magnesium carbonate. Here Andrews thinks he has recognized the traces of an ancient atoll. Small nodules are found formed of alternate concentric layers of calcium phosphate and manganese dioxide. The association of ancient guano beds, volcanic ash, sea-water, and limestone has afforded the requisite conditions for the formation of these mineral structures¹.

The formations of the summit are succeeded, in point of age, by the more recent deposits which form terraces on the slopes; some of these terraces have been produced by undercutting of the Tertiary beds, others are independent fringes of limestone. They descend to the sea in more or less well-marked steps; the last but one, at a height of about 15 meters, is formed of coral limestone with a very fresh appearance; the lowest lies only 2.7-3 meters above the sea.

In discussing the Suez canal we distinguished an ascending (superposed) and descending (apposed) series of deposits (I, p. 378). That the latter was formed during a mainly negative movement of the shore-line is certain: as to the former, the case is ambiguous. The limit between the two lies on the summit of the table-mountains. Similarly the dolomitized rock on the summit of Christmas island must be regarded as the last member of the ascending series, which belongs chiefly, or even entirely, to the Tertiary period, while the terraces are the visible expression of the intermittent negative movement. The deposits on the summit indicate the height at which this negative movement laid bare the then existing sea floor, and if it were certain that no tectonic movements had occurred subsequently, then this height would be 365 meters above the existing strand. But the Tertiary beds are intensely folded in parts of Java, and it is not at all impossible that in Christmas island also tectonic changes may have taken place since the Tertiary aera, simultaneously with negative eustatic movements of the strand.

This supposition becomes more probable if we turn our attention further east, where, between Sumba and Timor (long. 119° to 124° E.), a folded range emerges from the Maclear deep.

Sumba, according to Verbeek, is formed of ancient schists, granite, and Cretaceous diabase; *Rendjuwa* and *Savu* afford traces of Permian and Trias; on *Rendjuwa* we see middle Tertiary beds, with *Lepidocyclina*

¹ C. W. Andrews, A Monograph of Christmas Island, p. 290; E. W. Skeats, op. cit., p. 268. Gregory thinks it probable that the Tertiary limestone reaches the level of the plateau, op. cit., p. 208.

dipping at a high angle; on Savu a steep anticline of Eocene, striking to north-east, and above it beds with *Lepidocyclina* which attain a dip of 40° ¹.

Rotti and *Timor* reveal that varied series of sediments which were made known for the first time many years ago through the collections of Schneider, studied by Beyrich. Subsequently Rothpletz, from an examination of Wichmann's collections, was able to show the existence of Permian, Trias, various stages of the Lias, and traces of higher subdivisions of the Jurassic; lastly, Boehm recognized *Macrocephalites macrocephalus* in Verbeek's collection from Rotti. This series rests on Archaean rocks, the existence of which on the north-west coast of Timor had already been inferred by Beyrich from Salomon Müller's observations; and we now know from Verbeek that it is overlain by Cretaceous eruptive rocks and Tertiary beds².

The structure of the little islands lying to the north-west of Timor is of importance because it shows that *the cordillera of the Banda arc reaches here from Sumba and Timor*. We learn, indeed, from Verbeek's observations that *Leti* consists of crinoidal Permian limestone, together with gabbro, and serpentine; the latter are Cretaceous eruptive rocks and reappear in *Moa*, *Kissar*³, and *Sermate*; *Luang* is formed of crinoidal limestone, and from *Babar*, Trias(?), a Mesozoic *Lytoceras*, and diabase are known; the diabase also forms the island of *Dai*.

From *Seera*, in the Tenimber group, Martin mentions crystalline limestone, dolomite, and quartzite, while elsewhere in this group, as far as it has been studied, Tertiary beds prevail. *Vordate* is middle Tertiary, and *Great Kei* likewise; the latter, perhaps, with Eocene in its lower parts⁴. *Kuur* consists, according to Verbeek, of ancient schists, which again crop out on *Tuur*; no volcanos occur on this island, but there are basic eruptive rocks of Cretaceous age; and these are continued into *Watabele* and *Manawoko*. We have now followed the course of the arc to the neighbourhood of *Ceram*; but before discussing that great island the following facts may be mentioned.

The evidence afforded by the rocks from Timor on to the Babar group

¹ R. D. M. Verbeek, Voorloopig Verslag, p. 18 et seq.

² E. Beyrich, Zeitschr. deutsch. geol. Ges., 1862, XXIV, p. 537, and Ueber eine Kohlenkalk-Fauna von Timor, Abh. k. preuss. Akad. Wiss., Berlin, 1864, pp. 61-98; Schneider, Bijdrage tot de geologische kennis van Timor, Natuurk. Tijdschr. voor Nederl.-Indie, 1863, XXV, pp. 87-107, und Geologische Uebersicht über den holländisch-ostindischen Archipel, Jahrb. k. k. geol. Reichs., 1876, XXVI, pp. 113-134, maps; A. Wichmann, Bericht über eine im Jahre 1888-1889 ausgeführten Reise nach dem indischen Archipel, Tijdschr. Ned. Aardr. Geñ., 1892, IX, pp. 161-176; A. Rothpletz, Die Perm-, Trias-, und Jura-Formation auf Timor und Rotti im indischen Archipel, Palaeontographica, 1892, XXXIX, pp. 57-106, map; Boehm, in Verbeek, Voorloopig Verslag, p. 48, and Reise-notizen aus Ost-Asien, Zeitschr. deutsch. geol. Ges., 1900, LII, pp. 554-558.

³ Wichmann, Gesteine von Kisser (see above, note 1, p. 237).

⁴ Martin, Die Kei-Inseln (note 1, p. 237).

proves conclusively that Timor belongs to the arc¹. Some of the islands however (Kambing, Lirang, Wetar), lie to the north of Timor, the two latter, indeed, almost due north, and consequently within that portion of the volcanic arc, running from Pantar to Roma, which is described by Verbeek as of greater age. Even west of this fragment we meet, according to Verbeek, with melaphyre in *Alor*, and traces of Lias or Trias in *Kambing*². *Lirang* and *Wetar* are formed of ancient eruptive rocks, principally diabase.

All these circumstances combine to emphasize the significance of that interruption in the series of active volcanos which occurs, as pointed out by Verbeek, to the east of Pantar; they also show that in Sumba, Savu, Rotti, and Timor a new coulisse appears, and it is this which forms the cordillera of Banda. In accordance with this interpretation, the cordillera of Banda, throughout the whole of its course to Ceram, nowhere presents a single recent volcano. The older rocks and sediments lie towards the interior, while towards the exterior (Tenimber, Kei) Tertiary beds prevail, and still further towards the exterior the limestone platforms of the Aru islands assume the part taken by the Bahamas in the arc of the West Indies. In this way we perceive an increased resemblance between these widely separated island-chains.

General results of no slight importance might be expected from a detailed investigation of the girdles of coral limestone, and the terraces, which are known not only on Christmas island but in Java and very many of the Banda islands, and again in Halmahera and New Guinea, where they attain a considerable elevation. The middle Tertiary beds with *Orbitoides lepidocyclus* are, as we have seen, folded in Java, Sumba, and other islands; on the other hand, an observer so well qualified as Verbeek declares that within the girdles no line of division can be drawn between the upper Tertiary (Pliocene), Quaternary, and recent formations, and that the existence of such a line of division is even improbable. But no one doubts that the existing coral and limestone formations are of the same nature as those of the girdles, and in direct continuation with them, and that among these formations the highest are the most ancient.

Here we have the opportunity seldom offered of comparing the effects of orogenic movements of the lithosphere with those of intermittently negative movements of the strand, and of estimating the relative importance of these effects. It is precisely in a case like this that the independence of the two movements is most clearly displayed³.

¹ So also Wichmann, Wawani, in *Tijdschr. Ned. Aandr. Gen.*, 1899, 2nd ser., XVI, p. 135.

² Schwager in Wichmann, op. cit. 1892, IX, p. 184.

³ Verbeek mentions cases in which the uppermost limestone beds present a small inclination (5°-10°), the middle a still smaller, while the more recent lie horizontal. I should be inclined to attach little importance to inclinations of this kind in the direction of the dip, because observation shows that they may arise from secondary causes, even from decalcification due to the flow of subterranean water. On the other

Probable prolongations of New Guinea. The group of islands which includes Ceram and Buru, Amboina, and the Uliasser islands, has been described by Martin, and Verbeek has made a special study of Amboina¹. Both Wichmann and Verbeek mark a fault-trough between Ceram and the islands to the south of it, as though a splitting of the arc occurred there².

In *Amboina* we encounter, according to Verbeek, granitite and ancient diabase; more recent than these is the peridotite, and the greater area is occupied by the norite-porphyrates for which the name Amboinite has been proposed; these, as well as the peridotite, are regarded as Cretaceous. In any case, they may be considered, like a part at least of the rocks of the *Uliasser* group and the island of *Amblau*, situated to the west, as the continuation of those basic rocks which we have traced to Watabele and Manawoko. A sandstone, probably of lower Mesozoic age, also occurs in Amboina.

Ceram and *Buru* form, according to Martin, an imposing band of Archaean rocks, which runs east and west, and consists of mica-schist, associated with a limestone (the Buru limestone) of unknown age. On the south side of Ceram remains of an Ichthyosaurus were found, and in the north-west part of Buru, Belemnites and Aptychus are known to occur. At many localities in Ceram, as well as in *Kelang* and *Manipa*, the Cretaceous eruptive rocks appear³.

Near the west coast of Buru, the Kapala Madang, probably formed of Buru limestone, reaches a height of 2,600 meters.

It is, in itself, scarcely probable that the cordillera which comes from Sumba and Timor should reappear here in full development, after having broken up into a series of small islands and reefs. I am therefore inclined to regard the arc of Timor as uniting with another independent chain, striking east and west, and believe that Buru and Ceram should be looked upon as a continuation of the southern peninsula of New Guinea.

Many circumstances support this view, which, owing to the very hand, disturbances of the course of the horizontal line would be important. Here the difficulties connected with the Alpenfjord are possibly repeated. Verbeek, Voorloopig Verslag, p. 37 et seq.

¹ K. Martin, Ueber seine Reise in den Molukken, durch Buru Seram, und benachbarte kleinere Inseln, Verh. Ges. f. Erdk. Berlin, 1894, pp. 506-521, map; Reisen in den Molukken. I. Ambon und die Uliasser, 8vo, Leiden, 1897, maps. Ein Ichthyosaurus von Ceram, Samml. geol. R.-Mus. Leiden, 1898, IV, pp. 70-85; J. L. C. Schroeder van der Kolk, Mikroskopische Studien über Gesteine aus den Molukken, I. Gesteine von Ambon und den Uliassern, Jaarb. Mijnw. Ned. O. Ind., 1895, XXIV, pp. 1-57; R. D. M. Verbeek, Over de Geologie van Ambon, Verh. k. Akad. Wetensch., Amsterdam, 1899, 2 sect., VI, No. 7, pp. 1-26; and the works of Martin and Wichmann on the Wawani, quoted above.

² Wichmann also marks a third arc, which runs from the north-west coast of Australia across the Aru islands, the west coast of New Guinea, and the south coasts of Misul and Obi.

³ For the older rocks in the north of Buru cf. also Schroeder van der Kolk, Samml. geol. R.-Mus. Leiden, 1900, VI, pp. 77-127.

limited knowledge we possess of New Guinea, cannot be more closely investigated.

The great cordillera of New Guinea bends completely into an east-and-west direction at its western extremity, and reaches the west coast in lat. 4° S. under the name of the Charles Louis mountains.

The same direction is followed by the Arfak mountains (about 2,400 meters high) in the north peninsula.

The M'Cluer inlet enters so deeply in between the two northern peninsulas of New Guinea that it is separated from Gelwinck bay by a ridge only 25 to 30 kilometers broad. This ridge consists, according to A. B. Meyer, of limestone; while in the north and south Archaean rocks, especially granite, are known, and from the Arfak range gneiss also¹.

The position of M'Cluer inlet corresponds to a zone of the ocean almost devoid of islands, which extends westwards to the east coast of Celebes; this zone is bounded on the north by the islands of Misul, Obi-Besar, Manguli with Sula Bessi, Taliabo, and the Peling group, which are parallel to Ceram and Buru, and extend to Celebes. South of Obi the sea reaches a depth of 3,400 meters.

For information on this chain of islands we must again turn to Verbeek's observations. Archaean rocks, generally accompanied by granite, appear on most of the islands of the *Peling* group, also on *Taliabo*, *Manguli*, *Sula Bessi*, and, according to Wichmann and Kükenthal, on the *Obi* islands also.

On the south side of Taliabo and Manguli, Jurassic beds also appear, which, according to G. Boehm, contain *Stephanoceras Humphriesianum*, *Stephanoceras Brongniarti*, and *Belemnites Gerardi*; Cretaceous likewise occurs with *Hoplites*, *Acanthoceras*, *Schloenbachia*, and *Inoceramus*². To the east, in *Misul*, the 'Siboga' expedition met with *Ammonites* and *Belemnites*.

The Cretaceous eruptive rocks, so often mentioned, are known at several localities in the eastern peninsula of Celebes—*Bangai*, both in the north towards the gulf of Tomini, and in the south towards the gulf of Tolo; they reappear in Obi Besar, Obi Latu, and the little island of Tamat.

Wichmann states that a band of olivine rocks may be traced from the south-east peninsula of Halmahera, through *Fau* near *Gebee*, and through *Gag* to *Waigu*; and Verbeek mentions these Cretaceous eruptive rocks from so many localities between Misul and Waigu that they probably form, along with Tertiary sediments, the greater part of the islands between Halmahera and New Guinea.

¹ A. B. Meyer, Auszüge aus den auf einer Neu-Guinea-Reise im J. 1873 geführten Tagebüchern, fol., Dresden, 1875, p. 16; A. Frenzel, Mineralogisches aus dem ostindischen Archipel, Jahrb. k. k. geol. Reichs., 1877, XXVII (Tschermak, Min. petr. Mitth.), pp. 306-308.

² Boehm in Verbeek, Voorloopig Verslag, p. 48.

They also appear in *Batanta*, *Salawati*, as river pebbles on the north coast of New Guinea, and in the island of *Roon* in Gelwinck bay, which for the rest is formed of mica-schists. The natives search for the serpentine and make use of it, so Beccari states when referring to the neighbourhood of Humboldt bay¹.

It is a remarkable fact that the whole of that part of the archipelago which runs east and west between New Guinea and Celebes is without volcanos. It is not till we reach the north, in the direction of Halmahera, that Wichmann and Verbeek mark a number of andesitic cones. These are, according to Verbeek: *La-wien* (east of Obi Besar), *Pisang*, *Kofiau* (north of Misul), and somewhat further north, *Klaarbeek*. Wichmann regarded them as the continuation of a line of fracture starting from the south-west of Halmahera and convex towards the south-west; Verbeek marks two parallel and independent lines running in an east-north-east direction towards the north coast of New Guinea.

Formosa (II, p. 175). The Liu-kiu group consists of two series of islands: one, lying to the west, volcanic; the other, on the east, formed of the remains of the cordillera. We have traced the cordillera to Okinawa-shima (II, p. 176). Kotô supposes that this cordillera reappears to the south in the *Nambu-sho-to* (southern) islands, but with a bend of the strike, and at the same time with a screw-twist as it were, so that its folding appears henceforth to be directed, not to the east, but to the west, and it so continues to Formosa².

This theory accords with Yamasaki's statement that the *Niitaka chain*, the most important in Formosa, strikes in the north of the island to the west-south-west, further down to the south-west, and finally, in the south of the island, to the south, so that it forms part of an arc concave to the ocean. It first presents itself on the north-east coast of the island in a mighty precipice extending from lat. 24° 30' to 24° 10' N., rapidly ascends in Selsu (Sylvia) to 3,424 meters, reaches 4,145 meters in the Niitaka-yama

¹ O. Beccari, in *Cosmos* di G. Cora, 1875-76, III, p. 371.

² B. Kotô, *The Geological Structure of the Liu-Kiu Curve*, Geol. Mag. Tokyo, 1897, V, No. 49, pp. 1-12, map. In addition to the zones mentioned above (II, p. 176) Kotô distinguishes an eastern, outer, and more recent zone, by which the resemblance to the Antilles is increased. It runs through Tanega shima, Kitai, the south-west part of Okinawa shima, Miako shima (with *Lepidocyclina*), and the southern part of Nishi Omoti. It consists chiefly of coral limestone. The bend in Nam-bu-sho-to was marked by Kotô on the map, but has not yet been described; no competent geologist has yet visited this island. We know that granite and gneiss occur in the north half of Ishigaki, but only from hand specimens; the south half is Tertiary. Marine Tertiary, with coal occurring in a syncline, is described by Yoshishara from the north-west end of Formosa, op. cit., 1899, VI, No. 72, p. 333. A section across Formosa published by Ishii corresponds on the whole with the description given here. The *Geological Magazine* of Tokyo appears in the Japanese language, and I am indebted for the communication of these facts to Mr. Yamasaki.

(Mount Morrison), and then sinks towards the south beneath Tertiary deposits which form the whole southern promontory.

The Niitaka chain, so far as it has been examined, is formed of ancient schists and crystalline limestone. It is accompanied in the west by the *Kali chain*; regularly stratified Tertiary sediments, Nullipore limestone, and sandstone with *Lepidocyclina*, form its parallel ridges, 'resembling a number of books shoved one against the other.'

The east side of the Niitaka chain is very steep; a sharply defined longitudinal valley runs along its foot from lat. 24° to $22^{\circ} 45' N.$, and separates it from the narrow and parallel range of *Taitō*, which forms the east coast of this region, and consists of Tertiary deposits, with andesite and tuffs.

The most northerly part of Formosa is distinguished by the active volcanic group of the *Taiton*¹.

The statement that basaltic tuff occurs on the *Pescadores* is confirmed by Kotō; three separate streams of basalt are to be seen (II, p. 176). The presence of lignite beds in the tuff may be noted. The little islands south of the Rover channel also consist of basalt.

Kashō (Samasano), east of Formosa, is a conical mountain of andesite.

Kōtō-sho (Botel-tobago) shows feldspar-basalt and andesite, and also gabbro and serpentine; perhaps the basic rocks which attain so great an extension in the south commence here².

Kotō regards Botel-tobago, lesser Botel-tobago (*Shō-Kōtō*), the Forest, Belle, and Gadd reefs, the Batun and Babujan islands, as members of a chain which extends to the volcano of Cagua, in north Luzon. This view accords with Drasche's results. As a point of great interest it may be observed that the volcano of Cagua, in north Luzon, stands not on a coulisse, but in a coulisse valley, which precisely resembles the line of Barren island in the gulf of Pegu.

Borneo. The theory that tectonic relations exist between the Philippines and the Malay Archipelago is an old one. As early as 1845 Earl drew up a map on which one volcanic arc is marked from the Liu-kiu islands to Formosa, and a second from Formosa to Luzon; at Luzon the arc divides and runs to south and south-west in two arcuate lines which correspond almost exactly with the lines obtained by Centeno some years afterwards (II, p. 174). East of Flores these two lines again unite, and are continued through Java and Sumatra to Barren island, so that the Philippines and the whole Malay archipelago appear to be surrounded by a single volcanic arc. Another similar arc runs, according to Earl, from the north-west of

¹ N. Yamasaki, *Unsere geographischen Kenntnisse von der Insel Taiwan (Formosa)*, Peterm. Mitth., 1900, pp. 221-234.

² B. Kotō, *Notes on the Geology of the dependent Isles of Taiwan*, Journ. Coll. Sci. Tokyo, 1899, XIII, part 1, 57 pp., map.

New Guinea eastwards, through the Solomon islands and the New Hebrides, to New Zealand ¹.

Unfortunately the author of this remarkable work was led by incomplete observations to assume that the ancient rocks of Malacca strike across Borneo and the volcanic arc to Australia. And, just at the time his work appeared, Richard Owen, by his descriptions of the fossil marsupials of Australia, had seemed to confirm the conclusion that a connexion between Australia and Asia cannot have been in existence since a comparatively remote period. The views of Earl consequently met with opposition, and his work was forgotten.

By others the question has been raised, whether it is not possible to discover from a study of simultaneous eruptions some intimate connexion between the volcanos which extend from the Sangi (or Sanguir) group, north of Celebes, to Mindanao or even to Luzon. Perrey has collected data bearing on this subject ².

The works of R. von Drasche have made us better acquainted with the virgation of the Philippines, which opens out towards the south (II, p. 171). This virgation reveals the points of junction with the Malay archipelago. Its dominant lines may be easily recognized by a glance at the map. The first is the *Palawan* line, which cuts off the south China sea. The second is the *Sulu* line, which bounds the Sulu sea; the third, the *Sangi* line, which bounds the Celebes sea. A fourth line occurs, but less obviously; this lies to the north, off the west coast of Halmahera; it is the line of *Ternate*.

The first line is the most nearly continuous, the second less so, the third still less; the fourth is a fragment. The first is represented by ancient rocks, the second by recent sediments, partly resting on basalts. The third is represented by volcanos; it may be traced, especially with the help of Abella's observations, from the island of Bilirán, as far as the great volcanic zone of the Albai, in the south-east of Luzon ³. The fourth, likewise, is represented by volcanos; its northern continuation is not visible.

In comparing these lines, which are in part coulisses (Palawan), and in part volcanic (Sulu, Sangi, Ternate), it may be observed that here, and particularly in Mindanao, the fact again becomes apparent that the volcanic

¹ G. Windsor Earl, Contributions to the Physical Geography of South-Eastern Asia and Australia. This memoir appeared first in the Trans. R. Geogr. Soc. London, 1845, XV, and then, with very important additions, in the Journal of the Indian Archipelago, Singapore, 1852, VI, pp. 243-277, map, and 1858, new ser., II, pp. 278-286.

² A. Perrey, Documents sur les tremblements de terre et les phénomènes volcaniques dans l'Archipel des Philippines, Mém. Acad. Sci. Dijon, 1860, 2^e sér., VIII, pp. 85-194, map, according to Hochstetter; cf. also J. N. Aguilar, Mindanao, su historia y geografia, 8vo, Madrid, 1894, p. 73.

³ E. Abella y Casariego, La Isla de Bilirán y sus Azufrales, Bol. Com. Mapa geol. España, X, 1884, XI, pp. 359-369, map; in particular p. 365.

lines correspond more frequently to valleys between coulisses than to the coulisses themselves.

The north-east of Borneo corresponds to the breadth of the Sulu sea; only a few years ago very little was known of the structure of this great island (II, p. 167).

As regards the arrangement of the mountain ranges of the interior, it was supposed to resemble Halmahera or Celebes. Then the preponderant influence of the direction from north-east to south-west or from north-north-east to south-south-west received increasing recognition¹.

We have since learnt from Molengraaff's explorations, to which the latest great advance in our knowledge of the island is due, that the centre of Borneo is occupied by broad zones with an almost due east-and-west strike². A study of the observations at present at our disposal affords the following summary:—

The island of Banguay in the Palawan chain is formed of serpentine and marble³; a little south of it lies the small island of Malwalli, where a hot mud spring is mentioned; then we reach Borneo. The two promontories which bound the bay of Marudu mark the beginning of the most important mountain range in the island. Towards the south-east a vast plain extends, reaching the hilly ranges which form the north side of Darvel bay⁴, but towards the south-west a range formed of sandstone and slates rises higher and higher until it culminates in the mass of *Kinibalu* (5,088 meters), which is formed of syenitic granite, and dominates all the surrounding country. According to Spencer St. John's account, extremely steep and lofty cliffs separate the granite mountain on several sides from a deeply furrowed range which surrounds it. The summit, or rather the crest, is about three kilometers long, and towards the north-east, separated from it by a deep fissure, extends a longer jagged ridge which is 3,000 to 3,300 meters high. Another spur runs first to the south-west, and then to the south-south-west; it soon sinks to 2,400 meters, but is at least 30 kilometers in length. At a distance of 45 kilometers the height of the passes sinks to 1,370 meters. Towards the west the height of the granite cliffs

¹ See the works of Dutch geologists in the south-east of the island, which will be quoted later, and T. Posewitz, *Borneo*, 8vo, Berlin, 1889, maps, p. 198.

² G. A. F. Molengraaff, *Die niederländische Expedition nach Central-Borneo in den Jahren 1893 und 1894*, Peterm. Mitth., 1895, pp. 201-208, map, and *Geologische Verkenningstochten in Centraal-Borneo (1893-1894)*; uitgegeven door de Maatschappij ter Bevordering van het Natuurkundig Onderzoek der Nederlandsche Koloniën, 8vo, XXI, Amsterdam, 1900, atlas and appendix. Hinde, *Description of Fossil Radiolaria from the Rocks of Central Borneo*, Leyden, 1899, 56 pp.

³ F. Giordano, *Una esplorazione a Borneo*, Boll. Soc. geogr. Ital., 1874, XI, p. 209, map of the island of Buguey.

⁴ It has been described by W. B. Pryer, *Notes on North-Eastern Borneo and the Sulu Islands*, Proc. R. Geogr. Soc., 1883, p. 90.

reaches thousands of feet, but the adjacent chains sink so rapidly that at a distance of less than 40 kilometers we reach the sea-shore¹.

The trend of the crest of Kinibalu corresponds with that of the range, which, as Crocker recognized many years ago, runs first, with varying height, to the south-south-west and south-west, and reaches the mountain of Tjondong or Tidong in about long. $112^{\circ} 25' E$. In its course, from about lat. $1^{\circ} 30' N$. onwards, the range gradually bends into an east-and-west direction, then to the north-west. On the upper Sikajam (long. $110^{\circ} 20' E$.), where the bend to the north-west is most marked, masses of gabbro rise through the schist²; finally the arc reaches the west coast of Borneo in the schistose rocks of cape Datu and the granite of Gading, a neighbouring mountain (lat. $2^{\circ} 5' N$.)³.

Such evidence as we at present possess seems to show that the sediments on the north side of this arc are characterized by great variety. The sandstones appear to be widely distributed⁴; long limestone zones appear, in which the well-known bird caves are found. In Sarawak one of the early floras of the Gondwana series was recognized by Tenison Woods (II, p. 168); some of the limestone bands are probably Palaeozoic, but from a limestone of another kind, on the banks of the Sarawak, R. B. Newton has described examples of *Alectryonia amor*, a species which occurs in the middle Jurassic of Europe⁵. Finally the Tertiary coal of the island of Labuan must be assigned to the outer border.

It is this range to which Molengraaff has given the name of the *upper Kapuas mountains*: he has traced its southern slopes eastwards from the sources of the Kapuas to long. $114^{\circ} E$. The brilliant achievements of this explorer throw great light on the structure of the interior of the great island.

The river Kapuas, of greater length than the Rhine, flows in a westerly direction; it rises in lat. $1^{\circ} N$., and discharges into the sea a little south of the Equator. Its fall from Bunut, 738 kilometers from its mouth, to the sea, amounts to only 37 meters. At Bunut we are in the vast and

¹ Spencer St. John, Observations on the North-west Coast of Borneo, Geogr. Journ., 1862, p. 219; O. Stapff, On the Flora of Mount Kinibalu in North Borneo, Trans. Linn. Soc., 1894, 2nd ser., Botany, IV, contains a collocation in pp. 70-78 of all the observations made on the structure of this mountain mass.

² C. J. van Schelle, Onderzoek naar Cinabar en Antimonium-glans in het Bovenstroomgebied der Sikajam-Rivier, Jaarb. Mijnw. Ned. O. Ind., 1884, XIII, pp. 123-141, maps.

³ W. M. Crocker, Notes on Sarawak and North Borneo, Proc. R. Geogr. Soc., 1881, already marks on the map this deflexion to cape Datu.

⁴ e.g., D. D. Daly, Explorations in British North Borneo, Proc. R. Geogr. Soc., 1888, pp. 2, 12, 15.

⁵ R. Bullen Newton, On a Jurassic Lamellibranch and some other associated Fossils from the Sarawak River Limestones of Borneo, with a Sketch of the Mesozoic Fauna of the Island, Geol. Mag., 1897, Dec. 4, IV, pp. 407-415.

low-lying alluvial plain of the Kapuas; north of the river, great lakes broaden out. To the north of the plain and the lakes lies the range of Kapuas; it forms a gentle arc convex towards the south. Starting from Berau, on the east-north-east, it reaches a height of 1,767 meters in the mountain of Lawt, on the watershed of the Kapuas, and then forms the mountain of Tjondong (1,242 meters), previously mentioned. North-west of the great lakes (west of long. 112° E.) it sinks very low, then it rises again, bend to the west-north-west, and reaches, as we have seen, cape Datu.

The upper Kapuas range consists, in the region examined by Molengraaff (long. 112° to 114° E.) of lustrous phyllite with veins of quartz. It breaks off towards the south in a long fault running east and west, which separates it from the plain of the river. Out of the plain rise hills and ridges of the Danau formation, which includes marl, limestone, and occasionally diabase tuff with beds of jasper and Radiolaria, possibly, according to Hinde, of Jurassic age. These rocks are deeply let down along the phyllite chain: they have been traced from east to west for a distance of 280 kilometers. Towards the south we encounter above them folded Cenomanian beds with *Orbitolina concava*.

Above this faulted-down series a volcanic range of later date appears on its southern border; Molengraaff terms it the *Müller mountains*. It begins in long. $112^{\circ} 30'$ E. as a series of isolated andesite mountains, which run to the east, till their place is taken, in the same direction, by a broad table-mountain of horizontal volcanic tuffs, which are probably 1,200 meters thick, and contain silicified tree-trunks still in the position in which they grew, like those which have been discovered in the tuffs of the National park of the Yellowstone region. Still further east, taking the place of the tuff, we again see volcanic hills formed chiefly of very acid lavas. The Müller range also has been explored for 280 kilometers. Its eastern end is unknown. Further west isolated andesitic mountains stand in the midst of the plain of the Kapuas. It might well be asked whether the isolated volcanos formed chiefly of andesite, but in small part also of basalt, which occur further west, to the north-east of Bengkajiang, should not be regarded as remote outposts of the Müller range. Among these is Melabu (about lat. $0^{\circ} 50'$ N., long. $109^{\circ} 35'$ E.), long ago described; the others are situated to the north-east, in lat. 1° N.¹

The course of the volcanic rocks follows approximately the arcuate strike of the folded phyllite range. South of the phyllite range the united efforts of Dutch explorers have revealed as well the existence of sediments, of various ages, extending in a broad girdle which runs from the Müller range towards Bengkajiang, and corresponds to the downthrown band of the Danau formation and the Cenomanian.

¹ N. Wing Easton, De Vulkanen Sitong en Pando ter Westerafdeeling van Borneo, Jaarb. Mijnw. Ned. O. Ind., 1889, XVIII, pp. 24-51, maps.

On the Boelit, a little tributary to the Kapuas near its source (about long. $113^{\circ} 47' E.$), and in the very midst of the tuff region of the Müller range, Molengraaff observed a dark-coloured limestone containing fossils, which perhaps belong to the genus *Marginifera*, and thus suggest an upper Palaeozoic age¹. Far to the west of this locality, between Loemar and Sepang, north-north-east of Bengkajang, Wing Easton found Cephalopods, which Krause assigns to the Lias². A series of outcrops of the upper Jurassic appears to run north of Bengkajang in an east or east-south-east direction, from the neighbourhood of Kenda towards Buduk³. Then follows a series of outcrops of the Cretaceous, among which, however, only Cenomanian and Senonian have hitherto been observed.

In 1889 Martin announced the unexpected discovery, based on specimens found by van Schelle, that a part of the so-called 'ancient schists' of western Borneo is of Cretaceous age. The Cretaceous schists often dip at a high angle, and run with an east or south-east strike through the above-mentioned regions of Boedoek and Sepang. They were also found north-east of Bengkajang. Further, Everwijn also observed the Cenomanian with *Orbitolina concava*, mentioned above, far to the east, on the river Seberuang, and this horizon was also found by van Schelle on the river Bojang (long. $112^{\circ} 30' E.$). The middle Cretaceous probably exists along the whole outer margin of these scattered traces of a Mesozoic arc, until it disappears in the east beneath the volcanic accumulations of the Müller range⁴.

South of this downthrown band, which between long. 112° and $114^{\circ} E.$ is occupied, as we have seen, by the plain of the Kapuas, the country assumes a different structure. Mighty beds of Tertiary sandstone occur, with no signs of folding, and form table-mountains. According to Krause's investigations, they were deposited in brackish-water⁵.

¹ P. G. Krause, Ueber tertiäre, cretacische und ältere Ablagerungen aus West-Borneo, Samml. geol. R.-Mus. Leiden, 1897, V, p. 173.

² P. G. Krause, Ueber die Lias von Borneo, tom. cit. 1896, pp. 154-168; K. Martin, Notiz über die Lias von Borneo, 1896, tom. cit. pp. 253-256.

³ F. Vogel, Mollusken aus der Jura von Borneo, Samml. geol. R. Mus. Leiden, 1896, V, pp. 127-153; also Krause, Ueber die Lias von Borneo, tom. cit., p. 155. For the position of these beds see Molengraaff's map in Peterm. Mitth., 1895, pl. 14, and the atlas in his Central Borneo.

⁴ Molengraaff, Central Borneo, p. 463; K. Martin, Untersuchungen über den Bau von Orbitolina (*Patellina* aut.) von Borneo, Jaarb. Mijnw. Ned. O. Ind., 1889, XVIII, pp. 86-108; Versteinerungen aus der sogenannten alten Schieferformation von West-Borneo, Samml. geol. R.-Mus. Leiden, 1889, IV, pp. 198-202; Krause, Ueber tertiäre, cretacische und ältere Ablagerungen aus West-Borneo, pp. 181-187. A fairly abundant literature is already attached to these Cretaceous outcrops. Krause mentions a specimen from the river Seberoeang which probably belongs to *Lytoceras Sacya*.

⁵ Molengraaff, Geologische Verkenningstochten in Centraal-Borneo, p. 444 et seq.; Krause, Ueber tertiäre, cretacische und ältere Ablagerungen aus West Borneo, pp. 188-218; Martin has examined the fauna of the beds with *Cyrena*, which crop out in several

On the river Embahu (long. $112^{\circ} 20'$ E., tributary of the left bank of the Kapuas) Eocene occurs with *Cyrena borneensis*, which accompanies the lignite beds of south-east Borneo. To the east, between the meridians of $112^{\circ} 40'$ and $113^{\circ} 20'$ E., Molengraaff has drawn a section running southwards to the sea, which cuts through all the heights south of the Müller range; this we will now describe.

We find ourselves on the south border of the plain of the Kapuas; Tertiary sandstone covers the ground; above it rise isolated volcanic spurs of the Müller mountains; below the sandstone we see here and there some folded Cenomanian, and possibly traces of the Danau rocks with Radiolaria. Then the Tertiary sandstone rises gradually in a broad platform towards the south. It is traversed by fractures running east and west, along which it is vertically upturned, but it soon flattens out again, descends slowly to the south, and forms the *Madi plateau* (up to 1,138 meters). Before reaching the Equator this plateau breaks off steeply towards the south. On its southern scarp we again see the folded Cretaceous beds.

Here lies the upper course of the river Melawi. The Tertiary sediments may afford Cyrenas on various horizons; they again ascend gently in a broad platform towards the south, form the *Schwanner range*, and again break off steeply towards the south. This scarp, however, differs from the preceding. Granite forms its southern foot; and the face of the fracture has probably been denuded back towards the north, so that it is no longer straight. Where it extends furthest to the south, the peak of *Raja* (2,270 meters), formed of granite and porphyry, dominates both the escarpment and the whole of the sandstone plateau. All the country south of the Raja must be regarded, according to Molengraaff, as faulted down; once more, in lat. 1° S. we see comparatively recent volcanic rocks lying in a fault-trough which crosses the river Samba, and then granitic rock which probably forms the foundation of the whole of the low-lying country down to the coast (lat. $3^{\circ} 15'$ S.).

Molengraaff's section thus shows us the following:—

In the north (down to lat. $1^{\circ} 15'$ N.) there is a folded mountain chain (upper Kapuas range) with a gentle arcuate strike (east and west where crossed by the section). In the south (to the peak of Raja, in about lat. $0^{\circ} 40'$ S.), a granitic foreland is visible from the coast upwards and further north is buried beneath sheets of lower Tertiary brackish-water sandstone (Schwanner range, Madi plateau).

The whole border region between the mountain chain and the foreland is let down along faults striking from east to west. The downthrow of

localities in the region of the river Mälawi. They were formed in estuaries. The Mälawi enters the Kapuwas north of the Schwanner range. K. Martin, Die Fauna der Mälawigruppe, einer tertiären (eocänen?) Brakwasser-Ablagerung aus dem Innern von Borneo, Samml. geol. R.-Mus. Leiden, 1899, V, pp. 256-315.

the outer border of the chain is particularly great (lowland and lakes on the river Kapuas). On the south side of this great subsidence there once stood a chain of volcanos (Müller range), but the system of east-and-west fractures extends also into the foreland on the south, and Raja is perhaps a horst rising in the midst of the foreland.

As far as I have been able to ascertain, this granite foreland attains in places to considerable heights, and, covered here and there by patches of Tertiary or gold-bearing alluvium, extends over a wide area. Molengraaff points to the granite of Soekadam in Matam (close to the west coast, lat. 1° S.) as corresponding with it. In fact it probably forms the whole south-west of Borneo, and towards the south, according to the older map of Gaffron, engirdles the whole plain which occupies the south coast of Borneo round to Bondjermasin and beyond, and extending far to the north in the valley of the Barito, it includes the depression of Bekompei. No one can predict what future discoveries may bring to light; at present it looks as if the whole region, from the Schwanner range to cape Samban in the south-west, were an Archæan horst separating the folded ranges, somewhat after the fashion of the larger mass of Cambodia.

The *Natuna* archipelago on the west of Borneo seems also to consist chiefly of granite¹.

Two further remarks may be added to these observations on central Borneo.

Molengraaff has found on the slopes of the upper Kapuas range, lying on the phyllites, rolled pebbles of a dark limestone, in which R. B. Newton and Holland have recognized the presence of *Discocyclus*; this is the first indication of a marine submergence, which, according to our existing classification, must have taken place after the deposition of the Cyrena beds of the table-mountains².

In the next place, if we imagine Borneo in a state similar to that of many other parts of the Sunda archipelago, i. e. with the land covered deep by the sea; then if the volcanos of the Müller mountains were in activity they would not define the course of the cordillera (upper Kapuas range), but of the accompanying fracture.

The *south-east* of Borneo presents a different structure from that of those parts of the island we have just passed in review. We will begin our study of this region in the extreme south-east, following the detailed descriptions of Hooze³.

¹ Krause, Verzeichnng einer Sammlung von Mineralien und Gesteinen aus Bunguran (Gross-Natuna) und Sededap im Natuna-Archipel, Samml. geol. R.-Mus. Leiden, 1898, V. pp. 221-236.

² R. Bullen Newton and R. Holland, On some Tertiary Foraminifera from Borneo, Ann. Mag. Nat. Hist., 1899, 7th ser., III, pp. 245-264. This contains a detailed list of earlier works on this subject.

³ J. A. Hooze, Onderzoek naar kolen in de Straat Laut en aangrenzende landstreken,

The little island of *Sebeku* (long. $116^{\circ} 23' E.$), which stretches north and south, presents on its east side a steep and narrow ridge of serpentine and diabase, directed north and south. Along its western foot this is bordered by a narrow strip of lower Eocene sediments with beds of coal. The middle and west of the island are plains which extend to the strait of Djohor.

In the northern part of this strait rises a reef of diabase, the Pulu Manti. On the other side of the strait lies the much larger island of Pulu Laut, which is traversed from its southern to its northern extremity by the imposing mountains of Sebetung, formed of diabase, and towards the west of serpentine. In the northern part of the island, where a direction to the north-north-east sets in, the serpentine disappears, and again a band of coal-bearing Eocene beds borders the west side of the mountains; the beds dip steeply to the west beneath the Laut strait. On the island of Suwangi, which lies in the middle of the strait (lat. $3^{\circ} 25' S.$), they reappear, but with a dip to the east or in an opposite direction, and to the west of them we again see serpentine.

The northern part of the strait of Laut thus lies in a syncline of Eocene, which is bounded on each side by serpentine, and strikes to the north-north-east. Continuing in this direction, the Eocene beds once more appear in the promontory of Dewa and the adjacent group of islands, Nangka, where they are horizontally stratified, and belong, probably, to the centre of the basin.

Still further away, on the promontory of Batu, lat. $3^{\circ} S.$, we again see a long and narrow ridge of serpentine and diabase which bounds Klumpang bay. It may be the continuation of the serpentine of Suwangi, i. e. of the western margin of the Eocene basin. This ridge is likewise bordered by Eocene deposits, and indeed on each side. It runs along the sea coast to the north-north-east, and ends in Pamukan bay (lat. $2^{\circ} 33' S.$), where it is formed of diabase overlain on both sides by very steeply upturned Eocene beds. On the west side of the ridge inversion and overfolding occur¹.

In this part of Borneo there are thus three coulisses of eruptive rocks separated by basins of lower Tertiary beds. These are:—(1) The eastern side of the island of Sebukut; (2) the island of Laut; (3) the western side of the island of Suwangi, continued, probably, as the ridge of Klumpang-Pamukan. The first coulisse strikes to the north; the two others to the north-north-east.

From the southern extremity of Borneo to a little beyond lat. $4^{\circ} S.$, isolated reefs of gabbro, diabase-porphyrity, and serpentine crop out near

Jaarb. Mijnw. Ned. O. Ind., 1888, XVII, pp. 337-429, maps. Nadere gegevens betreffende enkele kolenterreinen in Koetei, tom. cit., pp. 431-466, maps.

¹ J. A. Hooze, Kolen aan de Oostkust van Borneo van de St. Lucia tot aan de Pamoekan-baai, Jaarb. Mijnw. Ned. O. Ind., XV, 1888, XVII, pp. 431-466, maps.

the west coast. According to Verbeek, they are of Cretaceous age. At cape Dewa, a little south of lat. 4° S., a ridge rises suddenly, the Goenong Bira (376 meters), which consists of the same rocks. Similar ridges join one to another; and at last a continuous range striking to the north-east appears. The diabase porphyry dies away, and the range consists of two long serpentine ridges, the Bobaris mountains and the much more important *range of Meratus*. They are united by a lower-lying region of mica-schist, chlorite, and quartz schist, between which some serpentine ridges are inserted. The north-western ridge of Bobaris is joined towards the north-west by a fairly broad range of conglomerate, sandstone, and shale, which contains upper Cretaceous fossils. These are overlain further to the north-west by lower Eocene coal-bearing beds, middle Eocene marls, and Nummulitic limestone. Hooze's geological map of Martapura shows this regular succession, and a general strike to the north-east¹.

The difference between these coulisses and those hitherto mentioned lies in the appearance of schists, perhaps of Archaean age, between the two serpentine ridges, the presence of Cretaceous rocks, and the altered direction. The older works of Verbeek show, however, that somewhat further north the ancient schists disappear, while the two serpentine ridges unite to form the Meratus range, which at the same time bends to the north-north-east, and then almost to the north, continuing in this direction for a long distance². This range is seen from Klumpang bay onwards (lat. 3° S.): in front of it, on the east, is a limestone range, the Bangkalaän mountains, probably formed of Nummulitic limestone. In its further continuation to the north it forms the inner boundary of the little sultanates of the east coast; the rivers flowing into Adang bay bring down serpentine, together with mica-schist and quartzite. Even as far south as the lower course of the river Kutai (lat. $0^{\circ} 35'$ S.) Hooze still found lower Miocene sandstone, which is there thrown into steep folds, and strikes north and south across the river³. In all probability the Meratus range and the meridional strike continue almost up to the Equator.

The investigations of Hooze and Verbeek thus show that we must add to the coulisses mentioned above: (4) the elongated range of Meratus, and (5) the Bobaris mountains. The southern part of both these ranges exhibits a marked deflexion to the south-west.

¹ J. A. Hooze, *Topographische, geologische, mineralogische, en mijnbouwkundige Beschrijving van een gedeelte der afdeeling Martapoera*, Jaarb. Mijnw. Ned. O. Ind., 1893, XXII, pp. 1-431, atlas. K. Martin, *Ueber das Vorkommen einer rudistenführenden Kreideformation im südöstlichen Borneo*, Samml. geol. R.-Mus. Leiden, 1888, I, pp. 117-125; *Die Fauna der Kreideformation Martapoera*, op. cit., 1889, IX, pp. 126-197.

² R. D. M. Verbeek, *Geologische Beschrijving der Distrikten Riam-Kiwa en Kanan in de Zuider- en Ooster-Afdeeling van Borneo*, Jaarb. Mijnw. Ned. O. Ind., 1875, IV, pp. 1-30, maps; cf. in particular the sketch map, plate 1.

³ J. A. Hooze, *Kolen aan de Oostkust van Borneo van de St. Lucia tot aan de Pamoekan-Bani*, pp. 439, 445, 447; also *Onderzoek naar Kolen in de Straat Laut*, p. 400.

As a whole, however, these coulisses converge to the north, and form a great virgation of kindred branches which, south of Bandjermasin, make a bend in the same direction as that of the folded range of north Borneo, that is, the upper Kapuas range of Molengraaff, which runs on the further side of the Archaean mass of the south-west, from the Kinibalu towards cape Datu.

A general convergence of all the mountain ranges of Borneo to the north or north-north-east certainly appears to take place, but existing observations are not sufficient to show whether, or in what manner, the coulisses of the south-east, and especially those of the Meratus mountains, are continued across the lofty ridge which, according to the maps, runs south-east from the middle of the island to cape Mangkalihat. The data relating to regions north of these mountains are also very scanty.

At cape Tinagat (lat. $4^{\circ} 13' N.$, long. $117^{\circ} 59' E.$), in the bay of St. Lucia, which marks the northern boundary of the Dutch possessions, Hooze found a rock which Retgers compares with a hornblende porphyrite from Pengaron in the Bobaris mountains¹.

Near the mouth of the river Sibuku, Lehnert mentions coarse-grained granite².

In spite of a lamentable deficiency of information, it is possible to make out the way in which Borneo fits into the virgation of the Philippines; and the resemblance between its south-eastern coulisses and certain parts of the Philippines is clearly apparent. At many localities in the Philippines gabbro, diabase, and diorite are covered by Nummulitic limestone, which there also surrounds long narrow cordilleras. There, too, we find Tertiary coal, and if this in all probability is of later date than the Eocene, it is also true that upper Tertiary coal beds are present likewise in Borneo. If we disregard the volcano on the Isla de Negros, then we see in that island, as in the neighbouring island of Zebu, first an ancient volcanic range, mapped as diorite, then, at all events in Zebu, Nummulitic limestone (II, p. 173), and finally coal-bearing beds. Centeno has further pointed out that the coal-bearing beds in these two islands dip towards one another in such a manner as to suggest that the intervening strait of Tañon occupies the middle of a coal basin.

This is a repetition of what we have already described, some 13 to 14 degrees of latitude further south, in the strait of Laut. In both cases the straits run to the north-north-east³.

¹ J. W. Retgers, *Mikroskopische Beschrijving van Gesteenten afkomstig van de Oostkust van Borneo, verzameld door J. A. Hooze, Jaarb. Mijnw. Ned. O. Ind., 1895, XXIV, p. 81.*

² J. Lehnert, *Um die Erde: Erdumseglung S. M. Corvette 'Erzherzog Friedrich'*, 8vo, Wien, 1878, p. 819. T. Frhr. von Oesterreicher writes, 'granite country,' *Mitth. k. k. geogr. Ges. Wien*, 1876, XIX, p. 217.

³ J. Centeno writes concerning the coal measures of these islands: 'that they all

Celebes is still to a great extent wholly unexplored; but the evidence afforded by such investigations as have yet been made is sufficient to show that, like the peninsula of Chalcydice, it owes its chiragratie form to the union of a number of dissimilar fragments.

The first of these is formed by the north-eastern promontory of *Minahassa*. It consists of a number of closely set volcanos, and forms part of the volcanic zone which runs from south-east Luzon across Mindanao and the Sangi (or Sanguir) islands¹. In the north, also, volcanos occur, as, for instance, Batu-Angus, Klabat, and others. Lake Tondano (lat. 1° 10' to 1° 17' N.), according to Wichmann and Bücking, is bounded on the west by volcanos, on the east by a ridge of andesite, forming the Lembean mountains². Towards the south volcanos again occur, and, according to Martin, a patch of Orbitoides limestone of middle Tertiary age.

According to the observations of the brothers Sarasin, the volcanic region terminates in a line of depression, which runs obliquely across the peninsula, forming the greater part of the valley of the river Dumoga; it cuts the north coast a little east of 124° E., and the south coast somewhat west of the same meridian. But already north of the basaltic platform of Mongondo, which marks the south-western end of the volcanic region, one locality (near Kottabangan) has afforded clay slates, with a dip to about north-east.

The islands of Tagean and Una-Una, in the gulf of Tomini, are regarded by several observers as volcanos, and as forming the continuation of Minahassa; according to an observation of the brothers Sarasin³, there is

form part of the same basin, which, appearing on the west slope of Zebu and the east slope of Negros, passes beneath the strait of Tanon situated between the two islands,' *Memoria geológico-mineralógica de las Islas Filipinas*, Bol. Com. Map. geol. España, 1876, III, p. 31. Hooze, in *Underzoek naar kolen in de Strat Laut*, writes, p. 423: 'This coal formation (of Poeloe Laut) is continued beneath the sea . . . cropping out east and south of Soewangi, at Tandjong Dewa, in the Nangka islands, &c.' The more recent age of the coal basins of Zebu is evident, since Martin mentions *Vicarya callosa*, which is characteristic of the upper Miocene of Java, as obtained from them, *Ueber tertiäre Fossilien von den Philippinen*, Samml. geol. R.-Mus. Leiden, 1895, V, pp. 59, 66.

¹ The condition of the volcano in Sangui is described by L. Hoeke, *Verslag omtrent eene Reis naar de Vulkaan Awoe op het eiland Groot-Sangi*, *Natuurk. Tijdschr. v. Nederl. Indie*, Batavia, 1893, LIII, pp. 162-171.

² P. and F. Sarasin, *Reiseberichte aus Celebes*, I, *Zeitschr. Ges. f. Erdk.*, Berlin, 1894, XXIX, pp. 351-401, map; in particular pp. 361, 400. Also a description of some of the volcanos of Minahassa, in W. Kükenthal, *Ergebnisse einer zoologischen Forschungsreise in den Molukken und Borneo*, Abh. senckenb. naturf. Ges. Frankfurt a. M., 1896, XXII, p. 235 et seq. H. Bücking gives a geological sketch map of North Celebes in his *Beiträge zur Geologie von Celebes*, *Peterm. Mitth.*, 1899, pp. 249-260, 273-280, pl. XVI. A. Wichmann, *Die Binnen-Seen von Celebes*, *Peterm. Mitth.*, 1893, XXXIX, pp. 227-231, map; F. Rinne, *Skizzen zur Geologie der Minahassa in Nord-Celebes*, *Zeitschr. deutsch. geol. Ges.*, 1900, LII, pp. 327-347, map.

³ P. and F. Sarasin, *Reiseberichte aus Celebes*, *Zeitschr. Ges. f. Erdk.*, Berlin, 1895,

probably a small volcanic mountain on cape Api, which projects from the south coast of the gulf, and this also would belong to the same zone.

The second fragment is *Gorontalo*, formed of a strip of Archaean rocks which stretch from east to west. On the east it includes the Bone mountains (1,400 to 1,500 meters), which consist, according to Sarasin, of a light-coloured granite with a mantle of gneiss; north of these mountains comes the chain of Huntuk-Bulu-dawa¹. This is joined, in the north of the peninsula, by a longer granite range running east and west, which is separated by a depression from a shorter and less lofty granite range running fairly parallel to it on the south. The northern scarp of the northern range is very steep; van Schelle and Wichmann agree in regarding the granitic chain of Gorontalo as a horst. According to Wichmann, the valley between the two ranges is a fault-trough². Near Sumulata (long. 122° 30' E.), according to Bücking, the veins of ore occur in a coarse conglomerate of eruptive rocks, which he describes as porphyrites. Diorite is also said to occur.

Herr Hundeshagen, a mining engineer, has the kindness to inform me that the veins of ore in north Celebes occur in a rock regarded by him as diorite, which surrounds fairly large masses of clay slate. The strike of these beds west of Palell in the Bvool state is north-north-east and north-east. In the north-west corner of Celebes, 1 to 8 kilometers west of Tontoli and near the coast, Hundeshagen met with red and green ancient schists veined with granite, and so intensely folded and faulted that it was impossible to determine a definite strike. In two or three localities a strike to the north was observed. From cape Stroonen, along the south coast to Sitjello and far beyond cape Dampelas, granite predominates. Volcanos are absent³.

The lofty mountains which occur in the bend of the peninsula where it turns round to the south-west and south, and form the north-western boundary of the gulf of Tomini, have not been explored.

At the head of the gulf, almost on the Equator, a deep subsidence runs across Celebes and separates the mountains on the north from those in the south.

XXX, pp. 350, 352. Cape Api is also called Fire cape, and owes its name to the fact that combustible gases are supposed to rise on the coast.

¹ P. and F. Sarasin, *Reiseberichte aus Celebes*, Zeitschr. Ges. f. Erdk., Berlin, 1895, XXX, pp. 376, 392, 393; Bücking doubts the presence of gneiss.

² C. J. van Schelle, *Opmerkingen over de Geologie van een gedeelte der Afdeeling Gorontalo*, Jaarb. Mijnw. Ned. O. Ind., 1889, XVIII, pp. 115-158; G. W. W. C. Baron van Hoëvell, *De Assistent-Residentie Gorontalo*, Tijdschr. K. Ned. Aardr. Gen. Leiden, 1891, 2^{de} ser., VIII, pp. 26-43, map; *Bijschrift bij de Kaart der Tomini-Bocht*, op. cit., 1893, 2^{de} ser., X, pp. 64-72, map; Wichmann, *Peterm. Mitth.*, 1893, pp. 255-258, map of the lake of Limbotto.

³ The red slates are mentioned by the brothers Sarasin as occurring in the Oleides chain; P. and F. Sarasin, *Reiseberichte aus Celebes*, II, Zeitschr. Ges. f. Erdk., Berlin, 1895, XXX, pp. 226-235, map.

Celebes was crossed by Wichmann in lat. $0^{\circ} 45' S.$; starting on the west, we first meet with a belt of sandstone and conglomerate, then gneiss and some granite, which extend as far as the east coast¹.

This probably forms part of the cordilleras which the brothers Sarasin have followed from the south-west end of the gulf of Tomini a long way to the south-east². Successive parallel chains of mica-schist and quartzite, sometimes of greenstone and serpentine, run from the end of this gulf, first to the south and then to the south-south-east, to form the steep slopes along the eastern shore of lake Posso. This lake is more than 300 meters in depth, and must be regarded as a tectonic feature.

The whole range then turns to the south-east and east-south-east. The tectonic line indicated by lake Posso now runs within the parallel chains, and upon it appears, extended in the same direction, the deep lake of Matanna; situated at a height of 400 meters, it is 480 meters deep, and consequently extends below the sea-level.

When the chains have entered the south-east peninsula of Celebes they turn rapidly from the east-south-east to south-west; the tectonic line of the lakes also follows this new direction, and a little north and south of lat. $3^{\circ} S.$ it crosses the lake of Towuti, which is the largest in Celebes. The brothers Sarasin call this series of great lakes the 'lake-trough.' The mountain ranges probably continue to strike south-west or south-south-west in the south-east peninsula.

These same ranges reach the head of the gulf of Boni. Then follows, in the extreme north-east of the south peninsula, the mountain mass of *Latimodjong*, running to the south-east, with a height of over 3,000 meters.

The rest of the south peninsula has a very different structure. Even between lat. $3^{\circ} 15'$ and $3^{\circ} 45' S.$ the brothers Sarasin found only Tertiary deposits between the mountain of *Latimodjong* and the west coast. These consist of grey clay, with brackish or freshwater mollusca and terrestrial plants, overlain by white limestone. The whole series is folded, and strikes due east and west; the limestones, which lie in the synclines, may attain a thickness of over 1,000 meters. On the rock of Loko a volcanic outcrop of Tertiary age occurs among them³. Since similar Tertiary beds extend from lake Posso to the gulf of Tomoiki, and the promontory west of the bay of Palos also appears, according to Wichmann, to consist of a Tertiary

¹ A. Wichmann, *Tijdschr. Aandr. Gen.*, Amsterdam, 1890, 2^{de} ser., VII, pp. 985-993.

² P. and F. Sarasin, *Reiseberichte aus Celebes*, III, *Zeitschr. Ges. f. Erdk.*, Berlin, 1895, XXX, pp. 311-352, and *Durchquerung von der südlichen Halbinsel*, op. cit., 1896, XXXI, pp. 339-357, maps.

³ P. and F. Sarasin, *Reiseberichte aus Celebes*, IV, *Zeitschr. Ges. f. Erdk.*, Berlin, 1896, XXXI, p. 11, map.

eruptive rock and Tertiary sediments, it is probable that deposits of this age mantle round the greater part of these cordilleras.

Let us again turn our attention to the south peninsula. At a trifling height above the sea lie the lakes of Sidereng and Tempe. Towards the south the land rises; we owe our knowledge of its structure to Wichmann¹.

The broad isolated mass of the Latimodjong (lat. 3° 45' S.), which rises north of the lakes, is possibly a volcano. Towards the south two mountain ranges extend, separated by a longitudinal valley; the western range, on the side next the strait of Macassar, is much the more important, and reaches a height of 1,000 meters. It consists of basaltic, andesitic, and leucitic rocks, and Tertiary beds; the eastern range is formed by higher subdivisions of the Tertiary series. The whole is folded, and the strike is due north and south, becoming west-north-west (300°) towards the extreme south-east.

The gulf of Boni is regarded as a fault-trough. In the south both ranges are united by the mass of a great volcano, mount *Bonthain* (Lompo-Battang, 3,057 meters), which thus closes the longitudinal valley. Archæan rocks are only known as rolled pebbles in one of the river valleys.

The elongated island of *Saley*, south of Celebes, is formed of volcanic rocks on its eastern side, which is the higher, and descends steeply towards the east; the western side is formed of more recent marine deposits².

In respect to the southern portion of the south-east peninsula of Celebes I have no information. The eastern peninsula, situated between the gulfs of Tomoiki and Tomini, and traversed by the lofty chain of Tokalla, presents, according to Verbeek, numerous exposures of diabase, peridotite, and other basic rocks.

Whether the islands which trend east and west (Obi, Taliabo, &c.) and lie in an east-and-west chain are continued into Celebes, and if so, in what manner, it is at present impossible to say. In view of the great dearth of information we can only give the following account.

In Celebes long ranges of ancient rocks exist which are partly surrounded by folded Tertiary beds. The best known of these are: the fragment of Gorontalo, trending east and west, which may be regarded as a horst; the region in the north-west of the island, where a strike from north-north-east to north-east prevails; then the group of parallel chains which proceeds from the region east of the bay of Palos, runs with a frequent change of direction through the middle of Celebes into the south-east peninsula,

¹ A. Wichmann, Celebes, Tijdschr. K. Ned. Aadr. Gen., Amsterdam, 1890, 2^{de} ser., VII, pp. 921-982, maps, and Peterm. Mitth., 1893, pp. 278-282; also his Leucit-Gestein von Celebes, Natuurk. Tijdschr. Ned. Ind., Batavia, 1893, LIII, pp. 317-331; also J. W. Retgers, in Jaarb. Mijnw. Ned. O. Ind., 1895, XXIV, p. 124 et seq.

² A. Wichmann, Zur Geologie der Insel Saleijer, Natuurk. Tijdschr. Ned. Ind., Batavia, 1895, LIV, pp. 236-268, map.

enclosing the lake trough on its way. Minahassa is of recent volcanic formation, and forms part of the Sangi zone. The whole of the south peninsula is built up of volcanic rocks of Tertiary age. The north-eastern peninsula is characterized by basic eruptive rocks.

In conclusion, we may mention the peculiar behaviour of the leucitic rocks. The long list of 121 volcanos situated in Java and the neighbouring islands, which has been published by Verbeek and Fennema, is headed by five volcanos geographically remote from the others, and also distinguished by the fact that they alone have hitherto furnished leucitic rocks. In age they certainly date back to the Tertiary period, although some may have again become active at a later time. They form a more or less arcuate series, which begins in the north-west with the island of Bawéan, lying north of Java, and proceeds to the north-east coast of Java, south of the island of Madura. The most easterly of these volcanos at the north-eastern extremity of Java is Ringguit; its crater measures $10\frac{1}{2}$ kilometers in diameter, and is the largest in Java¹.

We may perhaps associate with this leucitic series the leucite-bearing rocks, also of Tertiary age, which Wichmann met with in south-west Celebes; and thus it would appear that a leucitic arc, not without interruptions, it is true, exists in this region. But at any moment a fresh discovery may show that this hypothesis has no better basis than the insufficiency of our data.

Halmahera. Our knowledge of the structure of this island is based on the accounts furnished by Verbeek, not to mention the orographical description by Campen. In addition, Kükenthal has published observations, chiefly referring to the north, and Retgers has described rock-specimens obtained from various parts of the island².

Verbeek distinguishes several volcanic lines; they belong almost exclusively to the west side of the island, and follow a somewhat bent course, which nevertheless runs mainly from north to south. The older volcanos are formed chiefly of hornblende andesite and mica andesite, more rarely of pyroxene andesite or basalt. In very many cases the crater has disappeared. One of these ancient lines begins in the North Loloda islands, west of the northern extremity of Halmahera. It runs down in a gentle curve off the west coast, through the South Loloda islands, then touches Halmahera,

¹ R. D. M. Verbeek and Fennema, *Description géologique de Java et Madoura*, II, p. 994.

² C. F. H. Campen, *Het Eiland Halmahera*, *Tijdschr. voor indische Taal-, Land- en Volkenkunde*, Batavia, 1883, XXVIII, pp. 240-313, in particular p. 247. The orthography *Halmaheira* is erroneous, according to Campen, p. 240. Kükenthal, *Ergebnisse einer zoologischen Forschungsreise in den Molukken*, in particular p. 85 et seq.; maps of Halmahera and Batjan with Kasiroeta; Retgers, *Mikroskopische Onderzoek van Gesteenten uit Nederlandsch Oost-Indie, Molukken, Celebes*, *Jaarb. Mijnw. Ned. O. Ind.*, 1895, XXIV, pp. 107-124.

possibly coincides for a certain distance with the line of active volcanos—to be mentioned directly—which lie off the west coast, and continues through Kajoa, on the west side of the Patientie strait, to the south end of Batjan. There its direction is south-south-east. On the other side of the strait, at the south end of Halmahera, a similar line begins, with the same direction, which Verbeek marks as far as Kekeh (east of Obi-Besar), and from here another ancient line of volcanos runs east-north-east to the north-west coast of New Guinea. The islands lying off the southernmost point of Halmahera are basaltic¹.

A group of ancient volcanos formed of pyroxene andesite lies off the north-east coast of Halmahera; the volcano of Galeda stands in the middle of the group². From this region a line of recent and in part active volcanos runs south-south-west, with a slight convexity to the west, and so crosses the northern peninsula obliquely. It reaches the sea on the north side of Djalolo bay, and proceeds through the volcanos of the island chain, which begins with the islands of Hiri and Ternate, and ends with the island of Makian (lat. $0^{\circ} 15' N.$). It is in this latter region that the more recent line of Ternate and the older line of Loloda probably coincide.

The more or less meridional direction of these lines suggests a connexion with the Philippines, but we know nothing positive on this point. The *Talaur islands*, as Herr Hundeshagen informs me, are entirely or in great part of sedimentary origin. Verbeek points out that in Halmahera the line of active volcanos (line of Ternate), as it proceeds from Djalolo bay onwards, diverges from a straight course to the Philippines, and runs north-north-east (towards Galeda), but he is inclined to believe that the older (Loloda) line is prolonged to the east coast of Mindanao; this coast is regarded as a fracture³.

All the remaining parts of Halmahera, so far as we know anything of them, consist almost exclusively of gabbro, peridotite, serpentine, and other highly basic eruptive rocks. This is also true of the larger islands in the vicinity, such as Rau and Morotai in the north, and Batjan in the south-west. We have already observed how large a part is played by the same rocks in the structure of the islands situated to the south-east down to Waigoe, Batanta, and the coast of New Guinea. Quite recently they have all been assigned to the Cretaceous epoch.

Linck, who has examined the collections of Kükenthal, mentions in addition gneiss which occurs in Batjan, ancient actinolite schist in the

¹ Verbeek, Voorloopig Verslag over eene Geologische Reis door het Oostelijk Gedeelte van den Indischen Archipel in 1899, p. 23 et seq.

² On this region cf. also A. Wichmann, Der Ausbruch des Vulcans 'Tolo' auf Halmahera, Zeitschr. deutsch. geol. Ges., 1897, XLIX, pp. 152-159.

³ Verbeek, Voorloopig Verslag, &c., p. 33 note.

southern extremity of Halmahera, and white Nummulitic limestone in the south-east.¹

Recent coral limestone surrounds the greater part of Halmahera.

Survey of the eastern Altaides. Before us lies the southern part of the ancient vertex, the vast Mongolian highland of the Khangai. It consists of Archaean rocks. A broad girdle of Palaeozoic greywacke runs from trans-Baikalia through Urga nearly to its southernmost part, and it is here that the insunken valley of the Lakes begins. This step-like subsidence extends along the Dsapkhyun past Kobdo and Uliasutai, and its deepest part lies at its northern extremity in the Ubza-nor. It thus separates from the vertex the Gobi Altai, which presents the same structure as the vertex, and is indeed a fragment of it.

Far to the north-west is the younger vertex, or the Altai, whence proceeded those numerous waves which are first known as the Thian-shan; in this system they adapt themselves more and more to the west-north-westerly direction, and then bear in succession the names Bei-shan, Lung-shan, Nan-shan, and central Kuen-luen.

In the neighbourhood of An-si, on the Su-lei-khe, not far from the western end of the oases of Kansu, the San-sjan-tsy, a low range of gneiss running to the east-north-east, meets at an acute angle the Desert range which represents the southern border of the Bei-shan. This is the beginning of changed conditions, and from here onwards we see first the continuation of the Lung-shan, then the mighty Richthofen range, then all the several great ranges of the Nan-shan, such at least as are of sufficient length, bending themselves sharply round out of the west-north-west towards the east-north-east, into the direction of the Anembar-ula and the Altyn-tag, as though the latter ranges had been the seat of a folding force simultaneously active and of equal or even greater strength. This great turning movement affects all the chains from the western end of the oases of Kansu as far as Tsaidam and the high-lying lakes of Kum-kul, and as it is accomplished not only the chains, but the valley bottoms also, rise higher and higher above the plain of Yarkand-darya which lies in front of them. This is the western boundary.

In the east lies the great Sinian mole, with its undisturbed Cambrian beds. Its western part, covered with more recent sediments, forms the foundation of Ordos. The north-western elbow of the Hoang-ho here marks its almost rectangular boundary. We now see that the general movement towards the south which dominates the Altaides also makes itself felt in the east. The great Khingan is certainly a folded range, at least for a certain

¹ Linck was inclined to regard the serpentine of east Halmahera as an altered andesite rock, possibly hypersthene andesite, and to compare it in age to the volcanic outcrops of the north; Kükenthal, *Ergebnisse einer zoologischen Forschungsreise in den Molukken*, p. 88.

distance to the north; the direction of its folds, however, cuts across that of the post-Devonian folds of the ancient vertex: very possibly it maintains its folded character throughout its length. Towards Kuku-Khoto oblique coulisses, striking one after another to the west-south-west, form the In-shan and the arcuate range—completely resolved into coulisses—of Khara-narin-ula.

We find ourselves once more facing the most southerly part of the ancient vertex, south of the desert of Ala-shan. The great ranges of the Thian-shan have reached their wedge-shaped termination east of the mighty Karlyk-tag, and only the comparatively narrow Shujten Gobi separates the Bei-shan from the south border of the Gobi-Altai, or rather from the range of Adji-bogdo, which is the fore-lying range of the Gobi-Altai. With the wedging out of the Thian-shan the folds of the Altaides resume the direction of the arcs of the ancient vertex, and no boundary can be recognized between the two. Now the arcs coming from east and west encounter each other. The Adji-bogdo is prolonged into the Kōkō-tymyrtı, and rocky ridges indicate the track of the range across the desert to Tostu and Noin-bogdo on the eastern side. The eastern extremities of the chains of the Bei-shan bend round in the same direction. The Khara-narin-ula, proceeding from the east, is prolonged into the Yawarai mountains far away in the desert. Even the ends of the great northern arcs of the Nan-shan follow, rather more to the east, the same bend. The range of Ala-shan, however, is completely overfolded towards the east, and the flat, low-lying region of Ordos is its foreland. It is hard to say whether the deflexion of the Nan-shan chains towards the south extends as far as Lan-tshou-fu; in any case it has reached its termination at Di-dao, on the other side of the Hoang-ho, for south of this place the chains of the central Kuen-luen run unimpeded in straight lines to the east-south-east, and there form the Tsin-ling-shan, on the south border of the Sinian mole.

The constriction which the Altaides undergo in the east, under the influence of the foreland of Ordos, is essentially different in its nature from that produced by the Anembar-ula and Altyn-tag in the west; but the combined effect of the two is an extraordinary uplift of the whole mass of the Altaides, so that even the valley bottoms attain a height of 4,000 meters, and for a very great distance over the whole of eastern Thibet they do not sink below 4,500 meters. This mighty master group of closely crowded coulisses turns, however, more and more to the south, and it is only an isolated lateral branch which forms the Tsin-ling-shan. But the direction of this makes nearly a right angle with the direction of the main group, and it is possible that these two mountain ranges, lying almost perpendicular to each other, have both been carried towards the south-east; for a secondary range, the Ta-pa-shan, branches off from the main body to the north-north-east, surrounds the town of Ya-tshu-fu in an arc concave to the south-east,

and finally moulds itself on to the south side of the Tsin-ling-shan; its eastern end being driven into overthrust flakes which look towards the south. At the rapids of I-tshan on the Yang-tse-kiang a similar movement directed to the south-east may again be recognized.

Let us return, however, to the principal group. On the west it is again hemmed in by the eastern end of the Himálaya and the wedge-shaped fragment of Assam. When this obstacle has been overcome, the coulisses, which have hitherto been checked, advance in the Nága hills to the south-west and form the arcuate ranges of Arakan. Simultaneously with this escape from confinement or extension of space the Altaides manifest a tendency, as may be seen in the latitude of Ta-li-fu, to diverge from one another. This leads to a separation into two groups—an eastern, directed toward Yunnan, and a western, directed towards Burma; and again simultaneously with the extension of the surface, there occurs a decrease of height both in the valley bottoms and the mountain chains. The sharp bends in the middle course of the Mekong betray the contrast in direction, which now becomes apparent; finally the two groups are completely separated, and between them the older rocks of Cambodia appear.

In their further development these two groups are dissimilar.

In the eastern coulisses of the eastern or Yunnan group the gneisses and ancient schists of the great chains gradually sink little by little towards the south, till they finally disappear beneath a continuous mantle of sediments. This is limestone of Palaeozoic and Mesozoic age; it is folded, but the folds are worn down, and what remains in east Yunnan and Kuei-tshou is a high tableland. The median coulisses of this group have also lost in height, but they are continued in the direction of the Red river, and form the chains of Tongking. The last of the western coulisses is prolonged to a still greater distance; this is the cordillera of the east coast of Annam.

Far away on the other side of the south China sea we see a mountain arc. It begins on the west coast of the gulf of Lingayen in western Luzon, and extends as far as the Sierra de Zambales nearly down to the bay of Manila. It is continued through Lubang, the Calamianes, and the Paragua islands, where it is joined by Kini-balu and the arcuate range of Sarawak, which extends as far as cape Datu in western Borneo. This arc very nearly corresponds in its lie with the cordillera of Annam; it is at the same time the western branch of the virgation of the Philippines, separated in the south-west of Borneo by an older mass from the other branches of the virgation, which may be recognized on the other side of this mass in the Martapura range, and as far as the island of Sabekut, off the south-east coast of Borneo. Another branch of this virgation, represented by volcanos, runs from west Mindanao through the Sulu islands to Borneo; a third and similar one runs from the volcano of Apo, in south Mindanao, through the

volcano of Butulan and the Sanguir islands, to the volcanos of north-east Celebes, and perhaps to those of the gulf of Tomini. A fourth range is indicated by the volcanic line of Loloda close to the west coast of Halma-hera. The further out the trend-lines advance into the ocean the more distinctly are they indicated by volcanos.

In this manner the eastern group of the eastern Altaides comes to an end. All the coulisses have disappeared, with the exception of the most westerly. This, the cordillera of Annam, has described an arc convex to the east, and adapted itself to the curvature of the Philippine branches.

In the westerly or Burman group of the Altaides we see the same general decrease of the heights which here also accompanies the extension of the folded area. Here, too, it is the eastern branches which first disappear. These are the ranges which run with the Mekong above Vien-tian, and they have already vanished near the headwaters of the Menam. So much the longer are the ranges which follow them. These proceed, east of the Salwin, through lower Burma, and form, as coulisses ranged one after another, Tenasserim, the Malay peninsula, and the islands from Billiton to Karimoen-Djavu, north of Java. In this way the course of the great Burman arc is first indicated.

From Kunlon on the Salwin to Mandalay we now see a south-westerly direction of the chains, which becomes southerly further to the south, while in the Shan states a karst-land occupies a position similar to that of the limestone plateau of east Yunnan and Kuei-tshou. Between Sit-taung and the Irawadi lies the broad Tertiary band, which includes the Pegu Yomah, and is prolonged into the gulf of Pegu and perhaps into the flat eastern half of Sumatra. In the delta of the Irawadi a long and remarkable line of volcanos reaches the sea; it finds its continuation in Narcondam island and Barren island.

As in the Yunnan group so in the Burman group of the Altaides, the western branches are by far the longest. It is they which advance in the Patkoi and Nága mountains, and form the curve of Arakan and cape Negrais. To their outer border belongs the long series of islands which aline themselves between this promontory and Pulo Engaño, west of south Sumatra. The Barisan range in south Sumatra exhibits a still greater coulisse, but volcanic formations become more and more predominant. In Java we find in addition to eruptive rocks some Cretaceous and Tertiary strata. The long arcuate coulisse dies away; then a last coulisse proceeds from the west-south-west through Sumba and Timor, completes the curve around the Banda sea, and disappears. At the same time the sea, south of Java, attains a depth of 4,500 to 6,000 meters; and the Banda sea descends to 5,600 meters.

The position of the Australian continent has evidently influenced the course of the great arc. It will be shown on a later page that the

Australian cordillera extends across Torres's strait into the low lands of the Fly river, in New Guinea. Australia and New Guinea enframe the Banda arc.

Thus ends the western group of the eastern Altaides. Once more the coulisses have all disappeared, except the most westerly. This runs out as a long arc into the deep sea, continually decreasing in importance as it proceeds. A short coulisse, that of Timor, is the last to join the group, and then the arc bends back upon itself, gripped between alien horsts.

The Banda arc does not come into contact with the conjectured southernmost outrunners of the Philippine virgation; it reaches neither the volcanic line of Minahassa and the gulf of Tomini, nor that of Batjan and south Halmahera. A double line of east-and-west trending islands inserts itself in the interval between them; Misul, Obi-Besar, Mangoli, Taliabo, and the Peling group in the north, and Ceram, with Buru and Ambon, in the south, the last two being often assigned to the Banda arc. It is to be concluded that these two lines of islands are the prolongation of the two western promontories of New Guinea, and that the Ceram sea, which lies between them, corresponds with the gulf of Buru.

The importance of this region lies not only in its trend-lines. In the mountains of Arakan occurs that remarkable series of eruptive rocks, partly of Mesozoic age, and for the most part probably Cretaceous, which spread over the Moluccas and numerous other islands, as far as New Caledonia and New Zealand, everywhere characterized by a high percentage of magnesium. The eastern branch of the eastern Altaides marks the region where the Tethys entered what is now the continent of Asia. Many different circumstances, such as the damming back and overfolding of the Ala-shan range against the foreland of Ordos, or the enforced bending back of the Banda arc upon itself, leave no room for doubt that in this part of the earth also there are regions which have been actively moved or are still in movement, in contrast to resisting regions which have been little or not at all displaced; and that the process of mountain formation has in no wise been uniform.

If we attempt to follow the course of the trend-lines, it appears as though in some cases, long folds, seeking continuation in the direction of their length, had propagated themselves between the obstacles and along them; such, for instance, are the Tsin-ling-shan or the Arakan range, while in others the folds have originated under pressure against an obstacle, as in the Ala-shan; and between the two types there is evidently every stage of transition.

A fruitful task of a special character awaits future investigators in these regions. Here, and especially in the Moluccas, ranges including folded beds of middle Tertiary age, are engirdled by terraced belts of limestone, the highest of which date to all appearance from upper Tertiary

times. We can form some conception of the mechanical process of folding, and likewise of a spasmodic sinking of the sea-level owing to an enlargement of the marine abysses, but it is difficult to frame a theory which will account for a spasmodic upthrusting of islands, or explain the occurrence of a second and dissimilar movement of elevation independent of the folding. But that folding movements have continued to take place in the midst of the great ranges, even up to recent times, is clearly attested by the continental Gobi deposits.

These deposits lie horizontal in the basin of the river Wei; they reach the north border of the Tsin-ling-shan: at Tshing-tshou, on the Wei, Łoczy obtained from them *Stegodon insignis*. Further to the north-west, near Kun-tshang-fu, on the upper course of the Wei, they clothe the broken outlines of the ancient mountains. West of Lan-tshou, the Hoang-ho has cut its bed deeply into them, and from here they extend to the Sin-nin, forming a broad tableland. South of Lan-tshou, in the direction of the Tao-khe, they advance to Min-tshou and as far as lat. 33° N., sometimes horizontal or resting with a gentle inclination against the mountains, at others fairly well folded to the west-north-west, the prevailing direction in these regions.

But they penetrate also further to the west, extending as red saliferous deposits deep into the valleys between the lofty chains of Thibet. In long. 93° E., Rockhill found the whole valley between the Marco Polo and Kuku-shili mountains covered with brick-red deposits, and salt lakes extend over its floor. Beyond the Kuku-shili, in lat. 35° N., this traveller observed a table-mountain of red sandstone. Here we stand in the midst of the upswelling of the folds; the valley bottoms nowhere sink below 4,500 meters. Still further away, south of the chain of Dung-bure, Rockhill could see red sandstone, but no other rock, stretching away as far as the eye could reach. Even far down in the valley of the Yang-tse-kiang we meet with similar deposits; in the pass of Rishod-la, for instance, west of Batang, where horizontal beds of red sandstone and conglomerate are exposed¹.

Thus these sediments, perhaps not everywhere of equal age, cover the land like a torn red veil, and bear witness to the latest movements of the ground.

We may assume that the high-lying patches described by Rockhill were deposited in isolated basins at great heights. On the other hand, we have mentioned two instances from the Nan-shan which leave no doubt as to a later movement. The first of these is furnished by the extension of these beds from the oasis of Tshou-ma-er, towards the east-south-east, into the ancient longitudinal valley between the Richthofen range and the

¹ Rockhill, Diary, pp. 193, 204, 209, 330.

Tolai-shan; they ascend in this valley to the top of the pass of Tsin-nin-daban and above it, i. e. to over 4,220 meters, and in the course of the ascent the beds, which at first lie flat, are bent into a syncline with steep dips on each side. Obrutschew justly observes that the valley must have become narrower. The second instance is afforded by the plain which extends south of the south Kuku-nor; the beds, horizontal at first, become more and more inclined towards the great range, until they acquire a dip of 70° to 80°.

These facts show that the folding movements in recent times were not confined to the outer border of the Eurasiatic mountains. Within the amphitheatre of Irkutsk the great Cambrian tableland presents a picture of undisturbed repose, but here also the folding of the border either persisted up to the days of the Angara flora, or was renewed at that time. Outwards from the periphery, and onwards to the depths of the Pacific Ocean, the signs of a general movement increase. From Kamtchatka, as from the Malay peninsula, the cordilleras step down, as it were, into the ocean, and away out to sea, as far as the Bonin islands; we perceive that the arrangement of the volcanos is determined by processes of the same kind as those that determine the arrangement of the mountains.

CHAPTER VII¹

THE YARKAND ARC, IRAN, AND TURANIA

The Yarkand arc, or western Kuen-luen. Himálaya. Safed-koh. Sewestán. Iran. Hindu-Kush. Turania. Amu-darya. Sir-darya. The existing continent of Asia.

The Yarkand arc, or western Kuen-luen (I, p. 439). The Altaides, which are here represented by the Bei-shan and Thian-shan, maintain a complete independence in regard to the arc of Yarkand. They may be pictured as the chord of that arc. There is nothing to be seen in the western Gobi analogous to the denuded arcs of the eastern Gobi, or the fragmentary arcs of Ala-shan. The few hills that we meet with, such as the Masar-tag, are scarcely more than 'witnesses' formed by the gypsiferous deposits of the Gobi, and the Eocene ridges in the neighbourhood of the Sánju and of Yangi-Hissar have no connexion with the structure of the great arc.

The works of Piewtzow and Bogdanowitsch have led to a complete revolution in our conception of the structure of this arc². Its north-western segment is the range of Kashgar; west of this rises the lofty Mustag-ata. The range of Kashgar is joined towards the south by a chain to which the name of western Kuen-luen in a special manner belongs; it ends on the river Yurun-kash. Here the Keria range begins, which in lat. 36° N. forms the most southerly part of the arc. From this point the general trend turns to east-north-east; from Keria-darya onwards the arc is represented by the Russian range, or Akkar-tchekyl-tag, which consists, in fact, of two parallel chains, Astyn-tag and Usiu-tag, separated by a deep longitudinal valley. Beyond the Kara-muren these are joined by the Tokus-dawan; further on the coulisses of the Altyn-tag and Anembar-ula

¹ Revised by T. C. Chamberlin, LL.D., Professor of Geology in the University of Chicago.

² K. J. Bogdanowitsch, The north-west of Tibet, Kuen-luen, and Kashgar, *Izvestija Imp. ross. Geogr. Obsch.*, 1891, XXVII, pp. 480-504; Geological investigations in east Turkestan (Works of the expedition to Tibet directed by W. M. Piewtzow, vol. II), published by the Russian Geographical Society, 1892, 4to, maps; Observations on the Kuen-luen, *Izvestija Imp. ross. Geogr. Obsch.*, 1894, XXX, pp. 374-400, map; Some observations on the system of the Kuen-luen, *Mitth. k. k. geogr. Ges. Wien*, 1895, XXXVIII, pp. 497-526, map; cf. also G. Wegener, *Versuch einer Orographie des Kuen-luen*, Inaug.-Diss., 8vo, Marburg, 1891, map; *Die Entschliessung der unbekanntesten Theile von Tibet und die tibetanische Centralkette* (in *Festschrift für Ferd. Freiherr v. Richthofen*, Berlin, 1893), pp. 387-418; and K. Futterer, *Die allgemeinen geologischen Ergebnisse der neueren Forschungen in Zentral-Asien und China*, *Peterm. Mitth., Ergänzungsheft* No. 119, 1896, map, in particular p. 6 et seq.

make their appearance, striking out far to the east-north-east, and at length, as we have already seen, making syntaxis with the ends of the chains of the Nan-shan. On the inner side, that is to the north-west of these coulisses, lies the oft-mentioned range of San-sjan-tsy; also within the arc, and situated south-east of Khotan, lies the short range of Tekelik-tag.

Above the gneiss and crystalline schist of these mountains Bogdanowitsch encountered a thick series of conglomerate, quartzite, clay slate, and diabase, frequently much altered. To this series no doubt the chlorite schist, frequently mentioned by Stoliczka, also belongs. Black coral limestone has been found on the south slope of the Kyzyl-unguinen-tiure, and also further east, at a height of 16,000 to 18,000 feet. Frech has assigned it to the middle Devonian. The whole stratified series, from the summit of the crystalline schist upwards, must be included in the Devonian¹. It forms a broad zone, within which Stoliczka discovered, south-west of Sanju, some doubtful traces of lower Carboniferous beds². The middle Carboniferous forms a long band of grey limestone in the north of the range. On the south slope of the Tekelik-tag *Fusulina* limestone was met with, and furnished specimens of *Spirifer Mosquensis*, *Productus semireticulatus*, and other characteristic species.

On the river Gussass (left tributary of the Tiznab, which ends between Kárghalyk and Yarkand) Bogdanowitsch found a dark limestone full of Brachiopods lying discordantly on the older rocks. Diener has recorded the presence of *Productus cancriniformis* in this limestone, and has thus shown that it is probably contemporaneous with the *Productus* shales of Kumaon and Gurhwal, which, like it, are also defined by an unconformity at the base³.

Bogdanowitsch has been led by these facts to distinguish two phases of transgression. The first is the transgression of the *Kuen-luen*, which seems to have been preceded by the formation of a plain of denudation. The earliest deposits are coarsely clastic sediments; and the first fossiliferous beds are middle Devonian coral limestones. The second transgression is the Thibetan: it corresponds with the beds of Gussass, which appear to be represented by thick calcareous sandstone in the middle of the mountain arc⁴. On the Tekelik-tag the stage of *Spirifer Mosquensis* lies almost directly upon the gneiss.

¹ Beiträge zur Stratigraphie Central-Asiens auf Grund der Aufsammlungen von F. Stoliczka und K. Bogdanowitsch, Denkschr. k. Akad. Wiss. Wien, 1894, LXI, pp. 431-465; F. Frech, p. 445 et seq.

² Beiträge zur Stratigraphie, &c., tom. cit. F. Frech, p. 452.

³ Frech, Beiträge zur Stratigraphie Central-Asiens, p. 454; and C. Diener, Himálayan fossils: Permian fossils of the *Productus*-Shales of Kumaon and Gurhwal, Palaeontologica Indica, Ser. XV, vol. I, pt. 4, pp. 31, 54.

⁴ Bogdanowitsch in Piewtzow, Works of the expedition to Tibet directed by W. M. Piewtzow, II, p. 59 et seq.

In our study of the structure of the Yarkand arc, we are provided with three transverse sections by Stoliczka, and eight more or less complete traverses by Bogdanowitsch.

If we approach the inner arc of the system from Khotan and cross the foot-hills (probably Eocene), we at once encounter gneiss in the Tekelik-tag. Beyond the summit some granite follows, then a basin of grey Carboniferous limestone accompanied by Angara beds, 50 versts in breadth, and either faulted in or unconformable. South of this basin, in the second range of foothills, called Karangu-tag, gneiss again crops out¹. This chain and that of San-sjan-tsy are, strange to say, the only localities where gneiss has yet been found on the inner border of the arc. A girdle of light grey Carboniferous limestone occurs, however, towards the west, at the foot of the great

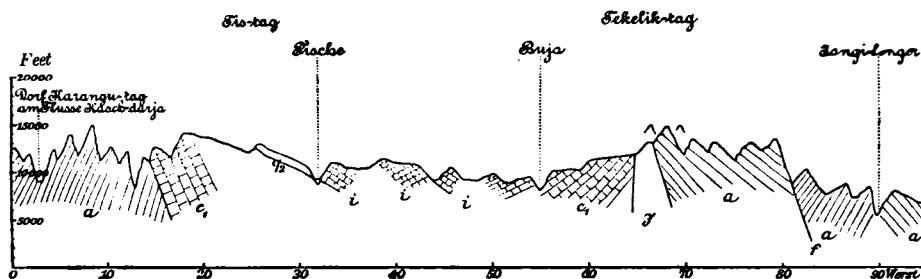


FIG. 14. Section through the Tis-tag and Tekelik-tag. (After Bogdanowitsch.)
a, a gneiss and crystalline schists; c Carboniferous with *Spirifer Mosquensis*; i, i plant-bearing beds; γ granite; q, talus and gravel; f, f faults.

range, or in the foot-hills south of Sánju, also to the south-west of Kárghalyk and west-south-west of Akka-aryk, near Yarkand, that is, in nearly the whole western sweep of the arc.

Then follows the great zone of Devonian beds. It forms the mountains of Kashgar as far as the Mustag-ata, the western Kuen-luen (as understood by Bogdanowitsch), the chain of Keria, and the whole Russian chain up to the less lofty limestone mountains of northern Tibet which lie to the south, as well as many parts of the chains lying more to the east; it thus includes almost the whole arc. Great bosses of granite rise out of this Devonian zone. They form many summits which attain or exceed a height of 6,000 meters, as, for instance, near the pass of Tachta-korum, on the line from Kárghalyk to the Mustag, and in the Russian chain. There can be no doubt that these great bosses are related to the structure of the mountains in the same way as those which so frequently emerge from the midst of the Devonian in Cornwall or the Hartz. The Yarkand range exhibits

¹ Bogdanowitsch, Works of the expedition to Tibet directed by W. M. Piewtrow, II, pl. 2, fig. 4.

similar protrusions of granite in the gneiss, but not in the Carboniferous zone.

South and west of the Devonian zone the conditions are different. The Russian chain ends abruptly on the south—both towards lake Dash-kul (Usiu-tag) and lake Shor-kul (Astyn-tag)—forming terrific precipices, and south of these stretch the folded limestone ranges of north-west Thibet. Towards the west, the boundary between the Devonian slates and the limestone range runs near Dong-lung over the upper Karakash (in Lingtsi-thang), and near Ak-tag, on the road to the pass of Kára-korum (lat. 36° N., long. 78° 10' E.). In these limestone mountains of the south, Permian Ammonites are known to occur, as well as marine Trias and marine middle Jurassic beds¹.

Further to the north-west the case changes. The limestone zone disappears, and the Devonian sediments, with their granite bosses, advance upon a great western zone of gneiss.

This has already taken place on the upper part of the Yarkand-darya. In the southern part of the Kashgar range the gneiss is reached about 30 versts to the east of the valley of Tagharma; the Kok-mainak pass lies in a granite boss which is surrounded by gneiss. At length, south-west of Yangi-Hissar, the Devonian sediments abut directly, at a great altitude, against the gneiss of the giant peaks of the Mustag-ata. The section published by Bogdanowitsch shows at the place of contact a fold in the Devonian overturned to the east.

'The granites of Bolun and Tachta-korum,' says Bogdanowitsch, 'pass into the granites of Kusserab, i. e. the Kashgar range, especially its eastern slope. The gneisses of the Mustag-ata may, in all likelihood, be brought into connexion with those of the central mass of the Mustag chain².'

These facts lead to the following results:—The interpretation given in an earlier chapter (I, pp. 439–443) is confirmed, in so far as the inflexion of the western Kuen-luen has now been established. The inferences drawn from the identity of the rocks at Sánju and Kárgalyk have received further support. The syenite gneiss of the Yangi pass must be included amongst the syenite and granite bosses of the Devonian. On the other hand, however, Stoliczka was mistaken in thinking (I, p. 449) that the Trias limestone of Aktash in the Pámir is continued towards the south-east into the fossiliferous limestones of the Kára-korum district. We perceive, on the contrary, that the masses of gneiss which Stoliczka crossed between Balgun,

¹ Beiträge zur Stratigraphie Central-Asiens, p. 458; Mojsisovics, Permian with Xenodiscus of Woabjilga, p. 462, Uhlig, Kelloway of the upper Karakask. In addition Trias is represented in the Kára-korum by Heterastridies; Belemnites are known from this pass.

² Bogdanowitsch, in Works of the expedition to Tibet directed by W. M. Piewtzow, II, p. 83; cf. in particular map B; Bolun and Tachta-korum lie far within the mountains towards the Mustag.

Tashkurgan, and Kanshubar (east of Aktash) are not only continued towards the north into the Mustag-ata, but in all likelihood also to the south, through the range of Tagdumbash to the high mountains of the Mustag. 'From Tagdumbash,' says Iwanow, 'the range rapidly increases in height and passes into the peaks of the Kára-korum-Mustag, which rise above the clouds to a height of over 20,000 feet'¹.

Thus we arrive at a scheme which differs still further from earlier conceptions. *The Mustag-ata becomes a part of the gneiss chain of Baltistán which runs through the Peak K₂, now Mount Godwin-Austen (8,610 meters), to the lake of Pangong in the south-east*².

Sven Hedin has discovered a great number of instructive features in the structure of the Mustag-ata³. This mighty mountain mass does not terminate on the Ges, but continues beyond it with a trend still more to the north-north-west. It has long been known that the Pámir consists of two parts; one, narrow, situated to the east and running from north to south; the other, broad, situated towards the middle and the west, and running from east to west. The resemblance between the relation of these parts and the syntaxis on the Jhelam has already been pointed out (I, p. 448). The mighty chain of Baltistán turns completely to the north, extending even past lat. 39° N., and determines the course of the Altaides, which come from the north and are now continued further along the west side of this chain, precisely like the chains of the Nan-shan, which are now able to continue their development on the east side of the other end of the Yarkand arc.

Thus on the east, as on the west, the Yarkand arc checks the long terrestrial waves which come down from the Altai. It is narrow throughout its length; the western spurs of the central Kuen-luen (Akka-tag and others), as well as the mountains—in part Mesozoic—on its south side, separate it from the arc of the Himálaya; on the other hand, it is connected with this arc by the inflexion of the principal chain of Baltistán from north-west to north.

On the northern slopes of its southern parts lie patches of the plant-bearing Angara beds, which attain so extraordinary an extension in Siberia.

¹ D. Iwanow, *Journey to the Pámir*, Izviestija Imp. ross. Geogr. Obsch., 1884, XX, p. 44.

² This interpretation has already been given by Richthofen (China, map to p. 272), not for the western Kuen-luen but for the Mustag-ata (the mountains generally designated the Kyzyl-yart). Lord Curzon's map of the Pámir (Geogr. Journ., VIII, 1896, p. 96) shows clearly the position of the points mentioned; the independence of the Tagdumbash Pámir and its divergent constitution, which the author emphasizes on p. 33, are caused by the peculiarities of its structure, which have just been described. For the height of Mount Godwin-Austen, see J. T. Walker, Geogr. Journ., 1894, III, p. 339, and H. H. Godwin-Austen, *ibid.*, p. 431.

³ Sven Hedin, *Forschungen über die physische Geographie des Hochlandes von Pámir im Frühjahr 1894*, Zeitschr. Ges. f. Erdk., Berlin, 1894, XXIX, pp. 289-346, maps; *Die Gletscher des Mustag-ata*, *op. cit.*, 1895, XXX, pp. 94-134, maps; and *Der kleine Karakul und Bassik-kul*, Peterm. Mitth., 1895, LXI, pp. 87-92, map.

Here they come to an end. South of the Devonian and granite zone of the Russian mountains, but still north of the gneiss range of Baltistán, their place is taken by the varied series of marine Mesozoic deposits.

We now enter the region of the Tethys. But our knowledge of this is confined to the boundaries of its sediments, and these only as determined by the imperfect data at our command; they may be modified, therefore, at any moment by some fortunate discovery. The boundaries of the sediments do not necessarily coincide with the original limits of the sea. The plant-bearing beds on the north side of the arc of Yarkand have undergone posthumous dislocations, and the Mesozoic sediments of the south have been subjected to the most intense folding. Even in the very midst of the glaciers of the chains of Baltistán, a zone of altered limestone runs at a great height for a long distance through the gneiss, in which it appears to form a syncline or a wedge opening towards the south-west (I, p. 438). So far as outcrops of Mesozoic are known to me in this region, they nowhere present clastic or littoral characters; but consist for the most part of limestone of various degrees of purity.

The region has been the theatre of dynamic phenomena on so grand a scale that the ancient and doubtless very variable outlines of the Mesozoic sea are no longer recognizable. We must content ourselves provisionally with the following general observations:—Nowhere on the horst of the Baikal are Cambrian sediments certainly known to occur; from this point towards the south Palaeozoic sediments exist, above them lie the plant-bearing beds of the Angara series, and finally, from the south border of the Yarkand arc onwards, the plant-beds disappear and are replaced by marine deposits of Mesozoic age.

The eastern part of the arc of Yarkand has already been studied in connexion with the western Nan-shan.

Himálaya. The Himálaya includes in its western part a series of mighty mountain chains which one after another, over their whole breadth from the alluvia in the south up to the Mustag in the north, are folded and overfolded to the south-west (I, p. 434).

The most important members of this range are: (1) The Tertiary foothills; (2) Pir Panjál and Dhauladár, formed of schist and granite; (3) the upper Palaeozoic and Mesozoic basin of Kashmir; (4) the gneiss zone of Zánskár; (5) the Palaeozoic and Mesozoic zone of Spiti and elsewhere; (6) the Eocene and basalt zone on the upper Indus; (7) the syenite and gneiss zone of Ladakh; (8) the remains of a pinched-in zone of upper Palaeozoic and Mesozoic in Braldu and Baltistán; and (9) the gneiss zone of the Mustag and of Baltistán.

All geologists who have studied this great range in detail agree that it has been produced by a succession of tectonic processes, commencing from a remote period and continuing into late Tertiary times, perhaps even up

to the present day, but always governed by the same plan. Griesbach, in his account of the region between the Spiti valley and the boundary of Nepal, has given a detailed description of zone 5 (locally scarcely separated from zone 6), which lies on the north side of the loftiest gneiss range; his description confirms the statement just made, and, in conjunction with the work of other geologists in India, leads to more definite conceptions of the course of events¹.

In the Himálaya, as well as in Afghanistan, and as far as northern Persia, Griesbach obtained evidence which showed that great physical changes had occurred towards the close of the Carboniferous epoch.

In Spiti, Painkhánda, and Yohár a marked unconformity occurs at the base of the Permian, as represented by the *Productus* shales, remarkable here as elsewhere for their intensely black colour. This unconformity, which, as we have already pointed out, probably coincides with the Thibetan transgression of the arc of Yarkand, was already known to Stoliczka. With it begins the 'Zanskár system' of Lydekker.

As regards later events, we will only mention the fact that on the upper Indus one shore of the Eocene sea lay on the south side of the chain of Ladakh (zone 7), (I, p. 438), and the disposition of the beds seems to indicate that in post-Eocene times the coulisses approached each other during the general movement from the north-east. Perhaps a disjunctive line, on which volcanos were seated, existed here in the Eocene epoch.

Finally the overthrusting of the Siwaliks (zone 1) bears witness to the persistence of the movement.

The extraordinary breadth over which the uniform movement towards the south-west has made itself felt led us to suspect that tangential dislocations must exist in this region comparable in importance with those of the Swiss Alps, and recent observations have shown that such dislocations actually occur. They lie in zone 5, on the boundary between Kumaon and Thibet, and we possess accounts of them by two distinguished observers, Griesbach and Diener, who are completely in accord as regards the facts².

In this region the Palaeozoic succession is visible up to the white Carboniferous quartzite. Above the quartzite lie the black *Productus* shales, the long and complex series of Trias deposits, always black or dark grey in colour, the white or greyish white Dachsteinkalk, the thick black

¹ C. L. Griesbach, *Geology of the Central Himálayas*, Mem. Geol. Surv. India, 1891, XXIII, maps. For general questions of this kind see R. D. Oldham, *Age and Origin of the Himálaya*, Geol. Mag., 1891, pp. 8 and 70; and C. A. McMahon, *The Geological History of the Himálayas*, Proc. Geol. Assoc., 1895, XIV, pp. 80-96.

² C. L. Griesbach, *Notes on the Central Himálayas*, Rec. Geol. Surv. India, 1893, XXVI, pp. 19-25, map; C. Diener, *Ergebnisse einer geologischen Expedition in den Central-Himálaya von Johar, Hundes und Painkhanda*, Denkschr. k. Akad. Wiss. Wien, 1895, LXII, pp. 533 to 607, maps; *Notes on the Geological Structure of the Chitichun Region*, Mem. Geol. Surv. India, 1898, XXVIII, pp. 1-27.

Spiti shales which belong to the middle and upper Jurassic and in part to the horizon of Berrias, and finally, the flysch-like Gieumal sandstone. The two latter members form the plateaux of Chaldu and Kiogarh at heights of from 17,000 to 19,000 feet.

This whole series is conformable, at least from the discordance above the quartzite upwards. It is surmounted by patches of a second series, some of them forming the isolated and shattered crowns of lofty summits.

This second or superposed series differs from the normal series of Spiti. Its oldest member as yet discovered is a white limestone rich in *Camaraophoria*, *Loftusia*, and other characteristic Permian fossils; this horizon is quite unknown in the subjacent series. It is succeeded by marine Trias, in which Diener has recognized two zones, and Krafft subsequently several others. The zone of *Ceratites subrobustus* (base of the beds with *Spirifer Stracheyi* of Krafft) is represented in these superposed flakes by red marble, while in the normal series of Spiti it occurs as a compact black limestone¹. This is followed by light-coloured limestone, identical with the Dachsteinkalk of the lower series. Finally, as Herr Griesbach has had the kindness to inform me, Krafft has found Lias with *Arietites* in these flakes, a horizon which has not yet been discovered in the lower series. The flakes are associated with diabase porphyrite, which is also visible in dykes in the subjacent Spiti shales and Gieumal sandstone.

The distribution of these flakes is independent of the folds of the foundation (Fig. 15), and although the schists beneath them are much crushed, yet in one case at least, that of the flake on Chitichun I, which has been carefully examined, the bedding would appear to be horizontal. Many little faults and slickensides traverse them, but the fossils are not distorted by pressure.

Generally speaking, the flakes are found over a wide arc, extending from Chitichun I towards the Kungri-bingri, on the summit of which (5,843 meters) Diener found a block of white Permian limestone.

The most remarkable fact in connexion with this subject is the difference which exists between the upper series and the lower. It recalls the difference between the 'Briançonnais' in the recumbent folds of the western Alps and the subjacent Helvetian formation. Thanks to the refinement which has been achieved of late in our subdivision of the Trias, Diener, after determining the fossils collected on the east slope of Chitichun I, was able to point out the horizon on which these fossils should be looked for at Spiti; and Krafft actually found them there, but in a different rock. This fact alone shows that the upper and lower series must have been formed under different physical conditions, and at a great distance from each other; it also proves that the flakes are not projecting anticlines, that they have

¹ A. v. Krafft, *Stratigraphical Notes on the Mesozoic Rocks of Spiti*, Gen. Rep. Geol. Surv. India, 1899-1900, pp. 204.

not been moved vertically upwards by dislocation, and that they have not been dragged upwards by associated eruptive rock; we seem, indeed, irresistibly driven to the conclusion that they have been brought here from afar off, as in the case of the recumbent sheets of Switzerland.

The flakes have not come from the south; the general movement of the mountains from north-east to south-west is opposed to this hypothesis. In the north, however, lies first the Eocene zone 6, next the mighty gneiss and syenite zone of Ladakh, 7, and then only come the probable continuations

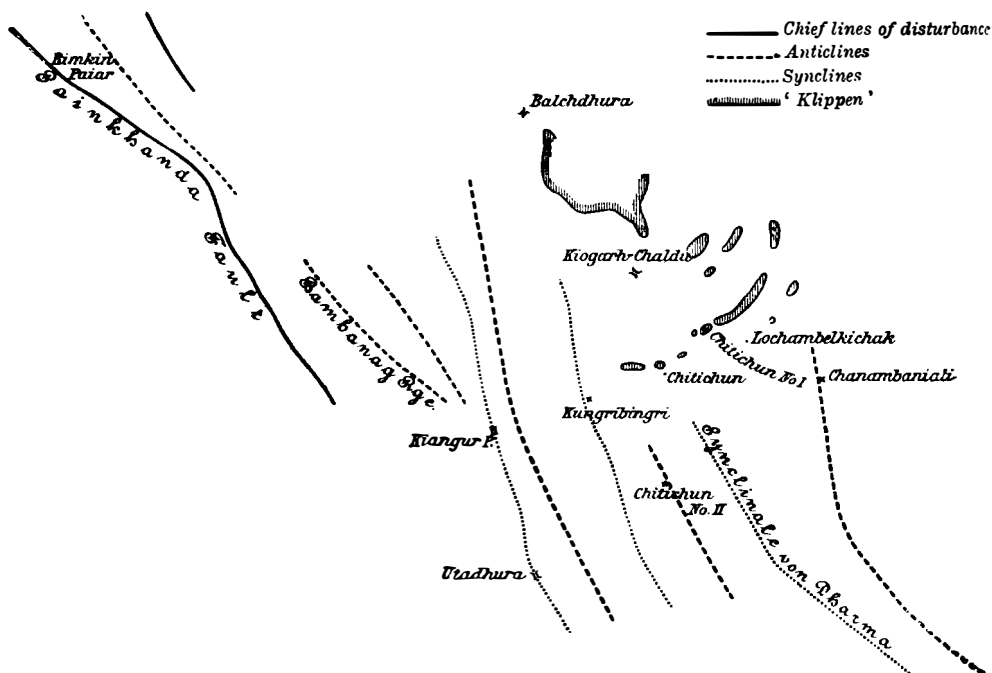


FIG. 15. The overthrust flakes ('Klippen') of Chitichun and Baldchura in the south Hündes. (After Diener.)

The Thibetan frontier runs through the Utadhura (5,361 meters) and Kiogarh-Chaldu (5,315 meters) passes. Further to the north-east lies the lake of Manasarowar.

of the pinched-in Mesozoic fragments of Bráldu, which, to judge from the strike, probably contain the wedge-shaped roots of these recumbent flakes. But nowhere in the Trias of these regions, whether represented by the normal series of Spiti, or by the recumbent flakes of Hündes, or by the pinched-in strips of Bráldu and Baltistán to the north, is there any indication of shore deposits. We must conclude, therefore, that the sediments of the Trias once extended over the whole zone of Ladakh, and, as in the western Alps, were thrown into folds, together with the rocks below them, and subsequently denuded off.

The eruptive rocks can only be regarded as a secondary or consequent phenomenon.

Indications, such as we have just encountered, of tangential movement on the grandest scale lead us to suspect that many phenomena in the Himálaya, hitherto unexplained, will find their solution in the theory of recumbent folds. We may refer to the isolated occurrence of a mass of black limestone with *Nummulites Ramondi* which overlies Palaeozoic quartzite on the summit of Z_4 (5,638 meters) near the pass of Singhe Lá¹, and also to a series of flakes more to the south; in particular, to the gneissose granite which forms the mass of Kalogarhi in British Garhwal, east of the point where the Ganges leaves the mountains. The precise descriptions of Middlemiss, and the amazement with which he saw the Tertiary sediments which surround this mass dipping beneath it, lead us to think that he would have arrived at another explanation from that he finally adopted, or rather that he would have held to his first impressions, if the recumbent sheets of Chitichun had been known at that time, or those facts which have since been brought to light in the Swiss Alps between the Aare and the Arve. The series which lies beneath the mass of the Kalogarhi includes Mesozoic sediments and Nummulitic beds; it forms a broad syncline; the gneissose granite rests immediately upon the Eocene, and there are no signs of transition².

Judging from what is actually known, it would seem probable that on the southern border of the Himálaya several very large flakes of crystalline rocks have been driven over the Eocene.

Siah-kóh and Saféd-kóh. In the year 1892 Griesbach showed that the Saféd-kóh, a lofty mountain range which runs east and west in about lat. 34° N., south of the Kabul river, must be regarded as an independent tectonic element, situated between the Hindu-kush and the Salt range³. The previous work of Waagen and Wynne led Griesbach to suppose that the Saféd-kóh, notwithstanding the intervening plains, finds its tectonic continuation in the fragmentary arcs of Hazára, which approach the syntaxis on the Jhelum from the west. The subsequent investigations of Middlemiss in Hazára have confirmed this view⁴.

Between the pass of Shutargardan in the west and Muzaffirabad in the

¹ La Touche, Rediscovery of Nummulites in Zánská, Rep. Geol. Surv. India, 1888, XXI, pp. 160-162; Singhe Lá is in lat. 33° 58' N. long., 76° 58' E.

² C. A. Middlemiss, Physical Geology of West British Garhwal, Rec. Geol. Surv. India, 1887, XX, pp. 26-40, maps; also Crystalline and Metamorphic Rocks of the Lower Himálaya, Garhwal and Kumaun, tom. cit., pp. 134-143; p. 142: 'a quaquaversal thrust-plane round the Kalogarhi centre, in post-nummulitic-limestone times.'

³ C. J. Griesbach, The Geology of the Saféd-Kóh, Rec. Geol. Surv. India, 1892, XXV, pp. 59-109; cf. also The Face of the Earth, I, pt. IV.

⁴ C. S. Middlemiss, The Geology of Hazára and the Black Mountain, Mem. Geol. Surv. India, 1896, XXVI, 302 pp., map.

east we find ourselves in the presence of a mountain arc, divided, as regards its outer form, into several parts, which do not yet possess a common name.

In the east the mountains of Hazára trend away from the syntaxis to the south-south-west, then to the south-west, and finally disappear beneath the alluvial plains of Haripur. All the mountains are folded or overfolded to the east-south-east or south-east, i. e. towards the syntactic axis. We have already seen that a long and important dislocation follows the general strike, and then describing an arc towards the west passes into an east-to-west direction, along which it may be traced even across the Indus to Kohát and beyond. Along this line older sediments are overthrust towards the exterior across the middle Tertiary region of Ráwalpindi (I, p. 444). This line of dislocation, however, is not the only one. Middlemiss found that the range of Hazára consists of four zones or 'blocks,' which are sharply separated from one another by similar lines (thrust-planes).

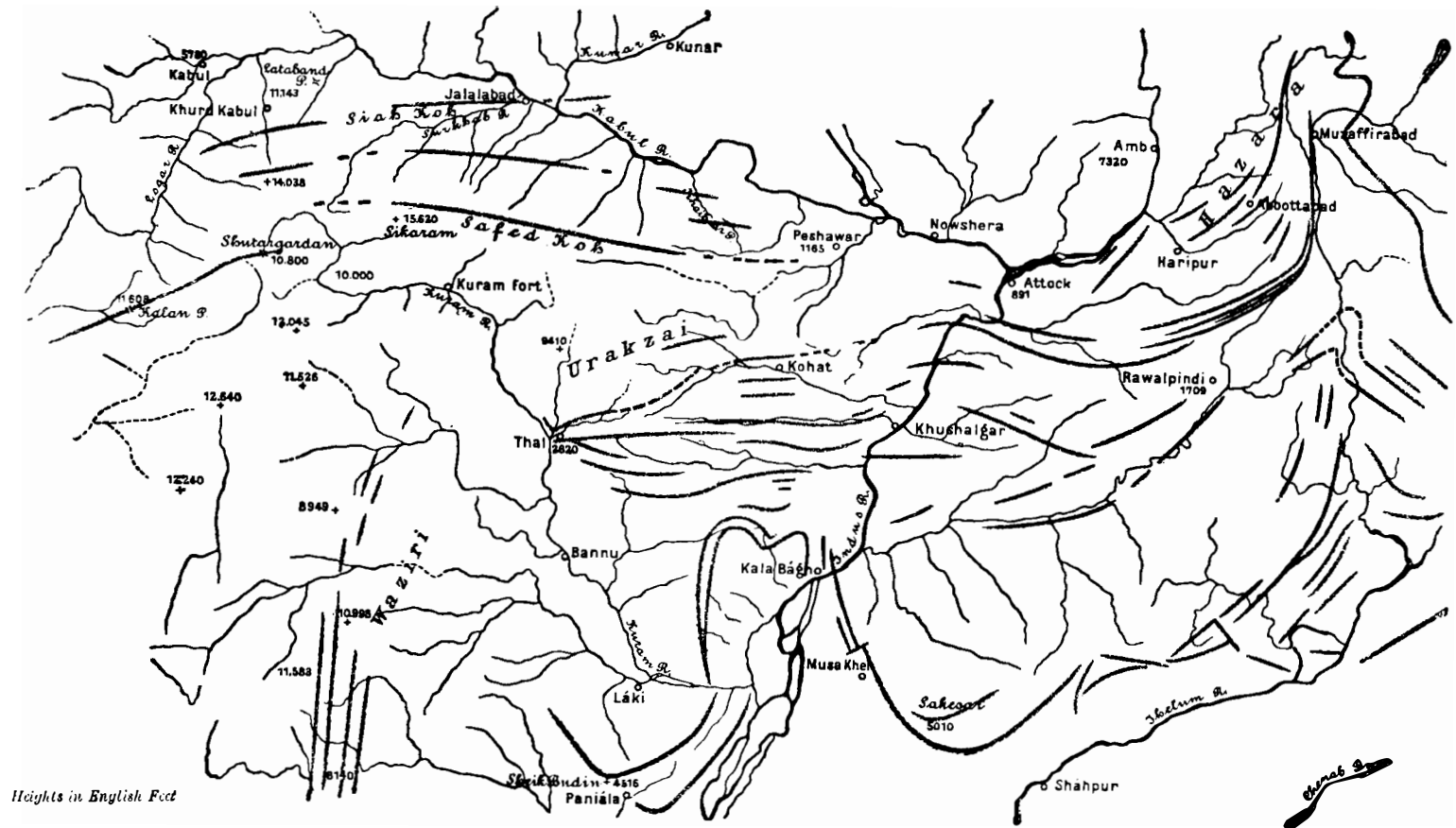
The first and innermost zone on the north-west includes the oldest rocks, gneiss and schistose beds in part highly altered. The second zone is formed of ancient schists, Mesozoic sediments, and the lower beds of the Nummulitic series. The third zone begins with Trias, and extends through the very thick Nummulitic series up to the Kuldana series, with which the Eocene terminates. Then follows the line mentioned above, running north of Ráwalpindi. The fourth zone begins with the upper horizons of the Nummulitic series, and consists chiefly of Miocene sediments.

This succession of zones, each commencing with sediments of earlier date than its predecessor, and the sharp separation of one from another by a long and continuous thrust-plane, testifies to a remarkable resemblance between the structure of Hazára and that of the north-eastern Alps.

The descriptions which Griesbach has given of the region between Peshawar and the Logar valley, taken in connexion with earlier accounts, and the latest observations made by Hayden in the mountains of Khaibar and to the south of the pass, enable us to recognize the following leading features¹:—

A main range of gneiss, mica-schists, and other ancient rocks proceeds from Kunar, and probably from a point much further east, towards the west and traversing the lower course of the river Kunar, crosses the Kabul river not far from Jalalabad, and continues still further in the direction of Khurd-kabul. Between the two latter places it is called the *Siah-kóh*, and forms the watershed between the rivers Kabul and Surkhab. Possibly, however, it is continued still further to the south-west towards the Logar

¹ A. B. Wynne, The Trans-Indus Salt Region in the Kohát District, Mem. Geol. Surv. India, 1875, XI, pp. 105-226; Note on the Tertiary Zone and underlying rocks in the North-West-Punjab, Rec. Geol. Surv. India, 1877, X, pp. 107-132, map; and Further Notes on the Geology of the Upper Punjab, op. cit., 1879, XII, pp. 114-133, map; W. Waagen, Section of the Kabul river through Kushialgurh to Kalabagh, in Salt Range Fossils, IV, Palaeontologica Indica, Ser. XIII, 1898, p. 13 et seq. Holdich, Tirah, Geogr. Journ., 1898, XII, p. 337, gives a map of the eastern Saféd-Kóh to the meridian of Kohát.



Fragmentary trend-lines between the Kábul river and the Jhelam

(After Griesbach, Middlemiss, Hayden, Wynne, and others)

valley. In this range the beds dip to the north; in the gneiss between Khurd-Kabul and the Logar valley, to the north-west. The whole range is overthrust towards the exterior, i. e. to the south and south-east, as are all the parts of the Saféd-kóh, to be mentioned later.

Towards the south the Siah-kóh is followed by a zone of sediments which are probably Carboniferous in age. In the east, towards the Khaibar, Permian beds also occur, and probably the whole Mesozoic series; in particular, limestones with *Dicerocardium* and *Lithodendron*. In the west the limestone range runs from Kunar across the river Kabul into the valley of the **Surkhab**, through the pass of Lataband, and probably also south of Khurd-kabul, south-westwards into the valley of the Logar. It is interrupted by masses of syenite and granite, and sometimes characterized by the presence of rubies.

South of the Siah-kóh, however, this limestone zone appears to be followed by another zone of schist, and a second series of limestone mountains, until we reach the *principal range of the Saféd-kóh*. This rises from the plain about 15 kilometers west of Peshawar, and reaches its culminating point far to the west in the Sikarám (4,816 meters). Its structure is very imperfectly known; gneiss is not recorded; in its highest parts large areas appear to be formed of schist, serpentine, and ancient limestone.

A great dislocation, apparently indeed a thrust-plane with overthrust towards the south, separates the principal range from a Mesozoic zone which follows to the south. On the east, south of the Saféd-kóh, Hayden encountered four parallel ranges formed chiefly of Mesozoic deposits, all overfolded towards the south¹. On the west this Mesozoic zone has been met with in the pass of Shutargardan; thence it runs to the south-west across the pass of Kalan (3,537 meters) towards the district of Kharwar and the town of Ghazni, which lies south of the upper Logar valley. In this western part of the zone also Griesbach has recognized the thrust-plane which bounds it on the north. In Urakzai the zone is broken up into flakes. South of it, near Kohát, that great thrust-plane is reached which has been mentioned as occurring in the east, north of Ráwalpindi, on the northern margin of the Miocene region. From Kohát it turns towards the south-west, and reaches Thal, on the river Kuram.

The lie of these parallel zones, the general overthrusting towards the south, and the widely extended thrust-planes, show how close is the correspondence between the structure of this region and that of Hazára. On the other side the zones approach the chains of the Suláimán range (I, p. 427), which trend due north and south. But Griesbach points out that the Suláimán range breaks up in the Waziri region into knots and isolated chains, which further to the north turn gradually round to the north-east

¹ H. H. Hayden, On the Geology of Tirah and the Bazár Valley, Mem. Geol. Surv. India, 1898, XXVIII, pp. 95-117.

in the direction of the Urakzai mountains (north-east of Thal). This circumflex junction reveals itself also in the deflexion to the south-west exhibited by the line of dislocation between Kohát and Thal, as well as by all the zones in the west which run towards the Logar valley or from Shutargardan towards Ghazni.

The trend-lines just described are shown in Plate III, together with Waagen's *diagrammatic* lines for the Salt range. They lie outside all the other lines. Waagen compares the Tertiary regions in the interval immediately north of the Salt range to the Molasse land of Switzerland, and the Salt range itself to the Jura mountains. We have already seen to what extent the proximity of the foreland makes itself felt in this locality¹.

The result of the laborious investigations which have been carried out in the region lying between the river Kabul and the Jhelam, and which redound so greatly to the honour of all who have taken part in them, is therefore as follows:—

The whole region has been subjected to a general movement, directed in Hazára towards the east; near Jalalabad, first towards the south, then to the south-east; and in the Waziri mountains to the east. The chains driven closely together on approaching the syntaxis of the Himálaya, i. e. towards the Jhelam between Muzaffirabad and Ráwalpindi, diverge from one another on the west. The first group is formed by the Siah-kóh and the Saféd-kóh, with their prolongations trending to the south-west. The second group runs through Kushalgar and Kohát, and turns sharply round in the Urakzai mountains and the vicinity of Thal into the meridional ranges of the Waziri mountains and the Suláimán chain. A third group is formed by the tectonic lines of the Salt range, which is divided into two arcs by its loop towards Kala-bagh. This range, thus represents the pre-alps of the Persian chains, and cannot, as I formerly supposed, be regarded as an irregular fore-chain of the Hindu-Kush.

Sewestán. West of Thal, Wynne came on eruptive rocks. Somewhat further south, travelling from Bannu in the valley of the Tóchi towards the west, Smith met with Siwalik conglomerates plunging steeply to the east beneath the alluvium of the plain, and followed regularly towards the west, first by the older members of the Tertiary series, and next by the Cretaceous². Smith was astonished at the similarity between the structure of this region and that of the range lying 300 kilometers further south, west of Déra-Gházi-Khán. Further up, however, in the Tóchi valley, serpentine and gabbro appear, then trachyte and amygdaloidal

¹ Waagen, Salt Range Fossils, IV, pp. 28 and 32.

² F. H. Smith, On the Geology of the Tóchi Valley, Rec. Geol. Surv. India, 1895, XXVIII, pp. 106-110; H. H. Hayden, On some Igneous Rocks from the Tóchi Valley, op. cit., 1896, XXIX, pp. 63-69.

basalt, which range apparently from the summit of the Cretaceous to the middle Eocene. It is a noteworthy fact that eruptive rocks, belonging approximately to the age of the Deccan trap, should extend so far as this.

The Suláimán chains (I, p. 427), the highest parts of which have recently been mapped by La Touche¹, detach themselves here from the chief Iranian arc and surround the eastern side of a smaller, fairly independent region, which may be distinguished as the *region of Sewestán*.

The trend of the Suláimán chains, which on the Takt-i-Suláimán is strictly meridional, turns towards the south-south-west even before reaching lat. 30° N.; and between lats. 28° and 29° N. the outer border of the less lofty chains which form their prolongation passes into an east-and-west direction. From here onwards this border, frequently interrupted by projecting anticlines, recedes far to the north-west, describing a re-entrant angle, and then encounters those meridional chains which separate Baluchistán from the Indus. Through this re-entrant angle runs the road to the pass of Bolan and Quetta.

Within the region thus bounded, successive folded ranges take the same turn to the west and finally to the north-north-west and north-west, as is clearly shown on the geological maps of Thal-Chotiali².

These folded ranges are generally of simple structure, and it is only towards the south-east border of the region that overfolding seems to occur. Like the lofty Suláimán chains, they consist chiefly of Tertiary and Cretaceous beds. The oldest bed visible is a massive limestone in which Lala Kishen Sing found Ammonites; Noetling has recorded the occurrence of *Macrocephalites macrocephalus*, and has established a correlation with Waagen's Chári group of Khach³. Noetling's investigations also show that the Neocomian with *Belemnites latus* is succeeded here by the uppermost part of the Senonian; and the intervening deposits of the middle Cretaceous, which are so largely developed in north Afghanistan, are unrepresented.

Mojsisovics, on the evidence of a loose fragment found in one of the side

¹ T. La Touche, Geology of the Sherani Hills, Rec. Geol. Surv. India, 1893, XXVI, pp. 77-96, map. On p. 93 there are some valuable observations on the syntaxis in the north.

² R. D. Oldham, Report on the Geology and Economic Resources of the country adjoining the Sind-Pishin railway between Sharigh and Spintangi, Rec. Geol. Surv. India, 1890, XXIII, pp. 93-110, map; Report on the Geology of Thal Chotiali and part of the Mari Country, op. cit., XXV, pp. 18-29, map; Griesbach, On the Geology of the Country between the Chappar Rift and Harnai in Baluchistán, op. cit., 1893, XXVI, pp. 113-147, map.

³ F. Noetling, The Fauna of the Kellaways of Mazár Drik, Palaeontologia Indica, Ser. XVI, Baluchistán, Part I, 1896, and Preliminary report on the Western Mari Hills and Zhob valley in Gen. Rep. for 1898-1899, pp. 50-63.

valleys of the river Zhob (North Sewestán), has established the presence of the alum-bearing stage of the upper Trias¹.

Afghanistan and Iran. Let us turn our attention to the pass of Bolan and the neighbourhood of Quetta. It is not only the folds of Sewestán, bent back towards the north-west, and those of the southern Indus chains trending towards the south, which meet together in this region. Griesbach's map of the country between Sibi and Girishk shows clearly how chains and fragments of chains, all running parallel towards the south-west, follow one another up to Kandahár and beyond as far as the Helmand chain². They probably proceed from the region between the Saféd-kóh and the most northerly part of the Suláimán chains. They run obliquely across the arc of Sewestán, bound this region on the north-west, and, still maintaining their south-west trend, reach a point west of Quetta. They are equally independent of the meridional chains of the Indus (Mts. Hala, Khirthar, and Lakhe, I, p. 426). At the same time the first important chain north-west of Quetta, the Khojak, belongs not to them but to the chains of the Indus.

The chains of the Indus join these ranges as a new fascies of folds which increases rapidly in breadth towards the south. From the instructive observations of Vredenburg on the boundaries of the desert basin, it may be inferred that the southern prolongation of the Khojak chain lies east of Nushki. Measured from this point across Kelát to the alluvial land of the Indus, the breadth of the folded region already amounts to about 150 kilometers. The chain which starts from Nushki and, running to the south-south-west, forms the south-east border of the plain of Kharan, attains an altitude of over 9,000 feet. While in the pass of Bolan the predominant rocks are Eocene and Cretaceous limestones, in this range, on the other hand, we find Eocene Flysch. From Nushki onwards the chains diverge more and more from one another, turning at the same time to the south-west and west, and finally to the north-west, thus surrounding the Hamun-i-Mashkel in their southern bend. Other ranges describing a gentler and interrupted arc, divide this closed basin from the much larger desert region of the Goad-i-Zirreh and the Helmand, which lies to the north of it³.

These chains have been formed by a thrust acting from north to south, and consist of folds having for the most part a very regular structure, but

¹ *Didymites afghanicus*; E. von Mojsisovics, Beiträge zur Kenntniss der obertriadischen Cephalopoden-Fauna des Himálaya, Denkschr. k. Akad. Wiss. Wien, 1896, LXIII, p. 611. The specimen was sent by M. Griesbach.

² C. L. Griesbach, Mem. Geol. Surv. India, 1881, XVIII, pt. I, in particular pp. 4-9.

³ E. Vredenburg, Baluchistan Desert, Gen. Rep. Geol. Surv. India, 1898-1899, pp. 63-68, and 1899-1900, pp. 50-52. A general idea of the folds is given in the maps by T. H. Holdich, The Perso-Baluch Boundary, Geogr. Journ., 1897, IX, pp. 416-422, and An Orographic Map of Afghanistan and Baluchistan, op. cit., 1900, XVI, pp. 527-531, map.

sometimes broken up into flakes. In certain cases, however, which were closely studied, Vredenburg found *that when a depression occurs to the north of a fold the direction of the folding is reversed and is turned towards the north, i. e. towards the depression.*

Great intrusions of granite and diorite penetrate into the highest beds of the Nummulitic series, and in the associated Siwalik beds pebbles of these rocks are found.

A. H. McMahon travelled through these regions at the same time as Vredenburg; the specimens he collected were described by C. A. McMahon and T. Holland. The intrusive rocks on the west slope of the Khojak range are hornblende granitite; they are continued towards the south-west into the Sarlat range, and also occur in the mountains between Helmand and Mashkel. Quartz-diorite and mica-augite-diorite are associated with them, and were also met with at the most westerly locality visited (lat. $29^{\circ} 50' N.$, long. $60^{\circ} 55' E.$), in the Persian chains running to the north-west¹.

In addition to these somewhat ancient eruptive rocks there are dislocations quite recent in age.

The Khojak range is pierced by a railway tunnel; on its west side lies the station of Sanzal. On December 20, 1892, a violent earthquake occurred, and near Sanzal a new and very long fissure opened along a furrow in the ground which corresponded to an ancient cleft. Griesbach has described the disturbances which affected the railroad where it crossed the fissure. The latter ran from north-east to south-west; the railway officials did not discover its termination in either of these directions².

According to A. H. McMahon, the fissure, ascending obliquely and gradually, crosses the crest of the main chain at a height of 7,000 feet, then reaches a valley, cuts obliquely through the slopes of several spurs of the Khojak range, and follows the foot of the Sarlat range along its whole length to Nushki. There, after a course of 180 kilometers, its termination was still unreachd. The fissure in some parts of its course looks like a railway cutting, and is used in places as a road. *This is a true disjunctive line of recent origin.*

Volcanic ashes occur in the Sarlat range, west of the fissure. They are the first of a long series of outcrops of ashes, pumice, and lavas, chiefly andesitic, which show that the Chagai mountains between Helmand and

¹ C. A. McMahon, The southern borderlands of Afghanistan, Geogr. Journ., 1897, IX, pp. 393-415, map; C. A. and A. H. McMahon, Notes on some Volcanic and other Rocks which occur near the Baluchistan-Afghan Frontier between Chaman and Persia, Quart. Journ. Geol. Soc., 1897, LIII, pp. 289-309, map; T. H. Holland, An Account of the Geological Specimens collected by the Afghán-Balúch Boundary Commission of 1896, Rec. Geol. Surv. India, 1897, XXX, pp. 125-129, map; also *ibid.*, pp. 252, 253.

² C. L. Griesbach, Notes on the Earthquake in Balúchistán on the 20th Dec., 1892, Rec. Geol. Surv. India, 1893, XXVI, pp. 57-61.

Mashkel are in the main of volcanic origin, notwithstanding the presence here and there of older rocks.

Our account of this region is fortunately continued by Blanford's description of the region between the coast and Kermán (I, p. 425). Several of the groups of parallel chains deflected to the north-west are accompanied by lofty volcanos. The Chagai mountains form only the innermost zone which trends east and west; the other volcanic groups or ranges lie within the chains which run to the north-west. One of the first of these chains is that comprising the lofty volcanic cones of *Koh-i-Basman* and *Koh-i-Naushada*. The latter, which is also called Koh-i-Taften, has been ascended by Sykes; it is about 12,800 feet high—according to Holdich's map, 13,500 feet—and its crater, in 1894, was filled with hot sulphurous vapours¹. A second zone is formed by the volcanic mountains described by Blanford between Bampur and Bam. The lofty *Koh Hazar*, situated between Bam and Kermán, and 14,500 feet high, should perhaps be assigned to this zone. Here we reach the field of Stahl's extensive investigations, from these we learn that no recent ashes and lavas have so far been observed in the range running from Kermán to the north-west, but that they occur at numerous localities in a chain situated further to the west, namely that which runs west of Behramabad and west of Yezd. They reappear repeatedly in this long chain, and extend even as far as a point a little beyond Kum (lat. 35° N.)². On Stahl's maps we see besides that the long couliisses which proceed from Kermán and from the west border of the great desert Dasht-i-Lut, already present the north-westerly trend of the Zágros chains. It would seem they are not a series of regular anticlines: one coulisse shows over long intervals a dip in one direction only, to the south-west, as though it were the half of an anticline; another possesses a synclinal structure, and so on.

The stratified series differs from that of the outer chains of Iran. The thick limestones with Nummulites and Alveolina which, superposed on the Hippurites limestone, descend from the pass of Bolan through the chains of the Indus, form the more southerly folds of Baluchistán and the greater part of the Zágros chains as far as Mesopotamia. In the inner chains the Hippurites limestone is also present, but beneath it older sediments crop out with a considerable extension. Several members of the Jurassic system are known; and coal-seams with plant-bearing beds, and associated with marine beds containing *Goniomya* and *Pecten*, make their

¹ P. Molesworth Sykes, Recent Journeys in Persia, Geogr. Journ., 1897, X, pp. 568–597; also his note in Quart. Journ. Geol. Soc., 1897, LIII, pp. 292, 293; Vredenburg, op. cit., p. 67, gives some details with regard to the more recent volcanos.

² A. F. Stahl, Reisen in Nord- und Central-Persien, Peterm. Mitth., 1895, Ergänzungsheft No. 118, and Zur Geologie von Persien, Geognostische Beschreibung von Nord- und Central-Persien, op. cit., 1897, Ergänzungsheft No. 122.

appearance near Kermán, in the Durmanu mountains. These plant-bearing beds belong to that widely distributed series—sometimes assigned to different stages of the Lias, sometimes to the Rhaetic stage, and probably not always occupying precisely the same horizon—which extends from this region across north Persia and the Caucasus, and is met with in the Balkans, in Servia, in the Gresten beds of the eastern Alps, on the other side of Bayreuth, and even still further west ¹.

In the same coulisse, Devonian beds with *Tentaculites* and *Spirifer Archiaci* appear beneath the Cretaceous limestone south of Abdid (about long. 57° E. and lat. 31° 10' N.) ².

In this latitude Palaeozoic rocks also occur on the inner side of the Zágros chains; this we learn from Rodler's travels in Luristán ³: they extend to the north-west into the great schistose region of Irak. Isolated masses of granite present themselves, and proceed as far as the great granite mass of Mount Elwend, near Hamadan, and those regions which we have already discussed from the data furnished by Loftus, Tietze, and Wähner (I, p. 492). The constancy of the strike to the north-west receives further confirmation from the investigations of Frech and Arthaber in Armenia ⁴.

As we have already seen, the Khojak mountains, north-west of Quetta, must be assigned to the chains of the Indus, the eastern branches of which follow the Indus in a meridional direction, while the western branches, diverging more and more to the north-west, sweep round the closed basins of Mashkel and the Helmand in a broad arc, and then proceed further to the north-west. To these north-westerly prolongations belong indeed the chains of Kermán and Yezd and, west of these, the whole of the Zágros chains, which extend along the Persian gulf to the syntaxis of Armenia. At the same time we are impressed by the remarkable fact that at the point where the curvature of these long chains reaches its maximum, i.e. in Baluchistán and Afghanistán, only recent sediments are known to occur; and it is not until we reach the north-westerly prolongations, the coulisses of Kermán and Luristán, and others still further to the north-west, that

¹ A good summary in F. Krasser, Ueber die fossile Flora der rhätischen Schichten Persiens, Sitzb. k. Akad. Wiss. Wien, 1891, C, pp. 413–432; for their further distribution see the map by Pompeckj, Zeitschr. deutsch. geol. Ges., 1897, XLIX, p. 828.

² A. F. Stahl, Zur Geologie von Persien, &c., Peterm. Mitth., Ergänzungsheft No. 122, pp. 63 and 68.

³ A. Rodler, Bericht über eine geologische Reise im westlichen Persien, Sitzb. k. Akad. Wiss. Wien, 1889, XCVIII, pp. 28–39, and Letter from Sultanabad, Anz. k. Akad. Wiss. Wien, Oct. 18, 1888; a map of the Bachtýaris in which the strict north-west direction of these chains appears is given by H. A. Sawyer, Geogr. Journ., 1894, IV, p. 481 et seq. Here also granite outcrops are mentioned and even a recent volcano.

⁴ F. Frech and G. von Arthaber, Ueber das Palaeozoicum in Hocharmenien und Persien, mit einem Anhang über die Kreide von Sirab in Persien; Waagen und Arthaber's Mitth. Palaeont. Inst. Universität Wien, 1900, XII, pp. 157–308.

Palaeozoic and older rocks in general make their appearance. Kurachee (lat. 25° N.), situated near the delta of the Indus, by no means marks the most southerly parts of the arc of Baluchistán, for these are covered by the sea. Nevertheless this place lies eight or nine degrees further south than the outer zone of the syntaxis on the Jhelam. To this extent, then, reckoning from the Himálaya, has the Iranian arc advanced to the south. The outer zone of the Armenian syntaxis, i. e. of the conjunction of the Iranian with the Tauric ranges, lies in the region of Diarbekr, between lats. 37° and 38° N., and thus the parts of the arc which trend to the north-west retreat even further towards the north than the meridional Suláimán and Indus chains have advanced towards the south. The Eocene arcs of Baluchistán consequently occupy an eccentric position, to the south-east, in the Iranian structure. In Iran, however, we perceive that in the extreme north-west a *secondary arc, the Albourz-range, rises* on the southern shore of the Caspian *as an almost independent structure.*

From the descriptions of previous writers, especially Tietze, we were led to conclude that the Albourz is an arc of central Asiatic type (I, p. 492), thrust towards the south, composed of closely crowded folds, frequently traversed by faults, and crowned by the volcanic cone of mount Demavend. The works of Stahl afford more exact data concerning the western, central, and eastern portions of the range, but the structure of the regions intervening between these three portions is still completely unknown¹.

In the west, where the Albourz proceeds into the mountainous land of Ghilan, there rises, south of the mouth of the Sefid Rud, the broad volcanic cone of Dulfak; on its southern side, near Umom, lie volcanic bombs. Towards the interior it is followed by folded chains. On the south side of the Albourz, volcanic accumulations, which are more recent than the folded chains, again appear, and extend towards the interior of the Albourz as far as mount Demavend. At the same time, in the middle region the northern limbs of the inner anticlines remain turned towards the Caspian. On the east, the north side of the Albourz descends towards the plain of the lower Atrek along numerous fractures, which have broken up the folds.

The cone of Dulfak in the west does not seem to mark the end of the folded range. On the contrary, its anticlines and synclines are continued through Ghilan and along the south side of the Kur valley; the northern slope of the range is formed, according to Sjögren² and Valentin³, by anticlines of Cretaceous rocks.

¹ A. F. Stahl, Peterm. Mitth., *Ergänzungsheft* No. 122, 1897, in particular pp. 19 and 42, and section VIII.

² H. Sjögren, Om bildningen af Kaspiska hafvets bäcken, *Geol. Fören. Stockh. Forh.*, 1888, X, pp. 49-74.

³ J. Valentin, Bericht über meine Reise nach Tiflis und die Theilnahme an der Radde'schen Expedition in den Karabagh-Gau, *Ber. senckenb. naturf. Ges. Frankfurt am Main*, 1891, pp. 159-239, map, in particular p. 197. For the lofty volcanos adjacent,

In this manner the western part of the Albourz is closely connected by its direction with the Zágros chains and the other Iranian coulisses; with the Zágros chains the Karaghan forms a connecting link; it trends north-west, and consists of volcanic rocks and folded middle Tertiary beds of Mediterranean type. The eastern part of the arc, however, takes a completely different direction, and stretches across the deserts of Khorasan.

Thus the Iranian arc presents two concavities facing the north; the first of these corresponds with the desert of Registán and the fluvial region of the Helmand; the second, situated much further to the north, corresponds with the southern portion of the Caspian sea.

Hindu-kush (I, pp. 443, 469). This mighty arc which, issuing from the Pámir, thrusts forth its coulisses to the shores of the Caspian, and there gives signs of its connexion with the Caucasus, was raised up, according to Muschketow, by the same movement which produced the branches of the Thian-shan¹; and all the facts known to me support this view. But if so, it follows that the great phenomenon which we are accustomed to designate the virgation of the Thian-shan does not terminate in the northern prolongation of the Mustag-ata, but encroaches on the Pámir. We can even affirm that the whole of the central and western region of the Pámir belongs to this virgation.

Curzon's map of the Pámir marks the Hindu-kush as an independent chain running north-west of Chitral into the immediate neighbourhood of Kala-Pandsh, and, in agreement with Iwanow, this distinguished author assigns the pass of Baroghil (about long. 73° 30' E., 3,797 meters) also to the Hindu-kush². When Stoliczka's observations on the strike of the gneiss and ancient schist are represented on this map, we perceive that the north-east trend of the Hindu-kush, after running obliquely across the river Pámir, is maintained till it reaches the neighbourhood of Yol-masar, i.e. about half-way to lake Victoria; on the other hand, on the Upper Ab-i-Pandsh a west-north-west strike prevails, as though north of the pass of Baroghil the Hindu-kush, or a northern chain parallel with it, entered into syntaxis with a gneiss zone coming from the Mustag mountains in the south-east. This would be a repetition, in the Pámir, of the relations existing between the Nan-shan and Anembar-ula; unfortunately we do not possess sufficient data to form a definite judgement on this point. In any case, it appears as though in a tectonic sense the sources of the Oxus lay outside the Hindu-kush, and at the extreme end of the Mustag³.

H. Sjögren, Beiträge zur Geologie des Berges Savelan im Nord-Persien, Verh. russ. k. min. Ges. St. Petersburg, 1888, 2. Ser., XXIV, pp. 36-66.

¹ J. W. Muschketow, Sketch of the Geological Constitution of the trans-Caspian Regions, Verh. russ. k. min. Ges. St. Petersburg, 1891, 2. Ser. XXVIII, pp. 391-429, map.

² G. N. Curzon, The Pámir and the Source of the Oxus, Geogr. Journ., 1896, VIII, pp. 15-54, 97-119, 239-264, map.

³ W. T. Blanford, Scientific Results of the second Yarkend Mission, based upon the Collections and Notes of the late F. Stoliczka, Geology, 4to, Calcutta, 1878, pp. 38 et seq.

The Saféd-kóh, as we have seen, comes with a nearly east to west trend from the syntaxis in Hazára (pl. XII) into this region. Although it swings round to the west-south-west, yet the south-westerly direction of the Hindu-kush, as it comes from the Pámir, differs so much from this, that Griesbach, to whom we owe almost all our detailed information on the region of Kabul, has often expressed the belief that an independent Archæan mass must lie somewhere between the Saféd-kóh and the Hindu-kush.

The Hindu-kush bends parallel with the great eastern concavity of Iran; but opposite the western concavity, south of the Caspian, its prolongations maintain the independence which is so characteristic of the Altaides.

Hornblende granite and other eruptive rocks of Cretaceous age have repeatedly been mentioned as occurring in this region (I, p. 428 *et passim*). Precisely similar rocks crop out on the lake of Kabul, and form the heights north of this town¹. Griesbach has traced them up to Charikár, near the valley of Ghorband, which follows the south foot of the main chain of the Hindu-kush. The south slope of this main chain is formed of light grey limestone, lying with apparent conformity on altered rocks, or on graphitic schists.

The most easterly point of the Hindu-kush of which we possess, so far as I am aware, any geological knowledge was described by Lord in 1838. This refers to the south side of the Ghorband pass, which lies in the meridian of Kabul. As he ascended the slope Lord met with mica-schist at first dipping to the north-west, i. e. towards the interior of the range, and then becoming vertical; next gneiss, and then again schist traversed by granite. The next day he continued on gneiss and mica-schist, sometimes inclined towards the interior of the mountain, sometimes vertical; until finally, not very far from the summit of the pass, he reached lofty walls of granite so steep that the snow finds no resting-place upon them. White granite, with crystals of black hornblende which are sometimes agglomerated in roundish masses, forms at this point the core of the Hindu-kush². The observations of Griesbach beginning a little west of this region confirm this account.

The summit of the pass of Chahardár (4,300 meters) consists of the same granite, which here contains an included mass of white granular marble. Hornblende granite, extending over a broad area, forms in this region also the principal range of the Hindu-kush. Mica-schist and gneiss are also met with, and the granite is intrusive into them. At the south foot of the second pass, the Kotal-Fazak, which succeeds the Chahardár on

¹ C. L. Griesbach, Field-Notes from Afghanistan, no. 4, from Túrústán to India, Rec. Geol. Surv. India, 1887, XX, pp. 17-26.

² P. B. Lord, Some account of a visit to the plain of Koh-i-Damán, the mining district of Ghorband and the Pass of Hindu-Kush, Journ. Asiat. Soc. Bengal, 1838, VII, pp. 521-537, in particular pp. 525-529.

the north-north-west, Palaeozoic limestone, possibly Carboniferous, occurs. The summit of the Kotal-Fazak (3,000 meters) consists of marble; Griesbach describes how, as we look from these northern parts of the Hindu-kush across the valley of the Surkhab towards the north, we see even on this side of the main chain the dark intrusive rocks traversing like a network the white limestone of the range opposite. In these ranges of the north side the only deposits known, as far as Haibak and Tashkurgan, that is to say as far as the valley of the Oxus, are Cretaceous and Tertiary. They are of great thickness, form broad saddles and basins, and end in a somewhat steep anticline against the plain of the Oxus.

Further west, in the passes of Bamián, the hornblende granite contracts to a narrow band, while the mighty limestones of the transgressive upper Cretaceous form the uppermost parts of the Hindu-kush. The sediments consist here of two groups separated by an unconformity. The basal member of the lower group, a dark limestone, has furnished *Productus*, and in other localities *Fusulina*; traced upwards, it alternates with greenish sandstone, containing plant-remains, which is correlated by Griesbach with the lower part of the Gondwana series. On the limit of the two groups lie altered conglomerates, and there is a good deal of intrusive trap, which here, too, seems to penetrate up to and into the unconformable Cretaceous limestones. This is the case, for instance, in the pass of Ak-Robat, in the neighbourhood of Bamián¹.

Somewhat further north, the narrow band of hornblende granite again crops out, accompanied by gneiss and mica-schist, which are regarded by Griesbach as altered sediments, metamorphosed by the granite. The mantle of Cretaceous limestone passes over these rocks and, still further to the north, bounds the passes of Bali-Gali (2,926 meters) and Shabanshak. In this region we again encounter, beneath the Cretaceous limestone, in the neighbourhood of Chel, the intensely folded lower group. It includes shales with *Halobia Lommeli*, and, above these, beds with *Equisetites columnaris* and other plant-remains, which correspond, according to Griesbach, with the flora of Lunz, in the eastern Alps, and, at the same time, with the middle part of the Gondwana series. These are succeeded by thick beds of sandstone and shales, in part plant-bearing, a few marine beds are intercalated: and the series probably includes the whole of the Jurassic formation. Finally comes red sandstone, which represents the Neocomian; and then the whole is covered by the discordant upper Cretaceous limestone, followed perhaps by some beds of Eocene.

This succession of beds indicates a marginal region of the Tethys. It retains essentially the same characters throughout the whole breadth of

¹ See in particular Field-Notes from Afghanistan, no. 3, Rec. Geol. Surv. India, 1886, XIX, p. 235 et seq.; and Field-Notes, no. 5, to accompany a Geological Sketch-Map of Afghanistan and North-Eastern Khorassan, op. cit., 1887, XX, pp. 93-103, map.

north Afghanistan and as far even as the neighbourhood of Meshed. For the whole of this distance no rocks older than the Carboniferous are so far known, a sandstone affording a doubtful *Orthis* and equally doubtful *Productus* occurs in the pass of Dehrud, in the Binalut chain (east Khorasan). The plant-bearing beds above them play a large part in the structure of the mountain ranges, as may be seen near Bamián. From the lower beds of this series Griesbach records a doubtful *Vertebraria* from Palezkár (south of the Band-i-Baba, north of Herat), and *Glossopteris* from the pass of Gaukharchang (north of the river Djam, east Khorasan). Then follows on all sides the transgression of the upper Cretaceous limestone.

The region west of Bamián does not appear to have been visited by any geologist; but we know that the Hindu-kush is continued as the watershed of the country, and with heights exceeding 4,800 meters, into the Koh-i-baba, where it receives the names of Band-i-Baian and Saféd-kóh. It is not certain whether it is continued at about long. 63° E. directly into the Davendar chain (east of Herat), or whether this chain forms an independent coulisse. From here onwards, however, Griesbach's data are so explicit that we can readily follow the deflexion of some of the most important ranges as they pass from a west to a north-west direction.

The *Davendar chain* is the north limb of an anticline formed by the Carboniferous limestone and the plant-bearing series; its south limb is faulted down in such a manner that the Carboniferous abuts against the upper Cretaceous limestone along the line of fracture. The same feature is exhibited in the west by the *Doshak chain* (south of Zindaján, on the Hari-rud), and also by the *Yaktan chain*, directed to the north-west, and its continuation, the *Binalut chain*, which runs west of Meshed.

All these chains belong to the same principal branch of the range; they are a connected series of coulisses within which the bend to the north-west is accomplished¹.

A band of syenitic granite descends from the highest part of the Davendar chain through the valley of the upper Kurukh, runs, accompanied by gneissose rocks, a little north of the town of Herat, disappears to the west, and crops out again in Khorasan, south of the Estoi chain, on the northern slope of the Djam valley; it may be traced to Sangbast, south-east of Meshed, and, according to the observations of Russian geologists, somewhat further to the north-west. Griesbach believes it to be younger than the red sandstone of the Neocomian, and perhaps of the same age as the hornblende granite of south Afghanistan².

The *Band-i-Baba* (Paropámisus, Bárkhat-dagh³) represents as a whole

¹ C. L. Griesbach, *Afghan and Persian Field-Notes*, no. 2, *Rec. Geol. Surv. India*, 1886, XIX, p. 50 et seq.

² C. L. Griesbach, *Afghan and Persian Field-Notes*, p. 64.

³ In the nomenclature of this chain I am guided by a letter sent me by Herr Griesbach

a very much compressed anticline of the plant-bearing series. In Zurmest, i. e. in the east, this chain is traversed on its south side by a great fault striking east and west. In the Marbich pass (west of the Baba pass, almost on the meridian of Herat) this fault passes over to the north side of the chain, disappears as it reaches the Tertiary, and is visible again in Khorasan in the Estoi chain, with a north-west strike. In Kat-i-Shamsir hot springs issue from it¹.

In this way the Hindu-kush is resolved towards the west into long coulisses. The manner in which these coulisses join up with the Balkan and the Caucasus (I, p. 469) has been the subject of much investigation², and I have had the privilege of discussing the matter with M. Bogdanowitsch and Herr Griesbach. From their concordant observations I arrive at the following results:—

The junction actually takes place, but in the following manner:—

The most southerly of the coulisses in question, *Davendar-Doshak-Yaktât-Binalut* runs past Meshed on the west, but without reaching the Caspian. South-west of it are other ranges trending east and west, which Muschketow describes as the 'mountains of the Kibir desert'; their trend diverges from that of the coulisses of the Hindu-kush, and they form the transition to ranges running to the south-west. I assign them wholly to

from Camp Shadián, south of Balkh, on August 3, 1886, after the appearance of the first volume of the present work. He writes as follows: 'The classic name of *Paropamisus* has no significance at the present day. It was employed by Herodotus for the whole of the mountainous country between Persia and Ghazni. For some reason unknown to me, some of our Indian cartographers have given this name to the range which separates the valley of Herat from Badghis. For want of a better name I have retained this designation provisionally in the notes of my travels hitherto published, but there can be no doubt that it will one day disappear altogether from our maps. The inhabitants of the valley of Herat have no general name for this range; its grandest ridge, however, is known as the *Band-i-Baba*. The Turkomans of Padjeh call the whole range *Bárkhat Dágh*, and the Russians have adopted this name on their maps. If any one of the chains is to retain the ancient name of *Paropamisus* it would be most suitable to apply it to the great watershed of Afghanistan, if it did not already possess a good designation. But the little anticline which runs past Sarachs can lay no claim to this ancient name.

¹ C. L. Griesbach, *Afghan and Persian Field-Notes*, no. 2, pp. 56, 58.

² A. Houtum Schindler, *The Turquoise Mines of Nishapur, Khorassan*, *Rec. Geol. Surv. India*, 1884, XVII, pp. 132-142; *Die Gegend zwischen Sabzwâr und Mesched in Persien*, *Jahrb. k. k. geol. Reichs. Wien*, 1886, XXXVI, pp. 304-314; K. Bogdanowitsch, *Preliminary report on the oro-geological investigations in the mountainous part of the Transcaspian region in north Persia*, *Bull. Com. géol. Russie*, 1887, VI, pp. 66-104 (a German translation of the most important passages relating to the Kopet-dagh in Radde, *Wissenschaftliche Ergebnisse der im Jahre 1886 allerhöchst befohlenen Expedition nach Transkaspien und Nord-Chorassan*, *Peterm. Mitth., Ergänzungsheft* No. 126, 1898, pp. 5-7); Bogdanowitsch, *Note on the geology of central Asia*, *Verh. russ. k. min. Ges. St. Petersburg*, 1889, XXVI, 192 pp.; *Application of the theory of gliding (Reyer) to the dislocations of the Transcaspian region*, *Izviestija Imp. ross. Geogr. Obsch.*, 1895, XXX, pp. 27-34; and Muschketow's *Brief Survey*, &c.

the Albourz. The town of Nishapur lies in the region where these gradually approach and join up with the coulisse of Binalut.

The granite range of *Davendar-Herat-Estoi* does not extend far beyond Meshed.

The coulisse of *Band-i-Baba* (Paropamisus) *Estoi* (Pusht-i-kuh-Djam) does not appear to reach the town of Meshed.

On the left bank of the Heri-rud, between the mouth of the Keshaf-rud and the town of Sarakhs, a fresh chain lying still further north comes in; it consists of numerous long folds striking regularly to the north-west and frequently traversed by longitudinal, or almost longitudinal, faults. It is to this chain that the general name of *Kopet-dagh* is now usually assigned. The Balkhash and the mountains of Krasnovodsk are prolongations of the chain.

On the north the Kopet-dagh is bounded to a great extent by strike faults. A vast desert, part of the Karakum, lies north of the fractured border; and north of the desert lies a region having little or nothing in common with the coulisses hitherto mentioned, namely the Mesozoic platform of the Ust-Urt. Muschketow thinks it probable that a fracture also forms the edge of this platform, and points out that close by is the depression discovered by Lesar, which is believed to correspond to the *Aria palus* of the ancients. This is at least 100 versts broad, and near the wells of Mirsa Tchille it descends to a depth of 44-6 meters below the level of the Caspian. In the light of these facts, Muschketow regards the desert between the border of the Ust-Urt and the faults of the Kopet-dagh as a downthrown area which he names the 'fault-trough of Turkmen.'¹

Turania. The Tethys extended, for a great part of its existence at least, as a broad and rather shallow sea across the region of the existing Aralo-Caspian depression, along the south-west margin of the continent of *Angara*. We shall have occasion to mention marine deposits of the lower Trias in the mountains of Darwaz, and they also appear remote from this locality, on Mount Bogdo, in the steppe of Astrachan². I know of no evidence at present of the existence of middle and upper Trias in this region. The

¹ Muschketow, Brief Survey of the geological constitution of the Transcaspian region, pp. 31, 39.

² I have not succeeded in forming a definite opinion on the structure of the Great Bogdo; existing data indicate very diverse directions in the dip of the beds; on the whole the conditions are very complicated. The line from the Great to the Little Bogdo runs to the north-north-east; perhaps some of the divergent directions in the dip may be caused by subsidences in the gypsum. Tschernyschew has demonstrated the strange fact that a part of the gypsum lies beneath upper Jurassic or lower Cretaceous sediments. Among the works on this subject we may mention: J. B. Auerbach, Das Bogdogebirge (publ. by Trautschold), Zapiski russ. Geogr. Ges., 1871, IV, pp. 1-81; and T. Tschernyschew, Einige Angaben über den geologischen Bau der Steppe von Astrachan, Bull. Com. Géol. Russie, 1888, VII, pp. 221-232. The great Bogdo lies in long. 46° 51' 52" E. Greenw., the lesser Bogdo in lat. 47° 4' 30", Tchaptchatchi in 47° 55' 28" 5, and Bisstchocho in 48° 47' 3".

plant-bearing Angara series has been met with at several places, especially in the valley of the Sir-darya, and Rhaetic plants are known to occur near Derbent. The section at Mangyschlak, on the north-east shore of the Caspian has been described in detail by Andrussow and Semenow; apart from the ancient folded rocks which form the core of the range, the lowest beds exposed are sediments containing badly preserved plant-remains, and some not very characteristic shells, which belong possibly to the Lias or the lower Jurassic. From the Kelloway stage upwards, however, there follows a very varied and continuous series of marine deposits which extend into the later stages of the Tertiary¹.

Semenow, judging from the nature of these sediments, concludes that an alternation of deep and shallow water conditions occurred in the middle of the basin, indicating a positive movement from the beginning of the Jurassic epoch almost to its close, a negative in the Valanginian, and then a second positive movement which reached its maximum in upper Turanian and Senonian times; near the margin of the basin corresponding transgressions may be seen. We shall find the Kelloway stage in transgression at several places. Towards the south, in the Kopet-dagh, the lower Cretaceous is represented, as in the Caucasus, but in the north the Senonian alone occurs encroaching on the Siberian plain, which it enters through the strait of Turgai. In like manner, according to Romanowski, only the middle and upper members of the Cretaceous enter the valleys of the eastern mountains².

From the Cretaceous series we must separate the highest beds, or the Fergana stage, which is distinguished by *Gryphaea Kauffmanni* (= *Gryphaea Esterhazyi*); this we must correlate, according to the detailed investigations of A. Koch, with the lower Calcaire grossier of the Paris basin; but even so late as the period indicated by this stage a marine communication still existed, north of the Mustag-ata, between the Turanian region and the plain of Yarkand; it extended as far as Yangi-Hissar, and into the vicinity of Sánju³.

The horizon of Priabona is represented in the Crimea. Marine Oligocene sediments occur there also, as well as in the Ust-Urt. We have seen that

¹ N. Andrussow, Ein kurzer Bericht über die im Jahre 1887 im transcaspischen Gebiet ausgeführten geologischen Untersuchungen, Jahrb. k. k. geol. Reichs. Wien, 1888, XXXVIII, pp. 265-280; W. P. Semenow, Fauna of the Jurassic deposits of Mangyschlak and Tuar-Kyr, Trav. Soc. Nat. Saint-Petersb., 1896, XXIV, no. 2, and Fauna of the Cretaceous deposits of Mangyschlak and some other localities in the Transcaspien province, op. cit., 1899, XXVIII, no. 5.

² G. Romanowski, Materialien zur Geologie vom Turkistan, St. Petersburg, 4to, 1, 1880, pp. 43 et seq.

³ Beiträge zur Stratigraphie Central-Asiens, Denkschr. k. Akad. Wiss. Wien, 1894, LXI, pp. 463-465; A. Koch, Ueber das Vorkommen und die Verbreitung der *Gryphaea Esterhazyi*, Páv., Földt. Köszl., 1896, XXVI, pp. 324-330 in Hungarian, and pp. 360-366 in German.

even in the lower Oligocene period a communication with the Arctic Ocean still existed on the east side of the Urals ¹.

To the north, beyond the strait of Turgai, remains of the amber forests occur above these marine deposits, and in the middle of the plain as well as nearer its margin there are vast deposits of clay with salt and gypsum. Although some of these have been assigned by several observers to the Oligocene, and the precipitation of the saline deposits may indeed date from this remote period, yet many years ago Andrussow established the remarkable fact that some species characteristic of the salt formation of Wieliczka, i. e. of the Austrian Schlier, such, for instance, as *Pecten denu-datus*, occur in a dark clay with Meletta scales near cape Tarchan, on the sea of Azov. A section near Tjub-agal, on the north shore of the Kara-bugas, shows the presence on the east side of the Caspian of the dark clays with Meletta, here accompanied by gypsum; towards the summit of these deposits repeated layers of gypsum are intercalated between beds with marine shells, which are certainly on the horizon of the second Mediterranean stage. The species, if we except *Cerithium scabrum* and perhaps *Modiola discors*, are, it is true, entirely unknown in the region of the northern Mediterranean or in the valley of the Danube; but the existence of overlying Sarmatian beds removes all doubt ².

In Persia the salt occurs above the first Mediterranean stage; and this is also the case in Armenia. In the Crimea, on the borders of the Caspian, and further to the north and east, the first Mediterranean stage is so far not known. It is impossible, therefore, to determine at what horizon the salt deposits begin. On the other hand, it is clear that at least a part of these deposits must be assigned to the Schlier, and that the return of the sea at the time of the second Mediterranean stage must have been accompanied by oscillations. The evaporation of sea-water must amount to eighty per cent. before a deposit of gypsum is formed, and thus the intercalation of gypsum with marine beds shows that these oscillations must have been very considerable. In the west similar conditions did not recur until the Sarmatian period.

At the time when the beds of gypsum were being formed, a vast sheet of water having its surface below the sea-level must have covered these regions, and when the salt was being deposited its surface must have been lower still. The isolation of this water must have taken place through mountain-folding at some place far to the west; but a dry climate must

¹ C. von Vogdt, Ueber die Obereocän- und Oligocän-Schichten der Halbinsel Krim, Verh. k. k. geol. Reichs. Wien, 1889, pp. 289-295.

² N. Andrussow, Ueber das Alter der unteren dunklen Schieferthone auf der Insel Kertsch, Verh. k. k. geol. Reichs. Wien, 1885, pp. 213-216; Geotektonik der Halbinsel Kertsch, Matér. Géol. Russie, 1893, XVI, pp. 65-336, map, in particular p. 160; Bemerkungen über das Miocän der kaspischen Länder, Bull. Com. Géol. Russie, 1899, XVIII, pp. 340-369 et passim.

also be assumed to have existed during the deposition of the Schlier, since saline deposits occur on this horizon, even beyond the limits of the region we are considering; and, according to Depéret and Fourtau, the gypsiferous clay of the Jebel Geneffe, for example, near the Bitter lakes of Suez, lies between the first and second Mediterranean stages¹.

The salt deposits extend far and wide over Turania, and they penetrate deeply also into the great mountains of the east. To their horizon we must assign, for example, the steeply upturned gypsiferous beds and the numerous salt-lakes, which Obrutschew has described as occurring in the foot-hills of the coulisses of the Hindu-kush, south of Sarakhs, especially between the Hari-rud and the Kushk². Perhaps they mark the place where, long ago, the waters of Turania communicated with those of Iran. In the high mountains we shall have to record salt-beds even far above Garm. In the Pámir, on the margin of the Rang-kul, rock salt occurs in thinly laminated shales. The pass near the source of the Oxus, or Ab-i-Pandsh, is marked Baroghil on the maps, but Iwanow calls it Bor-agyl, i. e. the gypsum pass. Great quantities of gypsum are said to occur there³.

The shelly limestone recorded by Romanowski between Tchimkent and Tashkent is also of middle Tertiary age; *Ostrea herniglobosa* Rom., from the neighbourhood of Garm, perhaps indicates the same horizon⁴.

Sarmatian deposits are so far unknown on the other side of the Aral. They occur in the Ust-Urt. We have already pointed out that the Sarmatian region, although its extension from east to west is known to equal that of the existing Mediterranean, nevertheless lies entirely outside the limits of this sea, as we now know them (I, p. 331).

We need not stay to discuss the still more recent deposits of the Aralo-Caspian basin.

The existing outlines of the plain of Turania date evidently from very various times. To the north-west along the Urals, the Cretaceous and Tertiary sediments, lying undisturbed, extend across the upturned and denuded edges of the ancient formations. On the east, as a complete contrast, the long branches of the Thian-shan make their appearance, and the same sediments, thrown into folds, rise to considerable heights. But in the interval between these long branches, there is developed in the east an extremely peculiar form of folded intercalary chain, unlike anything known to me in any other part of the earth, and deserving of particular attention.

¹ C. Depéret et R. Fourtau, Sur les terrains néogènes de la Basse-Égypte et de l'isthme de Suez, C. R. Acad. Sci. Paris, 1900, CXXXI, pp. 401-403.

² W. Obrutschew, Preliminary Report on Geological Investigations in the Transcasian region in 1886, Bull. Com. Géol. Russie, 1887, VI, pp. 155-224, in particular pp. 194 et seq.

³ D. L. Iwanow, Summary of geological observations in the Pámir, Verh. russ. k. min. Ges. St. Petersburg, 1885, XXII, p. 3; Travels in the Pámir, Izviestija Imp. ross. Geogr. Obsch., 1884, XX, in particular p. 44 et seq.

⁴ Romanowski, Contributions to the Geology of Turkestan, II, 1884, p. 26.

On referring to Pl. V, Vol. I, we shall see that the course of the Amu-darya lies between branches 8 (Hindu-kush, Balkan) and 7 (Ghissar-Chasreti-Sultan); the branches 7 and 6 (Alai-Nuratau) are separated only by the valley of the Serawshan, and may be regarded as parts of the same system; on the other hand, the valley of the Sir-darya, between branches 6 and 5 (Talass-Alatau-Karatau), is related to these ranges in much the same way as the Amu-darya is related to branches 7 and 8. We will now proceed to discuss first the intercalary chains of the Amu-darya, that is, in chief the mountains of Bokhara, and then those of the Sir-darya basin, particularly the mountains of Fergana. The conclusions, as regards the northern parts of the virgation of the Thian-shan, will be self-evident. For both regions the work of Muschketow is of fundamental importance ¹.

Mountains of the Amu-darya. The Cretaceous eruptive rocks, comparable in some degree with the Teschenites of the Carpathians, that occur in Baluchistán, Afghanistán, the Hindu-kush, and even north of this range, are not known on the other side of the Amu-darya. The unconformable Cretaceous limestone, which rises to great elevations in the Hindu-kush, is folded along with the Eocene, to form the foot-hills on the north of the main chain. Even south and south-west of Maimena these foot-hills, which trend nearly east and west, attain a height of 3,500 meters in the Band-i-Turkestan. A steep anticline of these Cretaceous and Tertiary rocks forms, as previously stated, the north border of the mountains in the neighbourhood of Sar-i-kul and Maimena. At its foot the folding is continued into the salt-bearing beds which Griesbach correlates with the middle Tertiary salt deposits of Persia. As far on as the south side of the ferry across the Amu-darya, near Kelif, this geologist still found shelly limestone of Tertiary age containing Pecten, Ostrea, and Polyzoa. The indications of folding are so general that Griesbach was even led to imagine that an anticline is now in process of formation in the alluvium of the Oxus, and that in time this would cut off the affluents on the left between Tashkurgan and Maimena ².

Towards the east Griesbach's observations extend as far as Gori on the Kundus. The broad plain of the Amu-darya, which marks the end of the eastern range, nearly reaches Rustak.

Our study of the Pámir mountains lying to the north of the Hindu-kush must begin with the admission that our knowledge of their geology is very slight. Stoliczka has made some observations along the Pandsh, as far down as Kala-i-Pandsh; and we have already stated that the lower half of the Pámir river cuts obliquely across the strike of a great gneiss range which forms part of the Hindu-kush or represents one of its foot-ranges.

¹ J. W. Muschketow, *Turkestan*, I, 8vo, St. Petersburg, 1886; with a geological map in six sheets by Romanowski and Muschketow.

² Griesbach, *Rec. Geol. Surv. India*, 1886, XIX, pp. 257, 260.

This is the Wachan range of Iwanow; it borders the Pandsh on the north, probably enters the bend of this river near Ishka-shim, and may perhaps proceed towards the south-west into Badakshan.

It appears, in fact, as though the Pandsh below Kala-i-Pandsh, the upper Shach-dara, on the north side of the Wachan range, the Ghund (Alitshur), and the Murghab (up to the meridian of the Rang-kul), are not the only rivers which follow true tectonic longitudinal valleys, and bend through an arc in the lower parts of their course more and more towards the south-west—as is clearly shown on Curzon's map. The Jas-gulam, which assumes on the Russian maps a much greater importance than has hitherto been supposed, flows to the south-west throughout its whole course; the Wansch likewise; and both appear to occupy longitudinal valleys, as, in a word, do all the rivers which come from the Pámir and reach the Pandsh between the bend near Ishka-shim and Kala-i-Chumb.

The convergent direction of these valleys shows, however, that in the north the great western chains of the Pámir undergo an increasing curvature in trend, which almost passes into the south-south-west direction of the Chodsha Mohammed in Baltistán; with this they decrease rapidly in height, and their southern spurs reach Faizabad and the region west of lake Shiva.

The structure of the *Darwaz range* confirms this view. This range describes an almost knee-shaped bend towards the south-south-west, and is even more sharply curved than the arc of the Pandsh above Kala-i-Chumb. Iwanow, coming from the north, crossed the range by the pass of Sagri-dasht (2,400 meters) in the direction of Kala-i-Chumb; he met with red sandstone, covered by coarse grey sandstone and conglomerate in thick beds which ascend to a great height, but do not reach the south side. On that side we find crystalline rocks¹.

Valuable information on the structure of the rest of this range is furnished by Krafft. The conglomerates of Sagri-dasht may be assigned to the Eocene; further to the south-west they form lofty peaks (Chasreti-Shan, 4,000 meters), and are separated from the older range to the east, bordering the Pandsh, by a long dislocation. This dislocation curves from the south-west to the south-south-west, and the ancient range is bent in the same direction, but even more sharply².

The rocks of this range, described by Krafft as lower Palaeozoic, consist of mica-schist, 'para-amphibolites,' sericite schist, and eruptive rocks. They

¹ Iwanow, Summary of geological observations in the Pamir, p. 20.

² A. v. Krafft, Geologische Ergebnisse einer Reise durch das Chanat Bokhara, Denkschr. k. Akad. Wiss. Wien, 1900, LXX, pp. 49-72, map; Mittheilungen über das ost-bokharische Goldgebiet, Zeitschr. f. prakt. Geol., 1899, pp. 37-43; W. Rickmers-Rickmers, Travels in Bokhara, Geogr. Journ., 1899, XIV, pp. 596-620, map. Rickmers was accompanied by A. von Krafft. Herr von Krafft has been kind enough to send me his maps, which contain some supplementary indications as regards the west.

form the axis of an anticline having a curved strike, which descends from the north-east through the valley of the Chumban into that of the Pandsh, and is known to extend along this river from Dshorf to Kala-i-Chumb and for about 40 versts further down; until, striking in an almost southerly direction, it crosses to the east side of the river. With this direction, it would arrive west of Faizabad; but it probably disappears beneath more recent sediments, before reaching this locality.

Both on the east and west sides of the anticline Fusulina limestone crops out; then, nearer the axis, diabase, tuff, and sandstone. The western zone is very largely developed; Siaku and Kugi-furush attain heights of about 5,000 meters. Traces of the Arta stage have been observed¹. The next member which crops out towards the west is the lower Trias; Bittner has pointed out its close resemblance to the Werfen beds of the eastern Alps². Towards the north-west and west these older formations are cut through obliquely, one after the other, by the long dislocation mentioned above. The southern part of the dislocation also strikes to the south-south-west, and along its whole length it brings to the surface, instead of the older formations, the supposed Eocene conglomerate, at heights of 3,000-4,000 meters. From here onwards the mountains descend rapidly towards the west and south. Muminabad, on their western border, lies at a height of 1,140 meters, and somewhat further south, in the mountains of Chodja-Mumyn (1,280 meters), between Kuljab and the Pandsh, Regel has found rock-salt in great quantities³. We may assume that the axis of the anticline of Darwaz, after it has descended into the valley of the Pandsh, near Kala-i-Chumb, continues to sink rapidly to the south. The salt, however, may belong to the syncline which follows it in the west. The continuation of this syncline is represented by the syncline of the upper Chingau, which includes Eocene or Cretaceous deposits; describing an arc, it separates the Darwaz mountains on the north from the *range of Peter the Great* (Piriok).

Information on this last range is furnished by Iwanow. Before describing it, however, we must recall the fact that the great Alai valley is an ancient lake-basin, surrounded in places by terraces; it was emptied by a ravine cut by the Kysyl-su running south-west across the Trans-Alai. The Kysyl-su, therefore, is not the natural head of the Wachsh. This must rather be the Muk-su, which comes from the Pámir and runs parallel to the upper Chingau. Between the two latter rivers rises the chain of Peter the Great⁴.

¹ A. Karpinski, Ein Hinweis auf das Vorkommen von permocarbonischen Schichten in Darwaz, Verh. russ. k. min. Ges., 1883, 2. Ser., XVIII, pp. 212-220.

² A. Bittner, Ueber von Dr. A. von Krafft aus Bokhara mitgebrachte jungpalaeozoische und altriadische Versteinerungen, Jahrb. k. k. geol. Reichs., 1898, XLVIII, pp. 700-718.

³ Muschketow, Turkestan, I, p. 572.

⁴ Iwanow, Summary, &c., p. 17 et seq.; cf. also the maps by Hassenstein, which are

According to Iwanow, this range owes the wild and jagged form of its comb to a dark limestone, sometimes containing *Fusulina*, which, with a thickness of thousands of feet, descends precipitously on the north side towards the Muk-su and parts of the Wachsh.

This is succeeded by Mesozoic deposits, among them a limestone believed to be of Jurassic age, then by variegated Tertiary clays and sandstones with salt and gypsum. These Tertiary beds form a long belt bordering the mountains from Garm upwards along the south side of the Wachsh and the Muk-su, and salt is dug at several localities, even far to the east, in the hollow of the pass of Ters-agar (Altinmazar, long. $72^{\circ} 15'$ E. on Curzon's map), in the Pámir. The steep descent of the north side is again met with in the valley of Kandi.

Let us now turn our attention towards the west. Iwanow mentions very high peaks (Suganaki, about 5,400 meters) even at some distance below the mouth of the Kysyl-su. From here onwards the north slope becomes broader and lower. When Iwanow crossed the range further to the west, starting from Garm, he found its whole breadth covered by Cretaceous or Tertiary sandstone and conglomerate, beneath which the Palaeozoic limestones are exposed in a few places only.

Thus, in the chain of Peter the Great, all the pre-Cretaceous rocks disappear even more rapidly than in the Darwaz range, and, so to speak, in the bend itself. The chain, which has now become lower and is curved towards the south-west, is cut through below Garm by the Chulass (lower Chingau), and the Cretaceous anticline which Krafft marks between Baldjuan and the Wachsh is all that now represents it.

From the preceding it follows as a general result that the Muk-su and (Surchab) Wachsh represent—save for the local bend south of Faizabad—a true tectonic trend-line which embraces all the folded ranges emerging from the Pámir south of the great Kara-kul, and that probably all the valleys descending from the Pámir towards the west below Ish-kashim are true longitudinal valleys, which the Pandsh cuts off, until, for some distance below Kala-i-chumb, it also follows a longitudinal valley. This part of the Pandsh, however, does not lie, like most or all of the other longitudinal valleys, in a syncline, but in an anticline.

According to Muschketow's map, it is probable that north of Garm the *Karategin* range describes an arc similar to that of the Darwaz mountains and the mountains of Peter the Great, and strikes down towards Faizabad. I have scarcely a doubt that the mighty range of *Trans-Alai-Ghissur-Chasreti-Sultan* (7, I, Pl. V), which has hitherto been regarded as one of the branches of the virgation of the Thian-shan, is also deflected towards the south-west. Krafft, who, starting from Karatagh, ascended Chasreti-based principally on Regel's data, Peterm. Mitth., 1884, XXX, pl. IV, and XIII; and Lipsky, Otchet. Imp. ross. Geogr. Ges., 1899, pp. 15, 16.

Sultan, observed a different series of rocks. South of the Mura pass (3,730 meters) porphyry and granite follow immediately on Eocene and Cretaceous with *Acanthoceras Milletianum*, and further up lie remnants of transgressive Cretaceous let down into fault-troughs. Beyond the pass middle Devonian limestone with corals occurs on the Iskender-kul, and upon this, very thick dolomite of upper Devonian or Carboniferous age (Tursüll 5,000 meters)¹. Far to the south-west of this locality, north of the town of Baisun, there rises from a sea of Cretaceous and Eocene folds the range of Tchuldaïr, in which Krafft observed sandstone with Rhaetic plants and dark limestone, probably Jurassic. The latter turns in a long sweep towards the south-south-west, and forms the ravine of the Iron Gate at Derbent. Here, too, it is covered unconformably by the Cretaceous, and is described by Muschketow as the direct continuation of the great range of Ghissar². Still further in the same south-westerly direction lies Chatak, where, in the midst of the folded region of Cretaceous or Eocene beds, fossils have been obtained which Nikitin describes as Callovian³; here also rises a long ridge which trends to the south-west and includes the Cretaceous anticline of Kukaityn-tau. The view from the summit is described by Muschketow. Far away extends the broad valley of the Oxus; beyond, still further to the south, rise the great mountains of Afghanistan. But near by, to the left, a second anticline is to be seen running parallel with the first to the south-west. It is called Itym-tag or Djity-tag, i.e. the Seven Hills, because it breaks up towards the south-west into a series of isolated masses. One of these projects into the Oxus, and bears the town of Kelif. The range crosses the Oxus, a succession of rapids marking its course, and then forms the two ridges of Cham-tag on the south side. It is here, in upturned beds, that Griesbach collected Mediterranean fossils; and here, facing the foot-hills of the Hindu-kush, this long folded range, probably the continuation of the mighty Trans-Alai, disappears beneath the plain.

The direction of the spurs of the range has gradually changed from south-south-west to south-west; between the Wachsh and Kelif, i.e. between the mountains of Peter the Great and Trans-Alai-Chasreti-Sultan, the secondary folds insert themselves. Beyond Kelif their divergence from each other becomes still more clearly marked, and on the east border, facing Gusar and Karsh, the folds which form the hilly country become continually feebler. A few ranges even reach the Amu-darya. Muschketow

¹ A. von Krafft, *Geologische Ergebnisse*, p. 53. The strike of the downthrown Cretaceous segments on the Mura pass is directed to the south-west; if it were a question of folds the deflexion might be regarded as proved.

² Muschketow, *Turkestan*, I, p. 560. Ancient schist and granite were also obtained from an intermediate region on the Sengri-dag.

³ Nikitin, *Bull. Com. Géol. Russie*, 1889, VIII, pp. 82 et seq. This locality lies seven versts north-west of Chatak.

describes a Cretaceous anticline, the Aggs-tau, which crosses the river at Chodsha-salar below Kelif; another is the Felisidan-tau; the direction turns to west-south-west, the folds become straighter and feebler; at Kerki, Muschketow found the last trace of folding on the Amu-darya¹.

Let us fix our attention on the line—convex to the north-west—of Muk-su-Wachsh and the conjectured curve running parallel with it through the Mura Pass, the Iron Gates, and Kelif. The other curves flatten out towards the west, and the salt-bearing Tertiary deposits take a larger share in the formation of the corresponding ranges; on the river Karsh, however, a re-entrant angle arises. North of this angle chains make their appearance with the intermediary or east-and-west direction, but formed of granite, ancient schists, and Palaeozoic limestone. They have been described by Obrutschew².

The most northerly of these chains, the *Kara-tjube*, south of Samarkand, exceeds 2,000 meters in height; it slopes down towards the city and towards the great *longitudinal valley of the river Serawshan*; north of this valley the chain of *Nura-tau* (Kara-tau), accompanied by secondary ranges, extends towards the north-west. Many isolated hills show that the range is continued still further beneath the desert.

The valley of the Serawshan is one of the most remarkable features in the structure of the Thian-shan; bounded on the south by the Kara-tjube and the Serawshan range, on the north by the mountains of Turkestan, it extends east and west in a straight line, and is deeply insunken between these lofty chains, which in the east give rise to numerous glaciers. Even at Pastigau, more than 180 versts above Samarkand, Muschketow found that the lower slopes are formed by a Cretaceous syncline. This investigator has also established the fact that on the north side, at the head of the valley, in the feeding-ground of the Serawshan glacier, the Turkestan range is the uninterrupted continuation of the granite and gabbro range of the great Alai; while the southern range of Karategin (Ghissar) is formed of granite, gneiss, and metamorphic schists; the intermediate connective group of Kara-muk consists chiefly of diabase³.

Since we know that the valley of the Kysyl-su, where the river issues from the valley of the great Alai, is a recent feature due to erosion, which

¹ Muschketow, Turkestan, I, p. 593 et seq.

² W. Obrutschew, Preliminary report on geological investigations in Bokhara and the district of Seravshan, Matér. Géol. Russie, 1889, XIII, pp. 167-184; The occurrence of graphite and beryl in the Kara-tjube range near Samarcand, Verh. russ. k. min. Ges., 1888, XXV, pp. 1-8. The more southerly of these branches are assigned to the Chasreti-Sultan. Perhaps this name applies to the upper part of the chains, which diverge from one another in the form of a fan.

³ Muschketow, Geological expedition to the glaciers of Seravshan in 1880; Izviestija Imp. ross. Geogr. Obsch., 1881, XVIII, pp. 1-25. The beds with *Gryphaea Esterhazyi* have not yet been distinguished from the Cretaceous deposits.

must be left out of account in determining the tectonic lines, it follows that these must be drawn across the Kara-muk and that the valley of the Alai must be regarded as the continuation of the Serawshan. In this region also Cretaceous and Tertiary sediments are known to occur, and Tertiary beds were found by Muschketow in the pass of Taumurun (3,400 meters), at the eastern end of the Alai ¹.

In the pass we reach the watershed of the Yarkand-darya. From the Serawshan to Taumurun an important line of division runs between the mountains; it corresponds probably with one of the ancient straits by which the seas were brought into communication.

It is a remarkable fact that, notwithstanding the nearly straight course of this long east-and-west line, the mountains to the north of it do not possess a rectilinear trend. The great Alai clearly runs to the west-south-west, as well as all its northern foot-hills as far as Margelan; and in the meridian of Ura-tjube, somewhat west of the bend of the Sir-darya near Chodjent, the northern border of the range breaks up into great coulisses which strike to the north-west. The longest of these is the Nura-tau, of which we have already made mention.

Mountains of the Sir-darya. The resemblance between the structure of this range and that of the Amu-darya is truly astonishing. In both cases post-Jurassic sediments, extending from the middle Cretaceous transgression upwards, are involved in the folding, notwithstanding their unconformable relation to the older rocks. In the Sir-darya intercalary chains running to the south-west appear between the arc of the Kara-tau in the north and that of the Alai-Nura-tau in the south, just as in the mountains of the Amu-darya they appear between Alai-Nura-tau in the north and the Hindu-Kush in the south. In both cases the river turns these foot-hills and receives the waters of the longitudinal valleys coming from the north-east. At Chodjent the river cuts through the end of one of these anticlines, precisely repeating the behaviour of the Amu-darya at Kelif. To the north-west, on the course of the river Aryss, a re-entrant angle is formed between the intercalary chains and the principal branch—the Kara-tau—which corresponds completely with the re-entrant angle of the Kursch.

We will follow the masterly description which Muschketow has given both of these mountains and of the whole of Ferghana. First, however, we may recall the arc-like structure which prevails in the central Thian-shan (III, p. 164). The arcs are convex towards the south, with one branch extended to the west-south-west or south-west, the other to the west-north-west or north-west or even north-north-west. They encounter each other, and appear to mutually cut one another off, thus giving rise to the extremely peculiar disposition of the mountains, which resemble moving waves or the tiles of a roof. In the next place, it may be observed that at its eastern

¹ Muschketow, Turkestan, I, p. 15.

origin, south of the Gobi-Altai, the whole Thian-shan is a narrow wedge-shaped range, but as it proceeds towards the west it spreads out in a mighty virgation. The long branches of the virgation are, however, the north-western arms of the arcs.

One of the arcs surrounds the south side of the lake, Tchatyr-kul. Starting from the Suëk-tau, its north-western branch runs, under the name of the *Ferghana range*, along the east side of the depression of Ferghana, and thus crosses the direction of the great Alai range. Neozoic deposits occur in the furrow between these two ranges, and so sharp is the encounter that on the right side of the river Taldyk (south-east of Osh) the Tertiary conglomerates, somewhat steeply upturned, strike to the north-west, but on the left side to the east-north-east¹. In the same way the foot-hills of the Ferghana range maintain their north-west direction to beyond the Narin, and near this river they also encounter folds trending north-east. The whole range, north of Namangan, Tchust, and Chodjent, is dominated by an almost constant south-west strike, which persists up to the Aryss near Tchimkent although occasionally, as for instance north of Namangan, the opposite or south-east direction also asserts itself. These chains, among which that of the *Tchatkal mountains*, terminating north of Chodjent, is the most important, consist to a much greater extent of older rocks than the south-westerly trending chains of Bokhara; they are likewise much higher, but here also they pass into Cretaceous and Tertiary anticlines as they proceed to the west, especially in the neighbourhood of Tashkent. In this region again the south-west trending anticlines occasionally diverge somewhat widely from one another. But we also observe, especially in the valley of the Badam, near Tchimkent, and to the south of this region, a somewhat unexpected recurrence of the secondary north-west strike which encounters the south-west trending folds in zigzag, and even gives rise perhaps to convex arcs, as on the mountain of Moisar and in the Alym-tua, between Tchimkent and Tashkent.

Muschketow states that the south-easterly folds, or 'the folds of Ferghana,' are slightly convex towards the plain of Ferghana, while it seems to him as though the south-westerly folds might be slightly concave. Some of the western spurs certainly are so, and in these consequently the resemblance to the folds of Bokhara is the most striking. It is possible that the principal south-westerly folds, and perhaps even the Tchatkal itself in its northern parts, enter the Talas-Alatau with a concave curve; but we have no exact data on this point, and the junction is indicated on Pl. V by a dotted line only.

These great south-westerly folds to the north of the Sir-darya, such, for instance, as the Tchatkal, are explicitly described by Muschketow as 'folds

¹ Muschketow, Turkestan, I, p. 498 and elsewhere.

of the Alai.' One fact in particular seems to support this view; this is the existence of two recent tectonic lines, which bring the salt-bearing Tertiary beds to the surface and correspond at least in part to anticlines; they indicate the connexion of the Alai with the folded ranges of the north.

The Mogol-tau, a coulisse facing the southern part of the Tchatkal, is cut through by the Sir-darya west of Chodjent. South of this spot, near Nau, the first of these recent tectonic lines detaches itself from the northern border of the great Alai, crosses the Sir-darya obliquely, follows its right bank as the Salt mountain of Ak-tsheku, and extends to Tchust as an elongated range of hills. The second proceeds from Rishtan, runs south-east and east of Margelan and Andidjan, and probably meets the foot-hills of the Ferghana range in the Teke-bel.

We have already stated that Cretaceous and Tertiary sediments occur near Osh between the Ferghana range and the Alai, and have also pointed out that Tertiary beds are exposed in the pass of Taumurun, at the east end of the Alai valley. We may now add that Muschketow has found Cretaceous and Tertiary beds at a height of 11,600 feet on the Kugart at Süek, in the valley of Tshir-tash, west of the Tshatyr-kul, as well as on the borders of this lake itself, and has convinced himself of the continuity and identity of the Tertiary conglomerates described by Stoliczka with those of Ferghana.

Futterer, on the way from Osh to Kashgar, by Gulcha and Irkestan (below the pass of Taumurun), also observed these younger sediments, some Cretaceous probably, the rest gypsiferous Tertiary; and he remarked at the same time a striking contrast between the north-and-south strike of the Palaeozoic, and the prevalent east-and-west strike of these Neozoic rocks¹.

Whatever, then, may be the case with regard to details, it may be accepted as an established fact that within these parts of the Thian-shan, north of the Mustag-ata, there was a marine communication in Neozoic times between the Aralo-Caspian region and that of Yarkand. Its existence during the deposition of the lower Calcaire grossier of Paris is proved by fossils (*Gryphaea Esterhazyi*).

Structure of the intercalary chains. The elevated and highly disturbed position of some of the Tertiary deposits forbids the supposition that this marine communication took place through a definitely bounded strait. On the contrary, we must suppose, with Muschketow, that during the deposition of the gypsiferous Tertiary beds the mountains were much less lofty, and that afterwards folding broke up the sediments, carried them upwards or pinched them in, and at the same time closed the communication. We have before us indeed a compressed sea-floor, such as is presented on a large

¹ K. Futterer, Geologische Beobachtungen am Terek-Pass, Verh. Ges. Erdkunde, Berlin, Sitzung v. 15. Februar 1898.

scale by parts of the Tethys, or of which an excellent example is afforded by the Tertiary beds in the north of the western Alps (Rhône valley).

The structure of the curved intercalary chains on the Amu-darya and Sir-darya is far more difficult to understand. Their mutual correspondence shows at once that the Hindu-kush really forms part of the same tectonic system, and that the great folding movement has propagated itself not only from the Altai to the north-western end of the Yarkand arc, but beyond it to the west, into the Pámir, and even further towards the south. This affords a fresh confirmation of the independence of the Yarkand arc as opposed to the flood of the Altaides.

One of the most striking features of these intercalary chains is the rapid abasement of so many mighty anticlines and the fact that both in the basin of the Amur and that of the Syr they diverge from one another, on the north-west border, somewhat like a fan. It looks as though in this region the synclines were not the full complements of the anticlines.

The free anticlines tend to prolong themselves. There are certain indications which suggest that a prolongation has actually occurred in the region under consideration. The Amu-darya and Sir-darya, apart from their upper course in the high mountains, flow through the area abandoned in the last place by the sea or by some inland lake, and over the sediments deposited by these extensive waters, which have now either disappeared or been much reduced. These rivers are therefore the most recent occupants of their own basins. The first rudiments of their course on the surface of the sediments doubtless developed *pari passu* with the retreat of the lake or sea. Now, as we have seen, each of the rivers cuts through the south-western extremity of an intercalary chain. The surface of the flat-lying and most recent sediments may have been abraded by wind and other agents; but not to so great extent as to lay bare the Cham-tag, which rises to a fairly great height on the left bank of the Amu-darya, opposite Kelif, nor the mountain of Shirin-ferchat, which stands on the left bank of the Sir-darya below Chodjent.

These mountains are the natural extremities of the two most important south-westerly ranges of the intercalary chains; at Kelif—the chain coming from Derbent and probably that from the Chasreti-Sultan; at Chodjent—the mighty Tshatkal (Mogul-tau). *Possibly the Cham-tag, opposite Kelif, and the Shirin-ferchat, south-west of Chodjent, afford us a measure of the extent to which these two intercalary chains have been prolonged in the direction of their axis in recent times*¹.

¹ The lateral prolongation of the folds has been most conspicuous in the Kuen-lun from Arka-tag to Tsin-ling-shan. This question is so rarely investigated in Europe, because free ends of folds are so seldom seen there, though they are known, for instance, in the strata in the eastern portion of the Jura mountains, and in the folds of the Save, to be mentioned presently.

In both cases the connexion still existing between these heights and their axis on the other side of the Amu-darya and the Sir-darya is indicated by rapids. The same is true of the extremities of the Tertiary anticlines below Kelif, which are not completely sawn through by this river. The question of prolongation in one direction receives no light from the two Tertiary lines which cross the Sir-darya above Chodjent.

While these facts, together with the folding of the saliferous beds, render evident the occurrence of recent movement, yet it must not be forgotten that indications of much older disturbances also exist, especially in the principal chains. One of the most striking examples is the chain of Mangyshlak, where the whole Mesozoic series, from the Jurassic upwards, rests unconformably and but slightly undulated on the intensely folded older phyllites. But it is not merely that there have been movements of different dates. The undoubted interference of the folds striking to the north-east and north-west shows besides that there was not only a great and general movement of all the arcs of the Thian-shan, but that *each one of the principal arcs* (each disk-like segment, or, might we say, each tile) must have possessed or still possesses *a certain degree of independent movement*, which according to particular circumstances has found temporary expression and has produced interference by the formation of younger, secondary folds. In the region of the Amu-darya interference of this kind is not known. In the region of the Sir-darya, or at least in its western part, the folds striking to the north-west are younger and secondary. It will be seen, however, that these more recent north-westerly folds almost follow the direction of the main chain, the Kara-tau, while the more intense north-easterly folds follow very nearly that of the Alai; in other words, the two systems of folds present the direction of the principal arcs, but the north-westerly direction corresponds to the western half, and the north-easterly direction to the eastern half of these arcs. *The interference, therefore, is not the result of external influences, but represents the continued development of the principal arcs*, perhaps also a slight displacement of the vertex of curvature, and perhaps only some kind of later adaptation and compensation. It is not in the centre of its arc, but towards its eastern extremity, that the Hindu-kush attains by far its greatest dimensions; the intensity of the mountain formation evidently diminishes towards the west, and the western extremity of the range breaks up into couliisses. This is probably owing to the fact that it forms part of the Altaides. It is the same with the intercalary chains: all are much more grandly developed on the east and die away to the west. On the Sir-darya, where Muschketow has marked the intercalary chains as chains of the Alai, and where the two Tertiary connecting lines occur, they may be regarded as the *eastern moieties of the arcs of the Thian-shan*, here corresponding in direction with the Alai. But towards the western border (Moisar), and perhaps in the

north also, towards the Talas-Alatau, arcs arise which are convex towards the north-west and diverge from the direction of the Thian-shan. We have already mentioned that Muschketow is inclined to assign a certain amount of curvature in the same general direction to all these intercalary chains. This is opposed to the similarity in direction with the principal chains, already pointed out. On the other hand, it affords an increased resemblance with the very peculiar direction of the intercalary chains of the Amu-darya and the long line of Muk-su-Wachsh. These, as we know, begin in the Pámir with an approximately east-and-west direction; and then describe an arc which is so strongly curved to the north-west that as it proceeds further towards Kelif it becomes almost perpendicular to the trend of the foot-hills of the Hindu-kush; and not till we reach the most distant and westernmost Tertiary anticline below Felisidan-tau, does some approach to parallelism become perceptible.

We must again direct attention to the prolongation of the arcs. There are two kinds of folds, to be sharply distinguished from each other. Of these the longer, which we have termed the principal chains, project towards the west-north-west or north-north-west, far beyond the others, and thus form the virgation; but besides this we see in the case of the Hindu-kush how the enfeebled western end reaches as it were the opposite shore, and then forms the chord of the south Caspian arc. In a similar manner, though on a smaller scale, the chains of the Indus subtend the arc of Sewestán. The boundary is sharply defined only towards the smaller western concavity of Iran; in the great concavity to the east the Altaides appear to be as it were engulfed.

The Danube, urging its way to the right, held fast by many rocky ravines, and describing its meanders in the intervals between, has been compared to a suspended chain. This image may also serve for the Hindu-kush, but as a comparison, not as an explanation. As a comparison it is still more applicable to the intercalary chains of the Amu-darya; from these we obtain the impression that originally the folding force acted in the east, with great intensity and in a normal direction, but that later, while the anticlines continued their growth, it diminished, during a definite phase indicated by the position of the knee-like bend; thereby freedom was given to the further extension of the anticlines in a divergent direction to the south-south-west and south-west. Carrying out the comparison, we may say that the more recent, western parts of the intercalary chains hang free, as, for example, that which depends from the Iron Gates at Derbent in the direction of Kelif.

After what has already been said a further description of the more northerly parts of the virgation is hardly necessary. We have seen that the 'lost' folds south of the Balkhash result from the predominant development of either the eastern or western segment of one of the tile-like arcs;

the re-entrant angle of Kara-tash, on the south side of the Utsh-Kara, is a repetition of what occurs on the upper course of the Aryss and of the Karsh; the trough of the Ebi-nor is determined by disjunctive lines running parallel with the western segment of one of these arcs, and intersecting the eastern segment of another in the Ala-tau of Dzungaria.

The Hindu-kush, the most southerly of the branches, cuts the direction of the Saféd-kóh, approaches very closely to the direction of the outer arc of Iran, but runs across the southern arc of the Caspian. The Iranian arcs exhibit both to the east and west a marked intensity of folding, as is shown by the outcrop of ancient rocks, while in the centre none but younger sediments are to be seen. The Hindu-kush, together with the intercalary chains, and the whole southern part of the virgation, affords evidence of powerful movements in the east only; towards the west the decrease in intensity is very striking.

The northern branches of the Thian-shan develop freely up to their encounter with the continuation of the Kashgar range and the Mustag-ata in the north. Then the folds flow down on the west side of the Yarkand arc like those of the Nan-shan on the east side of this arc. According to existing observations the region of this downflow on the west side corresponds much more closely with the meridian of syntaxis on the Jhelam than has hitherto been supposed (I, p. 448).

The existing continent of Asia. We have now reached the end of our analysis of eastern Eurasia. We shall see directly that Asiatic folding reaches Europe, not merely along the line Kopet-dagh—Balkan—Caucasus, but, speaking broadly, that from the Arctic Ocean to the Mediterranean no natural boundary exists between eastern Eurasia and western Eurasia. But notwithstanding this tectonic indivisibility, the existing continent of Asia forms so vast a unit, particularly in its relations to all forms of organic life, that it is well worth while to cast a glance over its actual state.

Great masters have already made the attempt: Alexander von Humboldt, starting from the mountains, Ferdinand von Richthofen from the plains, Muschketow with special reference to the recent communication between the Turanian sea (Aralo-Caspian) and the region of Yarkand.

At the present time, the observations we now possess enable us to introduce the historical element in a somewhat greater degree.

First of all, we see that all the ancient regions possess well-developed river systems and a free discharge to the sea.

This is as true of Gondwána-land, in the Indian peninsula, as of the Sinian and the older part of the Angara continent, from the headwaters of the Selenga to the Arctic Ocean. Everywhere in these ancient regions the great rivers come down from afar out of the high mountains, where the action of their waters works backwards in enlarging their basins, as has

been shown by R. D. Oldham, in discussing the steep south side of the Himálayan passes¹.

The conceptions of 'central' and 'peripheral,' as Richthofen formulated them in the case of Asia, may be illustrated by two symbols, salt and coal. Salt, together with gypsum, corresponds to the closed drainage system or the central position; and coal, when it is formed as in Asia, in extensive freshwater basins, corresponds to the open outflow, without which no accumulation of water could maintain for long its original composition.

In the Indian fragment of Gondwána-land no saline deposits exist outside the Salt range; and there they were formed at an early period of the Palaeozoic aera. Ever since the lower Gondwána, if not before, freshwater conditions have predominated over the peninsula, and the great fault-troughs which stretched across the land after this period left them undisturbed; the Mesozoic transgressions are confined to the margins of the peninsula, and the river systems must have been in a state of continuous development, subject, no doubt, to frequent modifications, from the time of *Glossopteris Browniana* down to the present day.

In the middle of Angara-land the case is the same. The salt deposits on the Vilyui are believed to be lower Silurian; those of Minuzinsk belong to the upper Devonian, perhaps to the Culm, and they are the latest that exist in this region. From the time when the last of the *Lepidodendrons* flourished, termed in this region the age of the Tungusian flora, and probably almost identical with the lower Gondwána, down to the present day, no salt was deposited on the east Siberian platform or on the ancient vertex, but coal in abundance, and besides this freshwater sediments only. The Mesozoic transgressions of the extreme north did not produce any permanent disturbance of these conditions. The Obi, flowing over recent sediments, is, as we now know it, a recent river, but the conditions which determined the development of the drainage system extend backwards into a past which is just as remote in the case of Siberia and northern Mongolia as in the Indian peninsula. For this reason rapids are rare, except when they are due to basaltic lavas, as on the Angara. The supposition that the Selenga and Angara represent parts of the same river, and that lake Baikal is more recent than either, is in accordance with these facts.

In the east, even where the Amur cuts through the Little Khingan, the case is not fundamentally different. Comparatively recent folding no doubt occurs, but we know that only a very small part of the plains of the Amur were reached by the Arctic transgressions, and that, on the other hand, both these plains and those of Manchuria are occupied by freshwater deposits, which date at least from the time of *Asplenium Whitbyense*. These freshwater deposits even reach the existing sea-coast.

¹ R. D. Oldham, The River Valleys of the Himalayas, Journ. Manchester Geogr. Soc., 1894.

Iwanow describes Tertiary beds with brown coal, which extend in isolated patches from lake Chanka south-south-west to the ocean; they occur at a height (465 meters) which exceeds that of the existing watershed¹. In the islands of Japan also, the Mesozoic series is interrupted by fresh-water deposits.

Thus in the east, as well as to the west, erosion must have been active throughout a very long lapse of time.

All the ancient continental masses now bear within themselves the characters of peripheral regions. Everywhere the coal is more recent than the salt. But the plant-bearing beds of the Angara series extend also into regions which are at present shut off from the sea. Patches of them reach the northern margin of the Tethys, e.g. on the southern border of the Yarkand basin, and into the Turanian region, e.g. on the Sir-darya. These areas were once peripheral; whether their drainage was discharged into the Tethys is not always susceptible of proof; at present they are central. *We have now entered regions where the salt is more recent than the coal.*

Two events have exerted a profound influence on the history of the existing continents; these are the development of the long folds of the Altaides, and the renewed invasion of the west by the sea. The latter has given to the west—the most important of Richthofen's 'regions of transition'—a history of its own.

The Tethys, crossing Turania and parts of Iran, attained a wide development in the west. Beginning with oscillations in the Lias, it increased, towards the middle of the middle Jurassic, to such dimensions that one arm extending along the west side of the Urals entered the existing region of the Polar sea, which was thus united with the Indian Ocean by a communication that stretched right across Eurasia. The middle Cretaceous transgression penetrated deeply into the region of the existing Thian-shan; a communication with Iran existed across the site of the western Hindu-kush. At the time of the Eocene the same sea still extended into the basin of the Yarkand-darya, and even during the Oligocene marine deposits were formed along the east side of the Urals and reached the extreme north through the strait of Turgai. At this time the whole of the west, so far as it was not covered by the sea, was peripheral. Then this sea was shut off from the ocean and dissipated by evaporation.

It is scarcely possible to determine at what date the great period of salt formation began. It lasted up to the deposition of the Schlier and the beginning of the second Mediterranean stage, and at this time a sheet of salt water, lying below the normal sea-level, extended from the middle

¹ D. L. Iwanow, Gorn. Journ., 1891, III, pp. 248-304. Coal is worked by the side of the sea itself; Berg- u. Hüttenmänn. Zeitung, 1896, no. 36. Likewise in Sachalin and at different points of the eastern coasts.

Danube far to the east, possibly as far as Garm and Pandsh, perhaps even up to the Rang-kul of the Pámir and the Baroghil pass. Then signs of a communication with the ocean again set in: *Pecten denudatus*, found in the peninsula of Kertch, which came in during or immediately before the period of salt formation, is one of the earliest indications; still stronger testimony is afforded by the Spaniodon-beds on the borders of the Karabaghas, which belong to the second Mediterranean stage; and above all by the Sarmatian beds of the Ust-Urt. Then the communication was again cut off, and has not been restored up to the present day.

In central and eastern Asia there are no Tertiary salt formations, at least not of the kind just referred to. The gypsum and salt deposits of the Gobi, so far as we are acquainted with them, have not been produced by the isolation of parts of an ocean, but by the evaporation of very limited sheets of fresh water supplied by inland drainage. The mammalian remains as yet discovered in these deposits point primarily to a relationship with the Siwalik fauna, i. e. to a period which is later than the Sarmatian stage, and consequently later than the period of the great salt formation in the west. But in this case also we do not know at what date these deposits began to be formed. All the Gobi salt deposits lie in areas which are bounded by mountain arcs. Here in the east it is the development of the Altaides which has played the leading part, while in the west the transgression of the sea and the closure of its communications at some remote spot, as a result, probably, of tectonic movements, were the determining factors.

The influence of the mountain arcs has, generally speaking, been very different in different cases. The arcs of the Himálaya are broken through by numerous transverse valleys; the marginal arc of Iran which adjoins them is, on the contrary, completely continuous. Although there would seem to be some deep-seated cause for this contrast, yet we shall not insist upon it now, since objections might readily be raised, such as the difference in climate, and, in the case of Iran, the great remoteness of the high snowy ranges¹.

¹ It is well known that Medlicott in India, Hayden and Powell in North America, and Tietze, relying on observations in the Alburs and in the Carpathians, have, independently, arrived at the conclusion that the lines of the rivers are older than the folding of the region they traverse, and that their erosion has caused the folding to be cut through in proportion to its growth, 'as the beam in motion is cut through by the saw.' To this theory of 'antecedence' Emmons opposed the theory of 'superposition,' i. e. the assumption that the mountains have been covered by more recent sediments which have now disappeared. In this work, for Kelif and Chodjent, antecedence has been supposed; for the isolated Junction Peak in the proximity of the Uinta, superposition (I, 736); for the transverse valley of the Kysyl-su, the flowing over and away of the extinct lake in the valley of the Alai. In many cases there may be phenomena of retrogression. In the case of the transverse valleys in Hunza a larger rôle may fall to the glaciers. But the antecedence theory presupposes that all folded mountains with such transverse valleys

In the structure and history of Asia we may distinguish then the following elements in succession: first, the ancient vertex with the Cambrian platform, the Sinian mole extending from Ordos to Korea and the Indian fragment of Gondwana-land; then the Yarkand arc; finally, the younger vertex with the Altaides, which in the east as in the west meet the Yarkand arc in syntaxis, and at the same time continue to extend themselves further; in the east streaming forth as far as the virgation of the Philippines and the Banda sea, in the west opening out in the virgation of the Thian-shan and penetrating into Europe, in the south-east merging into the Burman arc, and in the south-west uniting somewhat closely with the Iranian arc. Between the two regions which are separated by the horst of India, and as a continuation of the Yarkand arc, rises the Himálaya.

Apart from pre-Cambrian rocks and volcanic flows or tuffs, the stratified sheets which take part in this structure are of four kinds: (1) Normal marine formations; (2) the products of evaporation, due to the isolation of parts of the sea (salt of the Salt range, the Vilyui, Minuzinsk, Iran, and Turania); (3) limnic transgressions (II, p. 249) represented by great sheets of freshwater (Culm in the Tannu-ola, coal-basins of Kusnetzky, the Angara series around the Angara, and the stony Tunguska, in the plains of the Amur and Manchuria and elsewhere; Tertiary lignites of east and west Siberia, &c.); (4) desert formations. The Gobi deposits with their red colour, the accumulations of the Bel, the local formations of salt and gypsum, afford excellent material for a study of the Rothliegende in Europe.

The outlines of the transgressive seas adapt themselves to the configuration of the surface, and this is affected by mountain formation, general denudation, the disposition of the river valleys, and other circumstances. The outlines of the limnic transgressions are similarly determined, but not those of desert deposits; these depend on very different conditions, since they are more independent of the relief. In the ancient land masses, those outlines which are determined by subsidence beneath the sea manifest a complete indifference to the strike of the folds, as is shown by the outlines of the Indian peninsula. In more recent mountains, inbreaks frequently conform themselves to the longitudinal disjunctive lines, as is shown by the sea of Okhotsk and the Sikhota-Alin.

We pass over for the present Taimyr-land and the arc of Verkhoiansk.

have originated on the dry land. It is better adapted to explain the preservation of the transverse valleys than their first formation. It appears indeed that, for instance, in the case of the cutting through of the Little Khingan by the Amur, antecedence since the period of *Asplenium Whitbyense* may be taken for granted.

CHAPTER VIII¹

THE TAURIDES AND THE DINARIDES

Asia Minor. The arc of the Eastern Pontus. Region from Heraclea to Amasra. Syntaxes in the west of Asia Minor. The Aegaeon islands. The Tertiary gulf of Albania. The dominant features of the Dinarides. The crossing of the Adriatic. Idria. The boundary cicatrice. The Carnic Alps. Transgressions. The more recent movements.

FROM the Armenian plateau a great segment of an arc sweeps through the Taurus and the adjacent chain of Amanus to the island of Cyprus. A second segment proceeds from upper Italy through the Dinaric chains to the island of Crete. Both segments are included in this work under the collective name of the Tauro-Dinaric arc (I, p. 499). But the two most important elements in this structure—the Taurides in the east, and the Dinarides in the west—maintain a certain independence of each other, which finds expression along the western coast of Asia Minor in the re-entrant angle of a syntaxis.

E. Naumann, in a very remarkable memoir, has sought to determine the trend-lines of the structure of Asia Minor. In his description he distinguishes three great folded arcs and parts of a fourth. The first, in the north-east, is the *East Pontic arc*; it borders the south shore of the Black sea, extending from the east towards Sinope. This is joined by the *West Pontic arc*, the south-western parts of which (Phrygian zone) approach the inner side of the third great arc. This is the *Tauric arc* which surrounds the Lycaonian plain; Cyprus forms part of it; towards the west, according to Naumann, it joins in syntaxis parts of a fourth arc, that of the *Aegaeon*, with which it forms re-entrant angles².

The previous work of Koch, Tschihatschew, and especially Abich, justify the separation of the East Pontic arc. On the lower Djorok it does look, no doubt, as though ranges trending from east to west and perhaps even to the north-west proceeded westwards for a great distance, yet here also, on the left side of the river, south of Batum, the south-west direction still prevails³.

¹ Revised by Professor Charles Lapworth, LL.D., F.R.S.

² E. Naumann, *Die Grundlinien Anatoliens und Central-Asiens*, Hettner, Geogr. Zeitschr., 1896, II, pp. 7-25; in part also in *Vom Goldenen Horn zu den Quellen des Euphrat*, 8vo, 1893, p. 373 et seq.

³ H. Abich, *Geologische Forschungen in den kaukasischen Ländern*, 4to, 1882, II, p. 185 et passim; also W. J. Hamilton, *Reisen in Kleinasien, Pontus und Armenien*, German edition, 1843, I, p. 197 et seq.

Cretaceous limestone and serpentine take a very considerable share in the constitution of this arc. Above Ardanutsch the Djorok, almost as far up as its sources, may well be regarded as a longitudinal river. In the Ehiaur-dagh, north of Kelkit, lies the vertex of the arc, advanced towards the south. A broad zone of volcanic ejectamenta, which grows narrower towards the west, proceeds from the Araxes towards the sources of the Euphrates. At the sources of the Araxes itself rises the crater of the Bingöl; many other lofty volcanos emerge from amidst the chains formed of limestone and serpentine. In the valleys deposits of the first Mediterranean stage occur, steeply upturned. North of the sources of the Murad the Tchatin-(Schatin-)dagh (I, p. 495) stands out as though it were the first spur of the folded ranges of the Taurus, which trend west-south-west and south-west. In the direction of Erzerum, Mamachutan, and Erzincan, the Tauric ranges seem to me to separate gradually from those of the east Pontic arcs.

According to Naumann, an inner zone of Tauric folds, coming from the north-east, runs within the bend of the Halys with a south-west direction towards the north-east of the Lycaonian depression, and breaks off against the border. Near Kaisarieh, east of this region, rises the mighty Argæus (4,000 meters), and here begins the zone of volcanos which border the inner side of the Tauric arc in a regular semicircle¹.

Kotschy was already aware that the highest parts of the principal chain of the Taurus consist of limestone; but we owe more detailed information to Schaffer, who has crossed the range three times. The most northerly of his sections runs south-east from Bulghar-maaden across the Bulghar-dagh (3,145 meters) towards the Gûlek-Boghas; the second crosses the Aidost chain (3,550 meters), and the most southerly the Dumbelek pass (2,700 meters). In all of them the north-western slope shows steeply upturned Eocene limestone, and probably Cretaceous also, while on the south-east and south side of the range are very thick limestones of the first or second Mediterranean stage. These show fairly undisturbed bedding, dip for the most part gently away from the range, and are also, perhaps, slightly bent to form a flat anticline; at the same time they reach astonishing heights. On the east side of the Dumbelek-dagh such almost horizontal limestones are met with at a height even of 2,300 meters. This mighty girdle of unconformable limestone forms plateaux with a surface recalling that of the Karst; it is continued towards the south-west and west far away into the valley of the Calycadnus.

On the north-west side of the Dumbelek an independent anticline makes its appearance, the Karabunar-dagh, which consists of Eocene or

¹ A good description of the eastern part in R. Oberhummer und H. Zimmerer, *Durch Syrien und Kleinasien*, 8vo, Berlin, 1899, in particular L. von Ammon, *op. cit.*, p. 330 et seq.

Cretaceous limestone and crystalline limestone also, together with serpentine and green schists; the summit of the Aidost exhibits grey limestone and black mica-schist. Similar rocks appear further north in the Cilician gates, and we know from Tschihatschew that in the Ala-dagh, still further to the north-east, serpentine occurs widely distributed¹.

Within the mighty Cilician Taurus scarcely a rock of higher antiquity than the Cretaceous has hitherto been recognized with certainty.

A problem, not yet solved, is connected with the structure of this range. Generally speaking, the rocks, in accordance with the outer form of the chains, strike, it is true, to the north-east, parallel with the Vulcan range on the one side and the Amanus on the other: it is also clear that the Mediterranean beds of Tertiary age were deposited against a range folded in this direction. But Schaffer has found that in several localities, and especially in the plain between the foot of the Cilician Taurus and the Amanus, there occur long bands of crystalline limestone and siliceous marls, and also of Aquitanian plant-bearing beds; these, standing out at times in cliff-like forms, strike from north to south, thus diverging from the direction of the great chains. As an example, Schaffer mentions the lofty limestone cliff, 350 meters in height, which forms the castle-crowned hill of Sis.

Russeger, Tschihatschew, and Schaffer have obtained Devonian fossils from the Anti-Taurus; Blanckenhorn has also found Palaeozoic Brachiopods on the Giaur-dagh, at the northern end of the Amanus. Further to the south-west, the same limestone rocks with gabbro and serpentine which form so important a part of the Tauro-Dinaric chains, crop out again both in the Amanus and Casius (Jebel Akra).

Following Blanckenhorn, we may place the boundary between these chains and the Syrian tableland in the Tertiary gulf, through which the Nahr-el-kebir reaches the sea at Latakia².

The Kurd mountains, as well as the little range of hills which as cape Karatash projects into the gulf of Alexandretta, also belong to the Tauric chains. Their continuation lies in Cyprus³.

Blanckenhorn has pointed out that in the valley of the Kara-su, between the Amanus and the Kurd mountains, there are recent lavas and a warm sulphur spring, and he has raised the question whether this valley

¹ F. Schaffer, *Geologische Studien im Südöstlichen Kleinasien*, Sitz. k. Akad. Wiss. Wien, 1900, CIX, pp. 498-525, and 1901, CX, pp. 5-18.

² M. Blanckenhorn, *Grundzüge der Geologie und physischen Geographie von Nord-Syrien*, 4to, Berlin, 1891, pp. 6-14, map, cf. I, p. 496, note 2.

³ The rocks of this island were first described by Gaudry and subsequently by Bergeat. Not only are serpentine and a rock supposed to be Cretaceous limestone present, but also traces of Jurassic; A. Bergeat, *Zur Geologie der massigen Gesteine der Insel Cyprien*, Tschermak, Min.-Petr. Mitth., 1891, XII, pp. 263-312, map.

should not be looked upon as a continuation of the great Syrian fault-trough. Schaffer has visited the northern part of the valley, and concludes that the fault-trough actually extends to Marash¹.

Here we will interrupt for a time our consideration of the principal arc of the Taurus, and again turn our attention to the north of the Lycaonian plain.

Naumann mentions a fold at Angora overthrown to the east-south-east; and towards Polatly, further westwards, there is horizontal tableland². According to the same observer, the Eocene beds lie horizontal in the whole region of the West Pontic arc.

For the stretch of country, more than 100 kilometers long, which extends from Heraclea to beyond Amasra, and is distinguished by the presence of coal measures, we have exact data from Ralli³.

It presents us with three long and narrow parallel bands of Carboniferous rocks—comprising Culm, lower Carboniferous limestone, and upper Carboniferous coal-measures. Their direction is more or less east-north-east (N. 70° E.). The country lying between these bands consists of nodular calcareous beds, chiefly Caprotina limestone [Cretaceous], but this is sunken as it were into the Carboniferous. Whenever the border of one of these bands is reached in working the coal seams, limestone is encountered below ground, and the seams are cut off by a fault. It is true that the coal measures within these bands are not only steeply up-turned in one direction but also thrown into anticlines; yet the axes of the anticlines follow in so striking a manner the direction of the faults, even when these are bent in hook-like curves, that we are left in doubt as to how far the formation of the anticlines is due to dragging along the faults.

This whole district exhibits the characters rather of a faulted-down than of a folded country.

Nor are we able to assert that the shores of the gulf of Ismid or the Bosphorus afford any further evidence as to the existence of a folded arc. The Devonian of the Bosphorus is overlain unconformably, as Toulas has

¹ Blanckenhorn, Die Structurlinien Syriens und des Rothen Meeres, in Festschrift für F. Freiherr von Richthofen, 8vo, Berlin, 1893, pp. 115–180, map, in particular p. 178; Schaffer, II, p. 15.

² Naumann, Vom Goldenen Horn, p. 372. The fossils of the Lias described by Pompeckii were also brought from the west of the Angara. Zeitschr. deutsch. geol. Ges., 1897, XLIX, pp. 712–828.

³ G. Ralli, Le bassin houiller d'Héraclée, Ann. Soc. géol. Belg., 1895–1896, XXIII, pp. 151–267, maps; also Schlehan, Versuch einer geognostischen Beschreibung der Gegend zwischen Amasry und Tyrla-asy an der nord-öst. Küste von Kleinasien, Zeitschr. deutsch. geol. Ges., 1852, IV, pp. 96–142, map; and Garella and Huyot, Rapport sur les mines de houille d'Héraclée, Ann. Mines, 1854, 5^e sér., VI, pp. 173–234. R. Zeiller, Étude sur la flore fossile du bassin houiller d'Héraclée, Mém. Soc. géol., 1899, No. XXI, 91 pp.

shown, by the lower Trias, but the observed disposition of the beds of the Trias can hardly be connected with a West Pontic arc. The horizontality just mentioned as characterizing the older Tertiary beds of the west Pontic region is maintained up to the border of the basin of Adrianople and even further towards the interior, where these beds rest on the Archaean rocks of the Rhodope mass¹.

Much more convincing testimony to the existence of a West Pontic arc is afforded by the steeply upturned stratified series which Naumann met with in the valley of the Sakaria, extending from Balaban upwards, past Lefke and Vezirkhan, but even this is immediately followed on the east by the mighty tabular mass of the Giöl-dagh².

But since the same far-travelled observer has rendered certain the existence of a south-easterly strike in the mountains between Kutaya and Balikesri, we must admit that there the western parts, at least, of a West Pontic arc are to be seen.

The Olympus of Brussa, as already known to Verneuil and Viquesnel, is an intrusive granite mass surrounded by ancient schists and serpentine. Near its summit there lies an isolated mass of white marble with garnets³.

The region of the west Anatolian syntaxis (i.e. the encounter of the western ends of the West Pontic and the Tauric arcs with the eastern ends of the fragmentary Aegæan arcs) is placed by Naumann in the district south of the middle of the sea of Marmora, about long. 28° E. Yet at present we may still retain a doubt whether the mountain segments regarded as West Pontic are not merely the inner fragments of the great Tauric arc. Further investigations, especially in Paphlagonia, are necessary to settle this point⁴.

¹ F. Toula, *Eine geologische Reise nach Kleinasien*, Neu. Jahrb. Min., 1899, I, pp. 63-70; also *Eine Muschelkalkfauna am Golfe von Ismid in Klein-Asien*, in Waagen, *Beitr. Z. Palaeont. Oesterr.-Ung.*, 1896, X, pp. 153-157, and *Eine geologische Reise nach Klein-Asien (Bosporus und Südküste des Marmara-Meeres)*, op. cit., 1898, XII, pp. 2-53 et passim.

² Naumann, *Grundlinien*, p. 15.

³ K. von Fritsch, *Acht Tage in Klein-Asien*, Mitth. Ver. für Erdk. Halle, 1882, pp. 101-139, map; and W. F. Wilkinson, *Notes on the Geology and Mineral Resources of Anatolia*, Quart. Journ. Geol. Soc., 1895, LI, pp. 95-97.

⁴ Certain distinguished investigators, such as Douvillé, *Comptes rend.* 16 March, 1896, and F. Toula, *Neu. Jahrb. Min.* 1898, have conjectured that the Balkans are not continued by the Crimea but by Asia Minor. M. Douvillé bases his theory on the concordant succession of strata at Heraclea. I have thought it best not to connect myself with these conjectures. The structure of the country between Heraclea and Amasra contradicts them. Hochstetter says Boué had already pointed out that the conception of the Istrandja mountains as a south-eastern spur of the Balkans is erroneous, since it is separated from this range 'not only geologically but also geographically' (*Jahrb. k. k. geol. Reichsanst.*, 1870, XX, p. 390). The presence of the Alpine type of the Mesozoic

But the question whether a syntaxis exists in the neighbourhood of the west coast of Asia Minor is of no small importance. For if it were answered in the affirmative it would follow that the Aegæan inbreak lies outside the Taurides, and belongs to the western or Dinaric region only.

In order to discuss this question we will begin in the south-west.

The western part of Asia Minor. In a large part of south *Lycia*, from the lofty limestone masses of the Massikytos (Ak-dagh) across the Susuz-dagh, up to the south coast near the island of Kekova, Tietze found a persistent strike to the east-north-east or north-east (between hor. 3 and hor. 5, chiefly 4). Perhaps, towards the western shore of the gulf of Adalia there followed a bending up of this strike towards the north. In these parts of *Lycia*, deposits of the age of the Schlier, or the second Mediterranean stage, are carried up to heights of more than 4,000 feet¹.

Southern *Lycia* must thus be assigned to the western or Dinaric (Aegæan) arc, in which, according to Bukowski's observations, we must also include the island of *Rhodes*². The Cretaceous limestone runs from Crete through *Kasos*³, and reaches the extreme west of *Rhodes* with a north-east strike. This direction is continued to the Hagion Elias, which is situated in the middle of the northern half of *Rhodes*; but here the strike bends from north-east to east, and finally towards the south-east, and thus reaches the east coast in extremely contorted beds. Here, therefore, a Tauric fragment really appears to be inserted in syntaxis; but north of the Hagion Elias, however, a range with the Dinaric east-north-east strike continues in the direction of the mainland towards Asia Minor.

Beyond this, the bay between the coast of *Lycia* and *Rhodes* lies on a transverse fracture of the outer Dinaric arcs; the sea-bottom sinks very rapidly to great depths, and at a distance of 38 kilometers from the coast of *Rhodes*, and not much further from that of Asia Minor, reaches 3,865 meters⁴.

In *Caria* attention may first be directed to the two gneiss ranges striking to the north-west, which have been described by Paton. The first of these

sediments has been established at several localities by fresh discoveries, such as the rich outcrops of Bosnia, the Trias of Balia Maaden, and the traces of the Trias in Greece, indicated by Douvillé.

¹ E. Tietze, Beiträge zur Geologie von Lykien, Jahrb. k. k. geol. Reichsanst., 1885, XXXV, pp. 283-384, map.

² G. Bukowski, Grundzüge des geologischen Baues der Insel Rhodus, Sitz. k. Akad. Wiss. Wien, 1889, XCVIII, pp. 208-272, map, in particular p. 220; also Geologische Uebersichtskarte der Insel Rhodus, Jahrb. k. k. geol. Reichsanst., 1898, XLVIII, pp. 517-688, map.

³ G. Bukowski, Der geologische Bau der Insel Kasos, Sitz. k. Akad. Wiss. Wien, 1889, XCVIII, pp. 653-669, map.

⁴ J. Luksch and J. Wolf in Berichte der Commission zur Erforschung des östlichen Mittelmeeres, III, Denkschr. k. Akad. Wiss. Wien, LXI, p. 92 et seq., map.

forms the greater part of the peninsula of Myndos (Halicarnassus); similar rocks occur towards the north-west of the island of Patmos, and towards the south-east in the eastern part of the peninsula of Cnidos, and are regarded as the continuation of this range. The second gneiss range forms the Latmos mountains (Beschparmak-dagh). It is parallel to the first, begins on the lower Meander and forms the southern watershed of this river nearly to Mugla. To the west of these gneiss ranges Paton found limestone in the north of Leros, in Kalymnos, Kos, in a part of the peninsula of Cnidos, and in the island of Syme¹.

According to Bukowski the same north-west direction determines the structure of the mountains far in the interior, from the Baba-dagh near Denizli (in which garnet-bearing mica-schist is visible) to the long anticline of phyllite which, as the Sultan-dagh, forms with its south-easterly prolongations the western border of the plain of Lycia Akshehr beyond. Limestones of different ages form the greatest part of this region; pebbles of Fusulina limestone have been found in Eocene sediments north of the Buldur-Gueul².

Continuing in the direction of Caria out to sea we remark in *Nisyros* the beginning of that arc of volcanos which runs through Santorin towards Aegina.

In the south-east part of *Kos*, Neumayr observed a mass of phyllite and marble rising high out of the Cretaceous limestone; its strike appears to describe an arc open towards the south, but the mass is too small to allow of any conclusion³.

In *Samos*, on the other hand, we are able to trace the continuation of the Carian mountains. According to the observations of Nasse, garnetiferous mica-schists, associated with white marble, run transversely across the middle of the island with a north-west strike in the imposing mountain range of Ampelos; similar rocks, accompanied by serpentine, diabase, and porphyry, form the hilly range of Kerki in the west, as well as the flatter country in the east of the island⁴.

Thence onwards the strike turns to the north. The collation undertaken by Teller of the older observations made by Strickland and Spratt in the

¹ W. R. Paton and J. L. Myres, *Researches in Karia*, Geogr. Journ., 1897, IX, pp. 38-54, map, in particular pp. 44 and 51. Tschihatschew has also crossed the Latmian gneiss range.

² G. Bukowski, *Kurzer Vorbericht über die Ergebnisse der in den Jahren 1890 und 1891 im südwestlichen Kleinasien durchgeführten geologischen Untersuchungen*, Sitz. k. Akad. Wiss. Wien, 1891, C, pp. 378-399, in particular p. 386.

³ M. Neumayr, *Ueber den geologischen Bau der Insel Kos*, Denkschr. k. Akad. Wiss. Wien, 1879, XL, pp. 213-314, map.

⁴ R. Nasse, *Ein Ausflug nach Samos*, Zeitschr. Ges. Erdk. Berlin, X, pp. 222-235, map; also Spratt, *Geology of the Island of Samos*, Quart. Journ. Geol. Soc., 1847, III, pp. 65-67, maps, and Di Stefani, C. J. Forsyth-Major et W. Barbey, *Samos*, 4to, 1892; Lausanne, *Aperçu géologique par Di Stefani*, pp. 71-81.

gulf of *Smyrna* with those made by himself in the little group of the *Spalmatori islands* and in *Chios* gives the following results:—

At mount *Tmolus*, east-south-east of *Smyrna*, phyllites crop out, and are followed towards the west, at mount *Corax*, by dark-brown and greenish shales with sandstone. Grey limestone, with a strike almost north and south, forms the main mass of the promontory of *Karaburun*, and on the west side reappears the stratified series of the *Corax*, as a broad zone with a dip to the east. The group of the *Spalmatori islands* belongs to the axis of an anticline of phyllites, which strikes in a northerly direction between the mainland and the island of *Chios*. In *Chios* we find first the western half of this anticline and then a fold with a north to north-north-east strike. The rocks of the *Spalmatori islands* correspond probably to those of mount *Tmolus*, a lower series in *Chios* is equivalent to that of mount *Corax* and the west side of *Karaburun*, but the upper limestones of *Chios* correspond to the limestone of the heights of *Karaburun*. Within the lower members of the succession in *Chios*, in a horizon which probably corresponds with the upper subdivisions of the series of mount *Corax*, *Teller* has found limestone with *Fusulina* and *Crinoids*¹.

Two anticlines are therefore present, one striking to the north-north-east, which is exposed in the *Tmolus* at *Smyrna*; and a second, striking to the north, which runs through the *Spalmatori islands*. These are joined by the subordinate folds of *Chios*. In the superposed beds we are at present acquainted with upper Carboniferous and Cretaceous.

Mitylene has been described by *De Launay*. Micaceous and chloritic schists, associated with marble, run through the eastern half of the island with a strike N. 15° E.; they are evidently the northern continuation of the rocks mentioned above, but are accompanied towards the east and west by two bands of peridotite and serpentine; perhaps that of the east is the continuation of a band of serpentine which crops out to the north of *Karaburun*. The western part of the island is covered by comparatively recent eruptive rocks, but beneath them we see traces of the ancient schist striking to the north-north-east as far as the extreme western shore².

Diller's description of the southern *Troad* shows that the volcanic formations of western *Mitylene* extend beyond the gulf of *Adramyti*, and cover the whole south-west of the *Troad*. Further to the north, in the direction

¹ H. E. Strickland, On the Geology of the Neighbourhood of *Smyrna*, Trans. Geol. Soc., 1840, V, pp. 393-408, map; T. Spratt, Observations on the Geology of the South Part of the Gulf of *Smyrna* and the promontory of *Karabournou*, Quart. Journ. Geol. Soc., 1845, I, pp. 156-162, map; F. Teller, Geologische Beobachtungen auf der Insel *Chios*, Denkschr. k. Akad. Wiss. Wien, 1880, XL, pp. 340-356, map.

² L. de Launay, Description géologique des Iles de *Mételin* et de *Thasos*, Archives des Missions, 1890, 3^e sér., XVI, 48 pp., map. Études géologiques sur la Mer Égée, La Géologie des Iles de *Mételin* (*Lesbos*), *Lemnos*, et *Thasos*, Ann. Mines, 1898, 9^e sér., XIII, pp. 157-319, maps.

of the Scamander, rises the Kara-dagh, which is formed of stratified rocks. On its northern slopes, towards Bunarbashi, Philippson met with a white limestone, fairly crystalline, with a strike to N. 5° E., which forms the north border of the mountains towards the Trojan plain¹.

The structure of the west coast of Asia Minor is therefore the following:—

From Crete an arc runs to the north-east through Kasos to Rhodes, where it meets a shorter segment coming from a north-west direction.

The volcanic arc extends from Santorin into Nisyros.

In the whole of the south-western part of the continent a north-west strike prevails as far as the coast of Caria and onwards to Samos: this is the western wing of the Tauric arc, which encloses the Lycaonian plain.

Between Smyrna and Chios a north to north-north-east strike appears and is maintained through the Spalmatori islands and Mitylene to the plain of Troy.

While the western limb of the Tauric arc can be followed with tolerable certainty as far as Samos, we are not so sure that the ranges directed to the north and north-north-east should be included with it. This becomes even more doubtful when we discover, from Bukowski's investigations in Mysia, in the neighbourhood of Balia-maaden, that a band of Carboniferous deposits, striking to the north-east or north-north-east, probably exists². Whether this band extends to Panderma on the sea of Marmora must remain an open question. On the continent of Europe the schistose ridges of Tekir-dagh and Kuru-dagh strike to the south-west on both sides of the depression which extends to the gulf of Saros, and we know from Hoernes that the island of Samothrace is a continuation of these ranges with the same south-west strike³. In Lemnos, however, according to De Launay, the strike of the folds becomes east and west, with a slight divergence to east-north-east and west-south-west⁴.

These mountain sections do not, therefore, belong to the western wing of the Taurides, but to the eastern wing of the Dinaric group.

¹ J. S. Diller, Notes on the Geology of the Troad, Quart. Journ. Geol. Soc., 1883, XXXIX, pp. 627–636, map. A. Philippson, Geologisch-geographische Reiseskizzen aus dem Orient, Sitz. Niederrhein. Ges. Nat., &c., Bonn, 1897, p. 41.

² G. von Bukowski, Die geologischen Verhältnisse der Umgebung von Balia Maaden im nordwestlichen Klein-Asien, Sitz. k. Akad. Wiss. Wien, 1892, CI, pp. 214–235, map. H. Coquand, Notice géologique sur les environs de Panderma (Asie mineure), Bull. Soc. géol. de Fr., 1878, 3^e sér., VI, pp. 347–357. In this exposure, however, which does not appear to be important, Coquand has observed a strike to the north-west.

³ R. Hoernes, Geologischer Bau der Insel Samothrake, Denkschr. k. Akad. Wiss. Wien, 1874, XXXIII, 2. Abth., pp. 1–12, map.

⁴ L. de Launay, Études géologiques, pp. 45–82, map.

A syntaxis in fact does exist in the proximity of the west coast of Asia Minor.

A north-east to east-north-east strike prevails on the European mainland (Tekir-dagh, Kuru-dagh) and as far as Samothrace, and perhaps also in the Carboniferous band of Balia-maaden. In the south this direction is represented by the volcanic line to Nisyros, and further by the line passing through Crete and Kasos to Rhodes, and the lofty mountains of southern Lycia. These regions we include among the eastern ends of the ranges of the Dinaric arc.

A north and south to a north-north-east strike is met with on the southern border of the plain of Troy, in Mitylene, Chios, the Spalmatori islands, the peninsula of Karaburun, and as far as Smyrna. These areas probably answer in part to the Dinaric arc and in part to the region of syntaxis.

A north-west strike makes its appearance in the valley of the Sakaria in the neighbourhood of the Olympus of Brussa, then in the south-west of Asia Minor as far as Samos, thence to the coast of Caria and to a restricted part of Rhodes. These tracts are the western ends of the Tauric arcs.

This enumeration, however, is not without considerable gaps; connected observations are especially lacking in Mysia. Nevertheless the two directions—to the north-east and to the north-west—may be clearly distinguished. We perceive that in the south the Dinaric lines encroach toward the east. And, further, it is plain that the Aegæan inbreaks lie within the Dinarides and hardly encroach upon the Tauric lines.

The Tertiary gulf of Albania. The investigations of Neumayr, Bittner, Teller, and Burgerstein have shown that the folded ranges of the Dinarides, striking north-north-west, downwards from Thessaly, undergo a complete deflexion towards the east and proceed thus through the islands of the Aegæan sea, and through the island of Crete towards Asia Minor, (I, pp. 497–8). De Launay has published a general geological map of the Archipelago¹, and Philippson, as the result of a large number of new observations, has clearly determined the arcs traced by the trend-lines as they cross from Epirus to Asia Minor².

At the same time the views held by Spratt and Neumayr as to the recent date of the Aegæan inbreaks (I, p. 344) have received confirmation. The Levantine deposits, formed in fresh water, are displayed on the shores of the inbreaks; the deposits of the third and fourth Mediterranean stages mantle over the coasts of the southern series of islands and the Peloponnesus, and invade the mainland in several bays. Philippson and Oppenheim

¹ L. de Launay, *Géologie des Iles de Mételin, Lemnos et Thasos*, pl. I.

² A. Philippson, *Die griechischen Inseln des Aegæischen Meeres*, Verh. Ges. Erdk., Berlin, 1897, XXIV, pp. 264–280, map; *La Tectonique de l'Égée*, Ann. Geogr., 1898, no. 32, pp. 112–141, map.

show that the mighty conglomerates which many years ago called forth the astonishment of the first investigators, Boblaye and Virlet, are younger than a part of the Levantine sediments¹, and Bukowski describes the thick masses of fluviatile pebble-beds of Levantine date and unquestionably derived from the mainland of Asia Minor, which occur upon the island of Rhodes².

While the only deposits, either freshwater or marine, thus known to us within a very extensive region, are such as scarcely descend lower than the third Mediterranean stage; yet we learn from Hilber and Penecke that within the Dinaric ranges of Macedonia and Thessaly there occurs a very elongated basin of a wholly different kind³.

According to the discoveries made up to the present by Hilber, this basin extends from the region south of the lakes of Ochrida and Presba, and in particular from the neighbourhood of Goritza (Giortcha), towards the south-south-east, through Lapsista, Grevena, and Kastoria into the depression of Trikkala. The sediments begin on the horizon of the Castel Gomberto beds, in the upper Oligocene (*Natica crassatina*, *Isastraea affinis*); near Goritza these lower beds overlies lignites which rest upon hills of serpentine; and further to the south, on the eastern border of the basin, north of Trikkala and elsewhere, they rest on ancient schists. Aquitanian deposits follow, and to these belong the conglomerate rocks of the Meteora monasteries. Next above come marine deposits of the first Mediterranean stage, traces of the Schlier with *Pecten denudatus*, and north-west of Kastoria we even meet with the Clypeasteridae of the Leithakalk, which belongs to the second Mediterranean stage. Deposits of later Tertiary times are represented only by the conglomerates with *Elephas meridionalis* and *Equus stenonis* which Gorceix discovered at Lapsista.

¹ P. Oppenheim, Beiträge zur Kenntniss des Neogen in Griechenland mit einer geologischen Einleitung von A. Philippson, Zeitschr. deutsch. geol. Ges., 1891, XLIII, pp. 421-487.

² Bukowski, Grundzüge, p. 235 et seq.

³ V. Hilber, Geologische Reise in Nordgriechenland und in Macedonien, 1893, Sitz. k. Akad. Wiss. Wien, 1894, CIII, pp. 575-601, in particular p. 596 et seq.; K. A. Penecke, Marine Tertiär-Fossilien aus Nordgriechenland und dessen türkischen Grenzländern, Denkschr. k. Akad. Wiss. Wien, 1897, LXIV, pp. 41-65. Boué had previously mentioned the Tertiary deposits of Trikkala, but without quoting fossil remains; La Turquie d'Europe, Germ. edit., I, p. 195. In 1892 Dreger described *Natica crassatina* and other species from the neighbourhood of Koritsa from specimens which had been sent to him; in 1893 Hilber penetrated to Koritsa in Macedonia; in 1894 Philippson and Oppenheim demonstrated the presence of sediments with *Cerithium margaritaceum* on the Macedonian boundary north of Trikkala, and they described an Arca sent from Koritsa; Tertiär und Tertiärfossilien in Nord-Griechenland sowie in Albanien und bei Patras im Peloponnes, Zeitschr. deutsch. geol. Ges., 1894, XLVI, pp. 800-822; Gorceix, who was the first to mention the bone remains of Lapsista, conjectured that these Tertiary deposits were continued towards the north.

The configuration of the country might lead us to seek the connexion once existing between this greatly elongated basin and the sea in the south-east. But this direction leads into the Aegæan region, in which no trace of similar sediments is known. Both on the east and the west the basin is enclosed by lofty mountain chains. A communication towards the north-west, on the other hand, is indicated by deposits of the first and second Mediterranean stages, which were made known by Boué and Hoernes in the Albanian lowland, between Durazzo and Tiranna and close to Kruia¹; Tietze met with the continuations of these deposits near Dulcigno².

While upon these grounds we recognize the existence of a marine gulf which opened into the sea south of Dulcigno, extended to the north-west, and lasted from the middle Tertiary into the time of the second Mediterranean stage, yet somewhat further to the south the only marine deposits known up to the present time belong to the third Mediterranean stage. According to the statements of Baldacci and Simonelli, thick petroleum-bearing beds rest against the north-eastern slope of the hills which reach the sea at Vallona; these beds contain, together with numerous Pliocene marine shells in great abundance, the Sarmatian species *Cerithium pictum*. Coquand had already recognized this basin, which extends towards Berat³.

The dominant features of the Dinarides. In the south of Macedonia and in Thessaly our knowledge of the structure of the Balkans has been considerably extended by the works of Hilber, and in Thessaly and Greece by those of Philippson⁴. Other meritorious investigators have been active in the north; Professor Cvijić, of Belgrade, has favoured me with many instructive communications. In spite of all the deficiencies in existing observations, two general results have already been won.

The first of these consists in the recognition of the fact that on the

¹ A. Boué, Der albanesische Drin und die Geologie Albaniens, besonders seines tertiären Beckens, mit einem Verzeichniss nordalbanesischer tertiärer Petrefacten von M. Hörnes, Sitz. k. Akad. Wiss. Wien, 1864, XLIX, pp. 179-193. The list includes species of the first Mediterranean stage (*Mytilus Haidingeri*, *Pecten solarium*) and of those of the second; the material examined was derived from two places, the mountain of Gradetz between Durazzo and Tyrana, and the mountain of Sörel (Zurel) between Tyrana and the Mat (p. 184).

² E. Tietze, Geologische Uebersicht von Montenegro, Jahrb. k. k. Geol. Reichsanst., 1884, XXXIV, pp. 1-110, map, in particular pp. 66 and 88.

³ V. Simonelli, Le sabbie fossilifere di Selenitza in Albania, Bull. Soc. geol. Ital., 1893, XII, pp. 552-558; also earlier, Coquand, Bull. Soc. géol. de Fr., 1868, 2^e sér., XXV, p. 20 et seq., for the continuation in Corfu; T. Fuchs, Die Pliocänbildungen von Zante und Corfu, Sitz. k. Akad. Wiss. Wien, 1877, LXXV, pp. 309-320.

⁴ Philippson's numerous writings on this subject are contained in the last volumes of the Zeitschrift der Gesellschaft für Erdkunde zu Berlin and the Zeitschrift der deutschen geologischen Gesellschaft; those of Hilber may be found in the Sitzungsberichte and Denkschriften of the Academy of Sciences of Vienna.

mainland, in spite of all the variations in the outer form of the country, the strike of the rocks, from Macedonia and Thessaly to the northern boundary of Bosnia and even to Istria, follows with great regularity the direction north-west or north-north-west. The great Shar range (Ljubetes, 2,510 meters) runs throughout its length from Divra to Katchanik, to the north-east, but Professor Cvijić informs me that over the whole of this tract the rocks strike to the north-north-west, transverse to the mountains. The Alps of north Albania extend north of Ipek towards the north-east; but from Oestreich's observations it appears that here also limestone and Flysch strike transversely across the range¹. In like manner the lofty south-eastern watershed of the Kara Su (right tributary of the Vardar), runs to the north-east, but the mountains, according to R. Hofmann, are formed of trachyte².

Off the Adriatic coast, however, there is a manifest tendency to diverge from the north-west to the west-north-west and even to the west. This shows itself in the alinement, Corfu-Salmastraki-Othonos³, in the Acroceraunian promontory and Saseno, then, north of the gulf of Albania, in a yet higher degree in certain Dalmatian islands. Thus the whole Adriatic coast presents a coulisse structure, which is even apparent on the map. But towards the north the coulisses continue to advance until finally they reach Istria.

The second of these results is that towards the interior these Dinaric ranges occupy a very great breadth of country. The neighbourhood of Seres, perhaps also of Doiran, may still be claimed by the Archaean mass of Rhodope, but the whole valley of the *Vardar*, down to Salonica, or at least as far as lat. 41° 15' N., belongs to the Dinarides. R. Hofmann has shown that in this valley, south of the Tertiary basin of Uskub, schists, presumably Palaeozoic, crystalline limestone, serpentine, and then dolomite, probably belonging to the Trias, succeed one another with a strike to the north-west as far as the Flysch basin of Negotin, which farther down the valley again becomes bordered by dolomite of the same kind. Beyond this we reach the chain of trachyte already mentioned on the south-east side of the Kara Su; and south of this river R. Hofmann found some badly preserved Mesozoic fossils.

The *Kara Su* itself, in its course from Monastir to the Vardar, runs chiefly over limestone, which belongs probably to the vast limestone region

¹ K. Oestreich, *Reiseeindrücke aus dem Vilajet Kosovo*, Abhandl. k. k. Geogr. Ges. Wien, 1899, I, pp. 331-372, map, in particular p. 338 et seq.

² R. Hofmann, *Antimon-und Arsen-Erzbergbau 'Allchar' in Macedonien*, Oester. Zeitschr. für Berg- und Hüttenwesen, 1891, XXXIX, no. 16, map, pl. VI.

³ F. Patsch, *Die Insel Korfu*, Peterm. Mitth., *Ergänzungsheft*, no. 88, 1887, 97 pp., map.

observed by Boué as extending from Siatista through Veria to Niausta and Ostrovo; it contains Rudistes, as Boué discovered¹.

To the west of this region rises a series of granite outcrops. Micaschist is also mentioned, but further investigation is necessary before we can be sure whether we have here a complex of Archaean rocks or of igneous intrusions into Palaeozoic schists. The upper parts of the *Peristeri* at Monastir consist, according to E. Naumann, of granite; immediately to the south, the eastern side of the *Neritshka Planina*, near Florina, is formed of syenite, and still further to the south a rocky range of protogine extends up to the north-east shore of the lake of Kastoria².

No continuation of these rocks, either to the north or south, is so far known. To the north, above Uskub, is the *Ljubeten* in the Shar range, which was ascended by Griesbach, Neumayr, and Burgerstein, Zujović³, Cvijić, and Oestreich. Here, as in all the mountains north of Uskub, the stratified series presents first phyllite, next some quartzite, then a very thick mass of crystalline limestone which forms the summit of the Ljubetes, and is compared by Zujović to the limestone of mount Athos or Olympus; finally, towards the east, come calcareous shales and Flysch-like sandstone with massive bands of serpentine.

Further west also, on the lofty mountain of *Gjalitsh* (Jalish), near the confluence of the Black and White Drin (south-west of Prisrend), Boué mentions marble and phyllite, and from this neighbourhood, according to Cvijić, these rocks run with a strike to south-south-east transversely across the Shar range, follow the east shore of the Black Drin, and form the heights which separate the *lake of Ochrida* from the *lake of Presba*. Both lakes correspond to meridional fault-troughs, and the east side of lake Ochrida obviously corresponds to a fissure, with solfataras and recent eruptive rocks⁴. From this point, Herr Cvijić further informs me, the zone of marble and phyllite strikes towards Kastoria, bordering the east shore of the upper Bystritza, and at length, slightly diverted to the east, reaches the mountains above Trikkala and forms their outer edge⁵. For a considerable distance this long track coincides with the eastern border of the Tertiary gulf of Albania, the breadth of which above Trikkala lies between 20 and 25 kilometers.

¹ A. Boué, *La Turquie d'Europe*, Germ. edit., Vienna, 1889, I, p. 178; Rudistes and corals between Čardžilar and Ostrova.

² E. Naumann, *Macedonien und seine neue Eisenbahnlinie Salonik-Monastyr*, 8vo, München und Leipzig, 1894, 58 pp., in particular p. 46.

³ J. M. Zujović, *Contribution à l'étude géologique de l'ancienne Serbie*, *Annales géologiques de la Péninsule Balcanique*, 1891, III, pp. 124-135.

⁴ J. Cvijić, *Die macedonischen Seen*, ein vorläufiger Bericht, *Mitth. Ung. Geogr. Ges.* Budapest (Földt. Közl.), 1900, XXVIII, 16 pp., in particular p. 10 and communications kindly made to me in person.

⁵ Philippson, *Reisen und Forschungen in Nord-Griechenland*, III, *Zeitschr. Ges. Erdk.*, Berlin, 1895, XXX, p. 487, and map in 1896, XXXI, pl. 9.

Here begins the deflexion to the east. The ancient schists enter into the structure of the *Othrys* mountains, strike across the southern part of the gulf of Volo, through Skiathos and Skopelos, and encircling on the south the whole of that region which Philippson designated the crystalline mass of the north Aegæan¹ they finally reach Samothrace and the phyllite ranges of Kuru-dagh and Tekir-dagh on the gulf of Saros.

To the north-west of lake Ochrida, at the village of Rodažda, Cvijić found Jurassic limestone with *Phylloceras*. Beyond this rises a long and lofty range of serpentine which extends across the whole of Macedonia. According to Boué, the serpentine intrusions which occur between Prisrend and Scutari may be counted as among the largest in Turkey; I do not know whether they are prolonged to the south. The western shore of lake Ochrida is bordered, according to Cvijić, by serpentine and *Rudistes* limestone; the mountains run north and south; the strike of the rocks is north-north-west. The same long range of serpentine crosses the Tertiary gulf; Hilber encountered it between Kolonia and Goritza, and over the whole mountain range up to the group of Smolitsa (2,574 meters) and as far as the Zygos pass at Metsovo (east-north-east of Janina)².

Here, at the *Zygos* pass, there occurs an important division of the mountains. Continuing in the direction of the long band of serpentine this rock disappears, and the lofty limestone mountains of the Thessalian Pindus come in with an almost identical strike. A range of limestone suddenly takes the place of a range of serpentine. According to Philippson's interpretation, the limestone dips beneath the serpentine in a great flexure: Hilber appears to think, however, that the limestone range is deflected towards the west.

This limestone range, the *Pindus*, forms the largest of the Dinaric arcs. It does not follow the eastern deflexion to the *Othrys* mountains. At first it strikes almost south-south-east, then runs to the south and, as the limestone Alps of Aetolia, reaches the gulf of Corinth. Here it appears to have undergone a slight displacement towards the east along a transverse line of disturbance, which, beginning west of the gulf of Salona, runs west-north-west to the lake of Ambrakia³. The range is continued, however, in the Peloponnesus, and, according to Philippson, prolonged through the whole peninsula till it reaches the most southerly part of the gulf of Messenia. There its direction is south-south-east, and it turns through Cerigo and Cerigotto towards Crete and Rhodes.

¹ A. Philippson, *Tectonique de l'Égée*, p. 117.

² V. Hilber, *Geologische Reise in Nord-Griechenland*, &c., p. 620. Isolated points were previously known to Boué; their continuity has now first become clear.

³ Neumayr, *Denkschr. k. Akad. Wiss. Wien*, 1878, XL, p. 112; Philippson, *Zeitschr. Ges. Erdk.*, Berlin, 1897, XXXII, p. 273; Hilber, *Sitz. k. k. Akad. Wiss. Wien*, 1894, CIII, p. 592 et passim.

This great zone of limestone is bordered on the west, from its origin in the north to the south shore of the Peloponnesus, by a zone of more recent sandstone; on its east side also a similar zone of sandstone extends for a great distance.

Owing to the divergence of the meridional zone of mount Pindus from the south-east or east direction of mount Othrys, a broad intermediate space is formed inside the Dinaric arcs. In this space are inserted segments of arcs represented by limestone mountains, such as *Oeta* and *Parnassus*, first with a transitional strike to the south-east or south-south-east: then these also, as appears from the observations of Bittner and Teller, complete the bend to the east and north and strike across *Euboea*.

Further to the south, or rather further towards the exterior of the Dinaric system, ancient formations again emerge. *Attica*, south *Euboea*, *Andros*, *Keos*, and *Thermia*, and the succeeding islands as far as *Syra* and *Siphnos*, are formed of ancient schists and marble. The strike bends here to the north-east, in correspondence with the course of the great arcs. Already even in *Syra* and *Siphnos* albite gneiss appears as the foundation of the ancient schists; in *Tinos* still older gneiss crops out with a strike to the north-north-east, and gneiss and granite gneiss form the greater part of *Antiparos*, *Paros*, and *Naxos*¹.

Philippon regards this gneissose mass of the Cyclades as an ancient mountain core, which has determined to some extent the position and trend of the arc. In the schists the trend in an arc is clearly evident, and its continuation should probably be sought in those older rocks which have been referred to as occurring in the region of the Tauric syntaxis with a strike to north-north-east or north, in Chios, the Spalmatori, and Mytilene.

But, as appears from the description by Lacroix, a zone of ancient schists and marble also exists to the south of the gneiss of the Cyclades. To this zone the southern, non-volcanic part of Milos belongs, as well as *Polykandros* and the limestone mountain of Hagion Elias in Santorin².

Amorgos, formed of dark limestone, strikes to the north-east in the sense of the syntaxis.

It is a very remarkable fact that, far away from this region, in the north of the island of Cerigo, there exists, according to R. Leonhard's observations, a patch of ancient phyllite which strikes to the east-north-

¹ Philippon, Verh. Ges. Erdk. Berlin, 1897, XXIV, Sitzungsbericht vom 10 April 1897, Tectonique de l'Égée, p. 119; and Baron von Foullon and von Goldschmidt, Ueber die geologischen Verhältnisse der Inseln Syra, Syphnos und Tinos, Jahrb. k. k. geol. Reichsanst., 1887, XXXVII, pp. 1-34, maps; also F. Schafarik, Geologische Notizen aus Griechenland, Jahresb. k.-ung. geol. Anst. (for 1893), 1895, pp. 177-192, especially p. 189 et seq.

² A. Lacroix, Sur la constitution minérale de l'île de Polycandros, Comptes rendus, 1897, CXXIV, pp. 628-630.

east. It is overlain unconformably by the limestones which there strike south-east; and in the south of the island towards the east, in accordance with the course of the great arc which runs from the Taygetos towards Crete¹.

The volcanic arc runs through *Aegina*, *Methana*, *Poros*, *Milos*, and *Santorin* to *Nisyros*. It therefore lies for the greater part inside the region of the ancient schists, but leaves this region in the east to follow the course of the outer arc.

The transition to this outer arc takes place first of all through the limestone mountains of Argolis and Arcadia. In the neighbourhood of *Sparta*, Douvillé has discovered indications of the Trias². Thus we reach the great arc which sweeps from the Pindus mountains to Lycia, engirdling the whole archipelago.

The Pindus shows an easterly dip of the beds almost throughout its whole length, and the zone of sandstone which follows on the west shows a similar inclination; from this fact Philippon justly concludes that the whole of the Pindus range is overthrust to the west.

West of this range, in Epirus and the Ionian islands, follow other ranges of limestone and sandstone; Eocene, Cretaceous, and Jurassic have long been known in these regions; in Epirus Lias has also been found³. These are the ranges, formed of Rudistes limestone, which run boldly out into the Adriatic sea as the Acroceraunian promontory.

The Crossing of the Adriatic. From the neighbourhood of Elbassan, according to Boué, a long wall of rock runs through Krucia towards Dulcigno. It forms the edge of the Albanian gulf. At Dulcigno, north-east of the border of recent Tertiary deposits, Tietze met with Flysch which strikes north-west out to sea⁴. Inside the Flysch, i.e. on its north-eastern side, there rises a long range of limestone mountains with steep scarps, possibly the continuation of the rocky wall mentioned by Boué. This range forms near Scutari the southern border of the lake of Scutari, reaches the sea in very steep cliffs at Spizza, and proceeds towards the north-west far beyond Cattaro. Bukowski shows that from Spizza to beyond Budua this range is cut up into flakes which include the whole of the stratified series from the lower Trias to the lower Tertiary inclusive, and which are thrust over one another in a south-westerly direction, i.e. towards the sea⁵. At the same time there is intercalated

¹ R. Leonhard, Die Insel Kythera, Peterm. Mitth., Ergänzungsheft no. 128, 1899, map, in particular pp. 7 and 10.

² Douvillé, Sur une ammonite triasique recueillie en Grèce, Buil. Soc. géol. de Fr., 1896, XXIV, p. 799.

³ A. Philippon and G. Steinmann, Ueber das Auftreten von Lias in Epirus, Zeitschr. deutsch. geol. Ges., 1894, pp. 116-125.

⁴ E. Tietze, Jahrb. k. k. geol. Reichsanst., 1884, XXXIV, pp. 59-69.

⁵ G. von Bukowski, Ueber den geologischen Bau des Nord-Theiles von Spizza in

in the Trias a massive seam of norite porphyry and associated green tuff and tuffaceous sandstone. These are Bukowski's Dsurmani beds; they contain the characteristic fossils of Wengen and St. Cassian¹.

In the years 1862 and 1867 F. von Hauer described an eruptive rock from the island of *Lissa*, and some neighbouring reefs. Although the island consists of Cretaceous limestone, yet he pointed out that gypsum and tuffs also occur; and at the same time he compared these beds with a series known within the Trias on the mainland of Dalmatia, south of Knin, and marked on his geological map of the Austrian kingdom the occurrence of Trias at Lissa. Tschermak distinguished the eruptive rock as diallagite. Subsequently C. von Foullon described rocks from the adjacent islet of Scoglio Pomo as augite diorite².

Viola and Cassetti have shown that monte *Gargano* is an anticline independent of the Apennines, exposing upper Jurassic along the axis and striking to the north-west³.

The *Pietre Nere*, on the lago di Lesina, north-west of monte Gargano, consists of eruptive rock. This, as Viola and Di Stefano have shown, forms a dyke striking N. 25° E. in the direction of Lissa, and associated with a mass of Trias limestone which contains a fauna like that either of St. Cassian or Raibl. Gypsum also appears in the neighbourhood. The rock has been included among the lamphrophyres, under the name of 'garganite'⁴.

Süd-Dalmatien, Verh. k. k. geol. Reichsanst., 1896, pp. 95-191, Neue Ergebnisse der geologischen Durchforschung von Süd-Dalmatien, op. cit., 1899, pp. 68-77.

¹ G. von Bukowski, Zur Stratigraphie der Süd-Dalmatinischen Trias, Verh. k. k. geol. Reichsanst., 1896, pp. 379-385. The regular strike to the north-west exhibited by the mountains situated towards the interior is shown on K. Hassert's Geologische Uebersichtskarte von Montenegro, Peterm. Mitth., Ergänzungsheft no. 115, 1896, p. 1. At Trebinje (Herzegowina), according to Bittner, coal appears in the Raibl beds; Verh. k. k. geol. Reichsanst., 1900, pp. 145-148.

² F. von Hauer, Verh. k. k. geol. Reichsanst., 1862, p. 257: Prehnit von Comisa auf der Insel Lissa und Eruptiv-Gesteine aus Dalmatien, op. cit., 1867, pp. 89-91; Der Scoglio Brusnik bei St. Andrea, op. cit., 1882, pp. 75-77; C. von Foullon, Der Augit-Diorit des Scoglio Pomo, op. cit., 1883, pp. 283-286. As early as 1867 F. von Hauer drew attention to the Pietre Nere, which had been described by Tschihatschew.

³ C. Viola e M. Cassetti, Contributo alla geologia del Gargano (Boll. R. Com. geol. Ital., 1893, XXIV, pp. 101-129, map). The question as to whether the Murga must also be included in Dalmatia is discussed in detail in F. Virgilio, Geomorfogenia della Provincia di Bari (reprinted from La Terra di Bari, delib. del Consiglio Prov. per l'Esposizione di Parigi del 1900, vol. III); Trani, 1900, 148 pp., map.

⁴ C. Viola e G. di Stefano, La Punta delle Pietre Nere, presso il Lago di Lesina in provincia di Foggia, Boll. Com. geol. Ital., 1893, XXIV, pp. 129-143; C. Viola, Le rocce eruttive della Punta di Pietre Nere, op. cit., 1894, XXV, pp. 391-403, map; G. di Stefano, Lo scisto marnoso con 'Myophoria vestitva' della Punta di Pietre Nere, op. cit., 1895, XXVI, pp. 4-50. We may add that Bittner has discovered an extensive mass of augite-diorite, gabbro, and diorite within the Trias on the Narenta; Bittner, Geologische Mittheilungen aus dem Werfener-Schiefer und Tertiär-Gebiete von Konijica und Jabla-

Here the much discussed question again arises, whether the existing Adriatic sea was not partly occupied by solid land during some part of the Tertiary aera (I, p. 268). A large number of observations have confirmed the view expressed many years ago by Stache, that the island of Pelagosa is a remnant of a sunken sea-coast which once extended from Stagno (in the peninsula of Sabioncello) towards Lagosta, thence to Pelagosa and the Tremiti¹.

North of this line to about as far as Görz and Udine no trace of marine deposits, either Miocene or more recent, has as yet been found. According to Tellini's observations, the Cretaceous and Eocene limestones of the Tremiti are covered by deposits of the second and perhaps even the first Mediterranean stage². The more recent marine deposits known in Pelagosa belong undoubtedly to the lower part of the third Mediterranean stage; nevertheless it appears as though Stache's hypothesis might be extended. I regard the ancient coast-line *Stagno-Pelagosa-Tremiti* as a continuation of the coast-line mentioned above, which coming from the south-east reaches the existing sea at *Dulcigno*. This, however, corresponds to that north coast of the gulf of Albania which, as we have seen, once extended through Macedonia to beyond Trikkala. In this way we arrive at a boundary to the Adriatic, very different from that which it now possesses, but almost certainly in existence during the closing epoch of the Tertiary aera, or at an even yet later time.

The strike of the Dalmatian island, passes now from west-north-west to due east. This latter direction prevails in *Lesina*; Söhle found it predominant in *Brazza*, and Kerner also in that part of the mainland near Trau which lies north-west of *Brazza*, and there the folds striking east and west are in great part overthrust to the south³.

nica an der Narenta, Jahrb. k. k. geol. Reichsanst., 1888, XXXVIII, pp. 321-342, in particular p. 334; C. von John, Ueber die Gesteine des Eruptivstockes von Jablanica an der Narenta, tom. cit., pp. 343-354. Traverso and Nicoli, judging from the nature of the sand at Ancona, Pesaro, and Ravenna, believed they could deduce the presence of a sunken eruptive rock, Atti Soc. ligust. sci. nat. e geogr. Genova, 1896, VII, pp. 139-141; Artini has disputed this in Rendic. R. Ist. lomb. Milano, 1897, XXIX, p. 800.

¹ Stache, Geologische Notizen über die Insel Pelagosa, Verh. k. k. geol. Reichsanst., 1876, pp. 123-127; M. Grollier von Mildensee, Topographisch-geologische Skizze der Insel Pelagosa, Mitth. Jahrb. k.-ung. geol. Anst., 1885, VII, 135-152, map (also I, p. 268, note 1). On the Adriatic in general, see also E. Cortese e M. Canavari, Nuovi appunti geologici sul Gargano, Boll. R. Com. geol. Ital., 1884, XV, pp. 225-240 and 289-304; M. Canavari, Osservazioni intorno all' esistenza di una terraferma nell' attuale bacino adriatico, Proc. verb. Soc. tosc. sci. nat. Pisa, 1885, V, p. 151 et seq.; T. Fischer, Grundzüge der Boden-Plastik Italiens, Vortrag auf dem X. deutschen Geogr. Tage in Stuttgart, 1893, Verh. d. deutschen Geogr. Tages, pp. 39-53.

² A. Tellini, Osservazioni geologiche sulle Isole Tremiti e sull' Isola Pianoso nell' Adriatico, Boll. R. Com. geol. Ital., 1890, XXI, pp. 442-514, maps.

³ U. Söhle, Verh. k. k. geol. Reichsanst., 1899, pp. 319-325, and 1900, pp. 185-187; F. Kerner, Geologische Beschreibung der Küste südlich von Sebenico, Verh. k. k. geol.

It is true that more to the north the normal direction to the north-west reappears over the whole breadth of the mountains and adjacent islands; nevertheless we perceive that a considerable part of the Dinaric folds (Meleda, Curzola, Lissa, Lesina, Brazza, Trau) strikes out much further towards the centre of the Adriatic. But just as monte Gargano strikes to the north-west, completely abandoning the direction of the Apennines, so, according to Borcarelli, monte Conero forms near Ancona a Cretaceous anticline striking to the north-west¹.

Some of the Dalmatian folds mentioned above are unable to reach Istria; on the contrary, it is evident *that a large part of the gulf of Venice lies inside the Dinarides*.

At the same time, all the Dinaric ranges situated further north become deflected over a great breadth of country into that mountainous region extending far beyond lake Garda which is formed chiefly of limestone, and is deeply influenced by the peri-Adriatic lines (I, p. 236). As they bend into it they present towards the west Cretaceous and Tertiary Flysch: towards the east Trias limestone, for the most part with a basement which is presumably Palaeozoic. The overthrusts towards the Adriatic, which have been mentioned as occurring at Budua and Trau, are characteristic of this region also. We have already called attention to their existence at Fiume. In the region of the deflexion near Idria we may see, according to Kossmat in the mercury mine itself, flakes of Palaeozoic schist thrust over the Trias towards the south-west. Here also we see within the Trias that occurrence of eruptive rocks and tuffs which is so very characteristic of the whole Dinaric region².

The Tonalite zone. The area upon which we are now about to enter offers a very remarkable problem to our comparative studies. The Dinarides, which are moved mainly towards the south and present as a whole characters distinctive of the arcs marking the southern boundary of Eurasia, here approach the Alps, which are moved mainly towards the north, though in this region they are deflected in the direction of the Apennines.

Nature has here prepared a surprise for the geologist. *The Dinaric region is constantly separated from the Alps by a continuous zone of profound dislocation more than 400 kilometers in length, and characterized over considerable tracts by homogeneous intrusions of tonalite.*

Reichsanst., 1898, pp. 364-387. For Trau and Bua, see Kerner, op. cit., 1899, pp. 236-240, 298-317, 329-348.

¹ Bonarelli, Carta geologica del Monte Conero presso Ancona, Boll. Soc. geol. Ital., 1895, XIII, p. 2.

² F. Kossmat, Ueber die geologischen Verhältnisse des Bergbaugebietes von Idria, Jahrb. k. k. geol. Reichsanst., 1899, XLIX, pp. 259-286, maps; 'Das Gebirge zwischen Idria und Tribusa,' Verh. k. k. geol. Reichsanst., 1900, pp. 65-78, small map. Here also the traces of negative movement or of irregular surface appear before the Raibl stage.

On a map this zone shows clearly along two lines only, namely in the direction of the Judicaria valley and in that of the Gail valley. The recognition of the tectonic unity of this great cicatrice has gradually been brought about as the result of many admirable investigations, and it would be difficult to say to whom the merit of the synthesis is due. We were already able in the first volume of this work (I, p. 246) to discuss the tract running from the Adamello to the north-north-east, together with the bend near Meran, and its prolongations across the Brenner, as made known by Teller; and we followed it from the lake of Idro to the Penser Joch (west of the Brenner), a distance of 128 kilometers. At that time it was already possible to deduce further from Teller's work that the line of separation through Brunneck extended to Sillian; this would give a length of 210 kilometers. In 1893 Frech added to this the length of the Gail fracture, which amounts to 110 kilometers¹, and the total length thus became 330 kilometers. In the same year Löwl published his observations on the tonalite range of the Rieser-ferner, and Becke, supported by the observations of Löwl, those of Geyer in the Gail valley, and those of Teller in the east, was able to demonstrate the unity of the arc from the lake of Idro, through Meran, to the Bacher range, i.e. for a total distance of 420 kilometers². This unity was then made the subject of further observations, especially by Salomon³. I ought to add that the masterly descriptions of Teller and Geyer have proved of the greatest assistance to me in my attempt to present a general idea of this phenomenon⁴.

The question may be asked whether this great line of dislocation actually terminates on the lake of Idro.

At the south end of the Adamello we note (I, p. 240) the remarkable fact that the beds of the Trias are inclined in such a way that their youngest members dive beneath the eruptive mass, while the older ones lie

¹ F. Frech, Die Tribulaungruppe am Brenner in ihrer Bedeutung für den Gebirgsbau, Festschrift für F. von Richthofen, 8vo, Berlin, 1893, p. 100, maps.

² F. Löwl, Die Tonalitkerne der Rieserferner in Tirol, Peterm. Mitth., 1893, pp. 112-116, map; F. Becke, Petrographische Studien am Tonalit der Rieserferner, Tschermak, Min.-petrogr. Mitth., 1893, XIII, pp. 379-464, in particular p. 462.

³ W. Salomon, Ueber Alter, Lagerungsform und Entstehungsart der periadriatischen, granitisch-körnigen Massen, Tschermak, Min.-petrogr. Mitth., 1897, XVII, pp. 109-176, map. For the Iffinger (apart from older writings) see U. Grubenmann, Ueber den Tonalitkern des Iffinger bei Meran, Vierteljahrsschr. d. Naturf. Ges. Zürich, 1896, XLI b, pp. 340-353; Ueber einige Ganggesteine aus der Gefolgschaft der Tonalite, Tschermak, Min.-petr. Mitth., 1897, new series, XVI, pp. 185-196; E. Künzli, Die Contactzone um die Ulten-Iffingermasse bei Meran, op. cit., 1899, XVIII, pp. 412-442, map. Künzli sees contact phenomena only on the north-west border, and conjectures the presence on the south and south-west border of a posterior subsidence.

⁴ In particular F. Teller, Erläuterungen zur geologischen Karte, Blatt 20, XI, Eisenkappel und Kanker, und 20, XII, Prassberg an der Sann, Vienna, k. k. geol. Reichanst., 1898.

more towards the exterior. In addition, Salomon has discovered, deep in the eruptive mass, fragments of Trias limestone¹. Further to the south, towards Bagolino, Permian sandstone, quartz porphyry, and, finally, older phyllites, crop out from under the Trias and are continued to the west towards the upper val Trompia. At this point we have the very important observations of Bittner. It appears from these that the Judicarian fault actually descends in a straight line to the lake of Idro; its direction is south-south-west. But to the east of the fault we see some fractures which cut obliquely through the Trias mountains of the Etsch gulf (monte Gaverdina) and follow a direction more to the south-west. One of these fractures comes down through the val Ampola, reaches the Judicarian line near Storo, and is continued south of the Adamello into the upper val Trompia².

Bittner, not without reason, describes the western part of this fracture as the tectonic equivalent of the Judicarian fault. It looks, however, so like a continuation of the fault of the val Sugana that we might imagine the latter had again come to life. South of the upper val Trompia other flexures, in part overturned, succeed, as they do south of the val Sugana.

Further to the west, in the val Camonica, the Trias extends more to the north, but in the absence of data I can form no opinion as to the structure along its northern boundary. Generally speaking, there can be no doubt that the Mesozoic zone which spreads out along the southern border of the mountains as far as lake Orta is a direct continuation of that of the Etsch gulf and of southern Tyrol. A series of longer and shorter ridges of granite, granitite, and quartz diorite may be followed far to the west and south-west, and even into the neighbourhood of Biella. Whether these should be regarded as a continuation of the marginal cicatrice can hardly be determined with certainty at present, although their position is similar³. Towards the south they are accompanied by a zone of phyllites and gneiss-like schist; these are followed by porphyry, porphyry tuff, breccia, and red sandstone, and these again by the Trias, which shows a tabular or block-

¹ W. Salomon, Neue Beobachtungen aus den Gebieten des Adamello und des Süd-Gothard, Sitzb. k. preuss. Akad. Wiss., Berlin, 1899, pp. 27-41, in particular p. 36.

² A. Bittner, Ueber die geologischen Aufnahmen in Judicarien und Val Sabbia, Jahrb. k. k. geol. Reichsanst., 1881, XXXI, pp. 219-370, map, in particular pp. 220, 233, 360 et seq.; also 1883, XXXIII, p. 426. The sudden break in val Trompia is figured in my memoir, Ueber das Rothliegende im Val Trompia, Sitzb. k. Akad. Wiss. Wien, 1869, LIX, pl. I.

³ A granite range of this kind comes down to lake Como near the frontier at Bellano; E. W. Benecke, Erläuterungen zu einer geologischen Karte des Grigna-Gebirges, Neu. Jahrb. Min., 1884, 3. Beilage-Band, pp. 171-251, map and description of the granite by Cohen; T. Taramelli, Osservazioni stratigrafiche nella Valsassina e nella Valtorta, Rendic. R. Ist. lomb., 1892, ser. II, XXV, pp. 563-578. There are numerous observations referring to this region by Spreafico, Parona, Calderini, Taramelli, Porro, Artini, and Riva in the last volumes of the Rend. R. Ist. lomb. Milano and in the Atti Soc. ital. Milano.

like bedding like that in the eastern limestone range, and is traversed by flexures, folds, and faults.

From the west to this point we already see on the south border of lake Maggiore, then at Mendrisio, Lecco, and the lake of Iseo, the broad masses of Trias and Jurassic beds which are also well regarded as the beginning of the so-called 'southern limestone zone of the Alps.' In the Alta Brianza, says C. Schmidt, the structure is 'the result of a tangential thrust directed from north to south and a simultaneous subsidence of the southern parts of the mountains'¹. The same structure prevails in the Grigna range, and further to the east the forward march of the Etsch lines makes itself evident as far as lake Garda. But on the other side of the Etsch lines Schmidt's words hold true for the whole peri-Adriatic region.

West of Biella the structure is very different. Here extremely close and intense folding prevails everywhere. Many years of arduous labour were accomplished, before the Mesozoic age of the Pietre Verde zone was established by the happy discoveries of Franchi. We must already assign to the Alps the great amphibolite band which comes from the north side of the lago Maggiore and reaches the plain near Ivrea. The contrast between the gentle lie of the Trias on the upper Italian lakes and the close folding which begins in the neighbourhood of Biella is precisely the same as that observed near Brunneck between the south and north of the Puster valley.

The downthrow of the Trias on the Sesia has been described by Rasetti².

Granite runs from monte Orfano and the well-known quarries of Baveno on the lago Maggiore, towards the south-west; through Omegna on the north side of lake Orta, and through Cellio and Valduggia, it is cut through by the Sesia above Borgosesia, and is prolonged still further across monte Tovo in the direction of Biella. The ancient schists do not appear west of the Sesia. The broad zone of porphyry and red sandstone follows there immediately upon the granite. Upon the porphyry and sandstone lies, east of the Sesia, the mass of monte Fenara (899 meters), let down in places along fractures into this foundation, but as a whole inclined towards the north-east. At the base lies dark limestone; upon this, dolomite with Diplopores, 300 meters thick, and above it a platform of Lias. The dolomite may be seen much lower down, towards Grignasco (348 meters), in a little isolated patch near the south border of the porphyry zone. Even

¹ C. Schmidt, *Zur Geologie der Alta-Brianza*, *Compt. rend. du Congrès internat.*, 1894, pp. 503-518; E. W. Benecke, *Erläuterungen zu einer geologischen Karte des Grigna-Gebirges*, *Neu. Jahrb. Min.*, 1884, 3. Beil.-Band, pp. 171-251; also E. Philippi, *Beitrag zur Kenntniss des Aufbaues der Schichtenfolge im Grigna-Gebirge*, *Zeitschr. deutsch. geol. Ges.*, 1895, pp. 665-734, map, and *Geologie der Umgegend von Lecco und des Resegone-Massiv's*, *op. cit.*, 1897, pp. 318-367, map; H. Becker, *Lecco und die Grigna*, *op. cit.* 1897, pp. 690-692 et passim.

² G. E. Rasetti, *Il Monte Fenara di Valsesia*, *Boll. Soc. geol. ital.*, 1897, XVI, pp. 141-175, map.

west of the Sesia, south-west of Borgosesia, a similar little fragment of dolomite is wedged in between granitite and the porphyry zone.

This is the western end of the Trias of the Lake region. Let us now turn our attention once more to Tyrol.

As early as the year 1855 Emmrich recognized the fact that the limestone mountains of Lienz present more resemblance to the distant north Alps than to the closely adjacent mountains of south Tyrol¹. This has been confirmed by later researches. The marine Bellerophon limestone which in the south occurs above the Gröden sandstone, is absent north of the boundary line which extends from the Brenner to the Bacher. In the north we see the Bleyberg beds with *Pinacoceras floridum*, in the south the Raibl beds with *Myophoria Kefersteini*; and although, even quite recently, some traces of closer approximation between the two types of development have been found, such as the occurrence in the southern mountains of the genus *Tropites*, previously known only in the north, and the discovery of the Oolitic rocks of the north in the southern area of Cadore, yet there still remain a number of distinctive characters which separate the stratigraphical series on the two sides of the great zone of dislocation².

That part of the zone of dislocation which extends between the Brenner and the Bacher, over a distance of about 300 kilometers, is not only characterized by long fractures and tonalite intrusions, but also by the fact that it forms the boundary of the facies for several members of the Permian and the Trias.

In contrast to the west, where the Adamello, Iffinger, and also the Rieser-Ferner form considerable heights, the boundary in the east is frequently indicated by a valley or furrow. Over the valley rise up on the north and south the white walls of the Trias. They reveal no signs of a neighbouring shore. The tonalite rocks between them are younger than the Trias. Nevertheless certain members of the Trias present one facies in the north and another, very different, in the south.

The southern facies persists towards the west and south-west to the Judicarian line, and beyond this in the south away through the region of the Lakes. In this western tract it is impossible to make any comparison with the northern facies. The Cretaceous formation already exhibits, in the inset mountains of the Etsch for example, the southern development in the form of a well-stratified white limestone, so completely different from the transgressive patches of the Gosau limestone which stretch away

¹ H. Emmrich, Notiz über den Alpenkalk der Lienzer-Gegend, Jahrb. k. k. geol. Reichsanst., 1855, VI, p. 449.

² G. Geyer, Über die Verbreitung und stratigraphische Stellung der schwarzen *Tropites*-Kalke bei S. Stefano in Cadore, Verh. k. k. geol. Reichsanst., 1900, pp. 335-370. On the existence in the Raibl section of a facies recalling the Bleyberg beds, cf. Jahrb. k. k. geol. Reichsanst., 1867, XVII, p. 580.

from here to Carinthia. Here, where we are not immediately concerned with morphological classification but with the ground-plan of the edifice, *we must separate from the Alps all the mountainous country lying east of the Sesia, east of the Judicaria, and south of the Gail, and assign it to the Dinarides.*

This mountain land presents the following structure.

As the Dinaric ranges strike in from the south-east they are bounded on the north-east by the north-westerly continuation of those ancient ranges which run from the Rhodope mass through western Servia, and lift their last peak in the neighbourhood of Agram. The breadth of the space which the Dinaric ranges occupy between Agram and the sea-coast amounts to 120 kilometers, and far more if Istria and the islands are included. About 70 kilometers north-west of Agram lies the south border of the Bacher range, which stands like a corner pillar on the edge of the Alps¹. This broad opening between the heights of Agram and the Bacher mountains lies as it were in the shadow of the deflected Dinarides, as they swerve to the north-west. But through this opening there enter from the west, and as it were from the rear of the Dinaric chains, a number of long folds *having the almost easterly direction of the great zone of dislocation*; they proceed far out into the plain of south Styria and Croatia, and die away gradually beneath the Tertiary deposits. On the Save these ranges, according to Teller, are not folds except in small part, but steeply upturned strips which are bounded and separated by fractures. The same direction may also be plainly recognized within the higher mountains towards the west, nearly as far as Krainburg; and it appears as though the great lowland north-west of Laibach must lie close to the contact of the Dinaric lines and the lines of the Save.

The Dinaric strike in the peri-Adriatic region now turns from the north-west to the west, and finally to the south-west, while on the north border of the val Sugana fracture there rises up the horst of the cima d'Asta². North of this, the mighty porphyry mass extends to the border at Meran (Fig. 29, I, p. 245). In the Etsch gulf, however, between the western edge of the porphyry and the Judicarian line, arises a series of flexures or knee-

¹ C. Doelter, Bericht über die geologische Durchforschung des Bachergebirges, Mitth. nat. Ver. Steiermark, 1892, pp. 2-23; F. Teller, Über den sogenannten Granit des Bachergebirges, Verh. k. k. geol. Reichsanst., 1893, pp. 169-182; also Dreger, op. cit., 1894, pp. 247-250 and 1896, pp. 84-90; Teller and Dreger, bl. 20, XIII, Pragerhof; Pontoni, Tschermak, Min. petr. Mitth., 1895, neue Folge, XIV, pp. 360-374; Ippen, Mitth. nat. Ver. Steiermark, 1892.

² I still hold with Krafft that a greater age must be assigned to the granite of the Cima d'Asta. A. von Krafft, Das Alter des Granites der Cima d'Asta, Verh. k. k. geol. Reichsanst., 1898, pp. 184-189. Salomon regards it as much more recent, Periadriatische Massen, p. 194 et seq., and Ueber das Alter des Asta-Granites, Verh. k. k. geol. Reichsanst., 1898, pp. 327-332; the ancient schists of the Asta are discussed by Vacek, op. cit., 1896, p. 459 et seq.

like folds overthrust to the east-south-east which run down parallel with the Judicarian line to lake Garda, and then form monte Baldo beyond the lake, diverge fan-like from one another towards Verona, and terminate on the fault of Schio (I, p. 253). In the north they lie in the Trias, towards the south they sink down into the Cretaceous—at least those lying towards the east—and they die out in the Tertiary ranges of Verona and Vicenza.

These Etsch-lines present a certain resemblance to those of the Save. Both proceed with an independent and divergent direction, like rays, from the interior of the mountains. Both lose in intensity as they advance, and eventually vanish. Both are incompletely separated from the main region of the peri-Adriatic lines, the one by the cima d'Asta and the other by the heights of Agram. Finally both are influenced in their strike more by the corresponding direction of the great zone of dislocation than by the Dinaric, that is in this region, the peri-Adriatic direction.

Both these systems, lying at the two extremities of the peri-Adriatic region, appear to be secondary effects of yielding which, as it were, issue through side gates from the region in which the greater dynamic activities have play¹.

In the middle of the peri-Adriatic region, as far as its northern border, we meet with nothing that would correspond to the folds of the Etsch or of the Save. At Brunneck, as already pointed out, we are presented with the same contrast in the bedding as that which appears east and west of Biella. Here the extremes are brought to within a few kilometers of one another. The crushed folds of Trias on the Penser Joch (I, p. 247) lie directly north of the tonalite band which strikes from Meran towards the Brenner road. Similar crushed folds of Trias also appear east of the Brenner; Teller has described one of these at Inner-Villgratten, and a second crops out at Brunneck. This stretches north of Toblach as a series of white 'klippen' towards the east-south-east or almost due east. When from the heights above Toblach we look southwards across the Pusterthal on to the summits of the Croda di Antruilles, monte Cristallo and the Zwölfer Kofel rising boldly up from their broad foundations, we recognize at once the greatness of the sudden contrast. The Pusterthal lying at our feet marks the boundary between the Dinaric and the Alpine regions.

¹ The interest connected with a knowledge of the free ends has already been referred to, Chapter VII, p. 308, footnote. 'Si nous considérons alors la surface, comprimée ainsi peu à peu entre des mâchoires à contours irréguliers, cette surface ne se plissera pas partout en même temps. Les premières rides se formeront tout d'abord dans les régions où la compression sera plus forte. Ces rides s'étendront ensuite par un effet évident de continuité, des deux côtés du centre de plissement.' Zurcher, 'Sur les lois de la formation des plissements de l'écorce terrestre,' Feuille des jeunes Naturalistes, Paris, 1^{er} Sept. 1891, p. 2; also 'Note sur la structure de la région de Castellane,' Bull. Serv. Carte géol. France, 1895, VII, p. 325 et seq. The example chosen is certainly on a small scale, but it would be equally true on the grandest, even for the lateral prolongation of the Kuen-luen.

The crushed fold above Toblach belongs to the Alps; the array of white peaks in the south shows the broad, open, tabular bedding, and, at the same time, the southern facies of the Dinaric Trias. This is the edge of the peri-Adriatic caldron (I, p. 263).

But, as Teller has shown, the compressed band of Trias 'Klippen' near Brunneck and Toblach is the same as that which opens towards the east, passing thus, probably along with the adjoined Trias range of Inner-Villgratten, into the *mountains of Lienz*, which form the western end of the Gailthal Alps. The surveys of Geyer have not only confirmed this hypothesis, but have given us at the same time so exact a picture of this closely compressed and longitudinally fractured range that we are here able to recognize more clearly than anywhere else in the eastern Alps the relation of the 'root-like' bands to the continuous Trias masses. It may be that as a rule these 'roots' are, as in Switzerland, the crushed-in ends of synclines, but the fact that above Laas a band of Trias limestone, 10 kilometers long and only 400 to 500 meters broad, is split off along longitudinal faults of this kind and let down into the ancient schists of the foundation, shows that fault troughs are formed also¹.

With this structure the *Gailthal Alps*, formed of Trias and Jurassic rocks, extend between the Gail and the Drau as far as Villach; they then disappear for a very short distance beneath the floor of the valley and again crop out to the east of the mouth of the Gail. Their direction, originally almost east and west, has here turned a little more to east-south-east; later on it again becomes east and west.

These resurgent limestone mountains are the *northern Karawanken*; Teller shows that they are characterized by their northern facies and by long strike-faults, precisely like the Gailthal Alps². They run nearly to Windischgrätz, in south Styria. Here they break off against a basin filled with Oligocene deposits. But beyond the basin, near Ober-Dollitsch, is a great segment which clings to the south-west side of the Bacher range and is separated from the Archæan rocks by a sharp fracture; this still belongs to the Karawanken³. (Fig. 17.)

From Brunneck onwards to the fracture between the segment of Ober-Dollitsch and the Bacher range, the length of this Alpine limestone chain amounts to 260 kilometers. *The southern border of the Gailthal Alps and the north Karawanken is the southern border of the Alpine Trias.*

We have already seen that the boundary between the Alps and the

¹ G. Geyer, Ein Beitrag zur Stratigraphie und Tektonik der Gailthaler Alpen in Kärnten, Jahrb. k. k. geol. Reichsanst., 1897, XLVII, pp. 295-363, in particular pp. 361, 363; Ueber die geologischen Aufnahmen im Westabschnitt der Karnischen Alpen, Verh. k. k. geol. Reichsanst., 1899, pp. 89-117 et passim.

² Cf. for example, Teller, Erläuterungen zur geologischen Karte . . . Eisenkappel und Kanker, p. 78.

³ Teller, Erläuterungen zur geologischen Karte . . . Prassberg, passim.

Dinaric range lies near Toblach, in the Pusterthal. Neither at this point nor anywhere in the Gail valley is the boundary marked by intrusions of tonalite. The rectilinear continuation of the zone is represented in the Gail valley by a broad strip of ancient rocks and by the difference in the lie and the facies of the limestone mountains to the north and to the south of this band. *The intrusion has moved away from the boundary for a distance of about 9 kilometers towards the north; it forms a long band of tonalite running east and west in the midst of the Alpine region.*

We have already had occasion to mention the older works of Teller and the later ones of Löwl and Becke on this tract of country. According to Löwl the tonalite band consists of two masses each 4 kilometers in breadth; these are the *core of the Reinwald* and the *core of the Rieser* (Hoch Gall 3,440 meters); they are united by a narrow neck. Patches of gneiss rest upon them, like the fragments of roof overlying a laccolite. The Zinsnock forms a small apophysis on the south. The Rieser core is produced into a long and very narrow range which extends a long way to the east.

The total length from the western slope of the Reinwald core, at Taufers, to the most easterly extremity of the Rieser core, in the Deferegggen valley, amounts to 37 kilometers. Here the tonalite vanishes, apparently owing to overthrusting from the south; but some traces still persist much further to the east. Teller found such traces in the Iselthal and the Canaval, and at a yet greater distance, though still in the same direction, on the Graa-Kofel, in the Kreuzeck group¹. This would give, measuring from Taufers to this point, a length of about 85 kilometers. It is worthy of remark that eruptive rocks of precisely similar character again appear in the extreme east. They ascend as far as the Aptychus shales, which are probably Jurassic, and also penetrate the Archaean rocks of the Bacher range itself².

Future discoveries will probably reveal the existence within the Alpine region of a *second intrusive zone* of tonalite, extending from Taufers eastwards to the Bacher mountains, *parallel with the principal cicatrice*.

Let us return, however, to the main dislocation, i.e. to the Dinaric boundary.

Teller's works give us a very clear idea of the manner in which the eruptive rocks again crop out in the eastern parts of the boundary³.

¹ F. Teller, Ueber porphyritische Eruptivgesteine aus den Tiroler Central-Alpen, Jahrb. k. k. geol. Reichsanst., 1886, XXXVI, pp. 715-746, in particular p. 736; J. R. Canaval, Die Erzvorkommnisse von Plattach und auf der Assam-Alm bei Greifenburg in Kärnten und die sie begleitenden Porphyrgesteine, op. cit., 1895, XLV, pp. 103-124, in particular p. 104.

² E. Hussak, Ueber das Auftreten porphyritischer Eruptivgesteine im Bachergebirge, Verh. k. k. geol. Reichsanst., 1848, p. 247; Baron von Foullon, Ueber Quarzglimmerdioritporphyrite aus dem östlichen Kärnten, op. cit., 1889, pp. 90-96; F. Teller, Erläuterungen zur geologischen Karte . . . Prassberg, p. 154.

³ Among recent works we may mention: E. Reyer, Reiseskizzen über das Smekrouz-

The precise locality at which these rocks first emerge can hardly be determined, for in this region also it is masked by overthrusting directed to the north. First comes a narrow band of granite striking nearly east and west; this is joined on the south side by a band of schist greatly altered along the zone of contact (Sf, Fig. 16); still further to the east, this is joined southwards by a band of tonalite often converted by subsequent pressure into tonalite gneiss. These three bands, of which the third becomes later the most important, now run, closely united, in a straight line first to the east and then to the east-south-east. Their greatest collective breadth is 3-5 kilometers, and the total length, including an exposure near the foot of the Bacher range, is 58 kilometers. Towards the eastern extremity we find tonalite only. The granite is

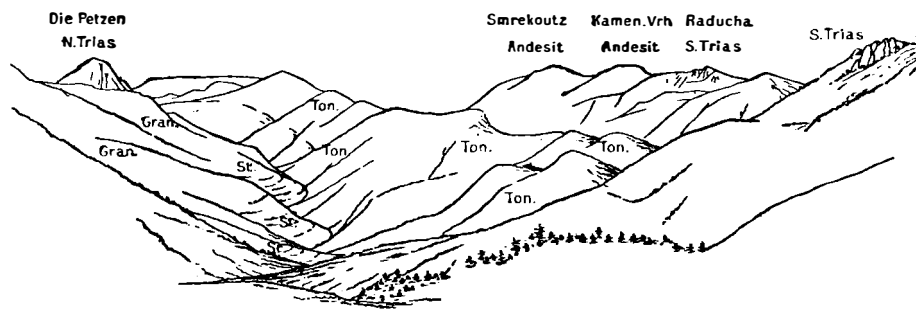


FIG. 16. View from the Uschova Saddle into the Miss-Valley.

the later intrusion, and forms a second injection in the same zone of dislocation. The visible breadth, particularly in the west, is determined by the overthrusting.

The total length of the line from the Judicaria to the Bacher range amounts to 420 kilometers. Of this distance a length of about 193 kilometers is marked by intrusions of tonalite. These are as follows:—(1) That of the *Adamello* (43 kilometers), very broad, slightly displaced towards the west and north with regard to the line of disturbance in the east (Judicarian line), and that in the south (line of the val Trompia), but still situated within the Dinaric facies of the Trias, the boundary of which is here unknown, though it certainly lies west of the Judicarian line. (2) The band of the *Iffinger* and the *Brenner road* (about 55 kilometers). This, it

Gebirge, Verh. k. k. geol. Reichsanst., 1878, pp. 296-298; H. von Graber, Die Aufbruchszone von Eruptiv- und Schiefergesteinen in Süd-Kärnten, Jahrb. k. k. geol. Reichsanst., 1897, XLVII, pp. 225-294, and the numerous publications of Teller on this subject, in particular Erläuterungen zur geologischen Karte . . . Eisenkappel, p. 120 et seq., and Prassberg, pp. 18 and 136.

would seem, faithfully follows throughout its course the dislocation and the boundary of the facies; on the Iffinger it increases somewhat in breadth, but is narrow elsewhere. (3) That of the *Rieser-Ferner* (37 kilometers) is displaced about 9 kilometers to the north. With respect to the line of dislocation, it lies entirely in the Alpine region, twice increases in the west to a breadth of 4 kilometers (Reinwald core and Rieser core), but is very narrow towards the east; if we include the isolated outcrops to the east, then its length up to the Kreuzeck group reaches 85 kilometers; but these, however, may belong to a parallel band lying more to the north. (4) The *eastern tract*, including the last outcrop near the Bacher range (58 kilometers); at first very narrow, it presents in the eastern moiety an almost uniform breadth of 1,800 meters; accompanied on the north side for a great part of its length by a parallel and more recent intrusion of granitite, which is very narrow, but, east of Koprein, expands in places to a breadth of 2 kilometers.

This intrusion, extending in an almost circular arc for a distance of over 400 kilometers, must be regarded, by reason both of its lithological uniformity and its tectonic position, as a single phenomenon, of the same age throughout. Consanguinity, in Idding's sense of the term, hardly comes in question, so uniform is the rock; its conversion into tonalite gneiss is due to subsequent movement. The later granitite of the east is doubtless derived from the same magma lake. In the east andesite also occurs, which is more recent than either the tonalite or the granitite.

Many kinds of eruptive rocks have made their appearance within this region since the Palaeozoic diabases. For these a reference to Brögger's observations may perhaps suffice¹.

The Carnic mountains. In the neighbourhood of Sillian, in Tirol, the western end of a mountain range becomes visible which, although situated within the marginal cicatrice, is yet independent of the Dinarides, and, like the cima d'Asta, older than these mountains. A glance at the map in vol. I, p. 245, shows a broad region of ancient phyllites between the northern edge of the porphyry and the infolded Trias band near Brunneck, which comes from the mountains of Lienz. It is very doubtful whether these are the same phyllites as those which occur further east. Above Sillian, Geyer encountered on the north side of the valley, not far from the wedged-in Trias band, the above-mentioned western end of a Palaeozoic zone which soon attains a considerable breadth, extends as the Carnic mountains along the south side of the Gail valley for 100 kilometers, and is continued still further to the east. South of the Rienz, above Sillian, this Palaeozoic series rests on quartzose phyllites, which, unlike the other rocks, strike to the south-east (Helmstspitz, 2,450 meters, Eisenreich, 2,664

¹ W. C. Brögger, *Die Eruptivgesteine des Kristiania-Gebietes*, 8vo, Kristiania, II, 1895, p. 154 et seq.

meters, &c.), reach Comelico, and do not finally disappear till they have proceeded almost as far as Forni Avoltri. Towards the north, in the Gail valley, a zone of mica-schist and gneiss lies in front of the Palaeozoic zone. This is followed towards the north by the northern Alpine Trias of the Gailthal Alps.

From Geyer's works we obtain the following¹:—

In the south, at Sexten, the Dinaric Trias lies fairly horizontal. The quartzose phyllites (Helmispitz, &c., and Comelico) and the Palaeozoic strata of the Carnic mountains belong to one and the same tectonic unit, and form in repeated scales a mighty range overthrust to the north. The mica-schists and gneisses in the Gail valley form an arch similarly overthrust, in places, towards the north. The Alpine Trias of the Gailthal Alps is also moved towards the north.

Further east, however, the conditions alter; the quartzose phyllites of Comelico have disappeared; Fusulina limestone of the upper Carboniferous rests unconformably upon the abraded Carnic folds.

The Carnic mountains are a chain, alien alike to the Dinarides and the Alps, with an independent strike, and of Variscan age; they are folded towards the north, and rise from beneath the Dinarides along the southern edge of the zone of dislocation.

These ancient mountains have been made the subject of many admirable studies; Stache discovered the first graptolites; Frech has made many valuable researches, especially with regard to the Devonian; Taramelli and his pupils have investigated the southern slope; and Geyer has made a detailed survey of all that region which is situated in Austria². The evidence so far afforded by fossils has enabled us to recognize in this range traces of the lower Silurian, both stages of the upper Silurian of Bohemia, various stages of the Devonian (including the *Clymenia* limestone); and, at one locality further east (Nötsch, near Bleiberg), the lower Carboniferous with *Productus giganteus*. Then follows the discordant upper Carboniferous³.

¹ G. Geyer, Ueber die geologischen Aufnahmen im westlichen Abschnitt der Karnischen Alpen, Verh. k. k. geol. Reichsanst., 1899, pp. 89-117; Zur Kenntniss der Triasbildungen von Sappada, S. Stefano und Auronzo in Cadore; op. cit., 1900, pp. 119-141.

² From the abundant literature on this subject I must content myself with mentioning the following: F. Frech, Die Karnischen Alpen, 8vo, Halle, 1892-1894, map; T. Taramelli, Osservazioni stratigrafiche sui terreni palaeozoici nel versante italiano delle Alpi Carniche, Atti R. Acc. Lincei, Rendic., 1895, pp. 185-193; G. Geyer, Ueber die geologischen Verhältnisse im Pontafeler Abschnitt der Karnischen Alpen, Jahrb. k. k. geol. Reichsanst., 1896, XLVI, pp. 127-234, map; Ueber neue Funde von Graptolithen in den Südalpen, Verh. k. k. geol. Reichsanst., 1897, pp. 237-252. On the relation to the eastern Alps in general: C. Diener, Grundlinien der Structur der Ostalpen, Peterm. Mitth., 1899, pp. 204-214.

³ For the stratified succession: G. Stache, Die palaeozoischen Gebiete der Ostalpen,

In the extreme west, the lowest horizon of the Palaeozoic series, of great thickness, and characterized by diabase¹ and green schists, forms the northern slopes and extends far over on to the south side, while the quartzose phyllites disappear. The structure has been described by Geyer. The upper Silurian lies in synclines, opening towards the north.

Somewhat further east the Devonian limestone also becomes visible in the synclines and forms the peaks of Paralba (2,692 meters) and Königswand (2,684 meters). The further we proceed to the east the deeper sinks the tectonic axis of the chain, for the lower members decrease, and the Devonian increases. Finally the whole of this older, closely folded structure dips beneath the horizontal transgression of the upper Carboniferous, upon which lies the Permian, and here and there, as on the Gartnerkogel, near Hermagor, an isolated patch of the southern Trias².

We may say that the whole range sinks towards the east, while towards the west it lifts itself out in the form of a wedge; and it so happens that this uplift occurs close to the place at which the Trias mountains of Lienz rise towards the west, leaving behind only the 'roots' of Brunneck and Inner-Villgratten.

Further to the east, from near Mauthen, in the middle of the Gailthal, to Hermagor and beyond, the following modification occurs. The lowest members, diabases and green schists, are no longer visible except on the north slope; but while the range is folded from south to north, these lowest members plunge perpendicularly down towards the foot of this slope, or incline towards the north, so that the totality forms an arch overturned towards the north, and sharply cut off on that side from the mica-schists of the Gailthal.

Yet farther to the east, a long and narrow zone of green schists and diabase makes its appearance to the north of the granite band, between this band and the Alpine Trias of the north Karawanken. It should probably be correlated with the lowest part of the Palaeozoic series; and there may be some reason for thinking that the schists with diabase, visible in the Missthal, somewhat further north, and in the midst of the Alpine region, should also be referred to the same horizon³.

I, *Jahrb. k. k. geol. Reichsanst.*, 1873, XXIII, pp. 175-248, and II, *op. cit.*, 1874, XXIV, pp. 135-274, map; the members of the Silurian are given by Stache in *Verh. k. k. geol. Reichsanst.*, 1890, pp. 121-126; also Frech, *Ueber das Devon der Ostalpen*, I, *Zeitschr. deutsch. geol. Ges.*, 1887, p. 659, and II, *op. cit.*, 1891, pp. 672-687, also *op. cit.*, 1896, pp. 199-201 *et passim*. For Carboniferous and Permian see the many works quoted in the following notes.

¹ Enstatite-porphyrite at one locality of the south side, according to Rosiwal, *Verh. k. k. geol. Reichsanst.*, 1895, p. 436; Milch mentions quartziferous porphyrites rich in feldspar (in Frech, *Karnischen Alpen*, p. 185).

² In particular Geyer, *Pontafeler Abschnitt*, pp. 127, 236 *et seq.*, and *Geologischen Aufnahmen*, 1899, p. 90.

³ F. Teller, *Erläuterungen zur geologischen Karte der östlichen Ausläufer der Karnischen und Julischen Alpen*, publ. in *k. k. geol. Reichsanst.*, 1890, maps, p. 46.

But in the east the typical outcrops of fossiliferous Silurian and Devonian are completely separated from the southern boundary of the Alps and the tonalite zone. They form, inside the Dinarides, a long and independent chain of hills which is nearly parallel to the tonalite line, but separated from it by the rocky ranges of Koschuta and Uschova, which belong to the Dinaric Trias. This Palaeozoic chain (Steuneck-Seeberg-Wistra-Sattel) is formed of folds which are either normal or overturned to the north, and is surrounded, precisely as in the west, by unconformable upper Carboniferous. As a rule it is regarded as forming a part of the east Karawanken; but under this name are included, from north to south, first an Alpine Trias range (Obir, Petzen, &c.), next the granite and tonalite zone (Kappel, Schwarzenbach), then a Dinaric limestone range (Koschuta, Uschova), and finally, this Palaeozoic chain with its border of upper Carboniferous. The merit of distinguishing the various members of the Karawanken must be ascribed to F. Teller¹.

The tract of country in which the presence of a folded Palaeozoic zone of greater age than the upper Carboniferous is known extends from Sillian to the Wistra Sattel, a distance of nearly 200 kilometers. It lies, with the exception of the doubtful outcrops in the Missthal, entirely within the Dinaric region, or in the region of the eruptive chain on its northern boundary. It is possible that the highly altered schists between the tonalite and granite (at the bottom of the valley in Fig. 16) also belong to it.

Transgression of the Dinaric sheet. In the Tsin-ling-shan, as in the oases of Kansu, and as in the whole region of the Variscan and Armorican arcs, we discover a profound unconformity, which is assigned sometimes to the upper Carboniferous, sometimes to the Permian. In the Yarkand arc an upper Carboniferous discordance presents itself in the Tekelik-tag, and further to the south, on the river Gussass, the unconformity has been placed in the Permian period as being probably contemporaneous with the discordance of the Productus shales which occurs over a considerable part of the Himálaya. We are now afforded a welcome opportunity of examining more closely into the nature of such a discordance.

The first matter to determine is the succession of the beds in the younger series.

We follow Frech in the view that the stage of *Spirifer mosquensis*, which marks the beginning of the unconformity in Asturias, has not yet been found in the Carnic mountains at the base either of this younger series, or any higher horizon; and again, following Frech, we designate the lowest visible member as (A.) *Auernigg-beds*, or zone of *Spirifer supramosquensis*, corresponding to the Gshel stage in Russia, and here alternating with beds which contain the flora of Ottweil (*Pecopteris*

¹ F. Teller, Die silurischen Ablagerungen der Ost-Karawanken, Verh. k. k. geol. Reichsanst., 1886, pp. 267-280 et passim.

arborescens, &c.¹). They are followed here by (B.) black limestone with *Schwagerina princeps*.

The third member is the light-coloured Fusulina limestone, frequently rose-red, in which, near Neumarktl in Carinthia, Schellwien discovered a rich fauna allied to that of Sosio in Sicily (*Agathiceras*, *Scacchinella*, and others). We term this, with Schellwien and Geyer, (C.) the *Trogkofel beds*². These are followed (as may be gathered from Geyer's observations on the succession), by that variegated quartz conglomerate (D.) the *Verrucano*, with an irregular distribution³. Above the Verrucano, and perhaps inseparable from it, lies (E.) the red *Gröden sandstone*, often containing pebbles of porphyry, Permian plants (*Walchia*), and, in its upper layers, gypsum. This is covered by (F.) the *Bellerophon limestone*; its fauna, first made known by Stache, is very peculiar (*Nautilus crux*, *Spirifer vultur*, and others); Diener has discovered Ammonites (*Paralecanites*) in it, but up to the present it has been found impossible to parallel it with other faunas⁴. It is succeeded by (G.) the *Werfen shales*, which doubtless belong to the Scythian division of the lower Trias. Above this lies the whole of that mighty series of marine Mesozoic strata which form the greater part of the Dinarides.

A. The *Auernigg beds* creep over the abraded Carnic surface, and the intercalated plant-bearing beds reveal the proximity of the shore. But Geyer has found that the superposition is not absolutely regular. On the contrary, it appears that local overlap probably occurs in places, for the upper beds of this stage come into immediate contact with the Devonian limestone, and in such a manner as to suggest that resistant masses of this rock, which had survived denudation, rose at this time above the ancient surface⁵. At Schwarzenbach the Auernigg beds reach the tonalite range, without, however, anywhere entering the Alpine region. In an easterly direction they remain visible as the foundation of the Dinaric series throughout southern Styria, over a great tract within the lines of the Save, and Rolle recognized many years ago that the iron ores of Weitenstein contain Carboniferous fossils.

Within the peri-Adriatic region the opportunity is frequently afforded

¹ *Lethaea geognostica*, I, *Lethaea palaeozoica*, 2. Band, 2. Lief, II, Die Steinkohlenformation, von Fritz Frech, 8vo, Stuttgart, 1899, pp. 354-364.

² E. Schellwien, Bericht über die Ergebnisse einer Reise in die Karnischen Alpen und die Karawanken, Sitzb. k. preuss. Akad. Wiss., Berlin, 1898, pp. 693-700; Die Auffindung einer permocarbonischen Fauna in den Ostalpen und die Fauna der Trogkofel-Schichten in den Karnischen Alpen und den Karawanken: I, Brachiopoden, Abh. k. k. geol. Reichsanst., 1900, XVI, pp. 1-122.

³ G. Geyer, Uggowitzer Breccie und Verrucano, Verh. k. k. geol. Reichsanst., 1899, pp. 418-432.

⁴ C. Diener, Ueber ein Vorkommen von Ammoniten und Orthoceren im südtirolischen Bellerophonkalk, Sitzb. k. Akad. Wiss. Wien, 1897, CVI, pp. 61-76.

⁵ Geyer, Verh. k. k. geol. Reichsanst., 1898, pp. 251-252.

us of observing the superposition of the Dinaric series upon older rocks, but nowhere do we see upper Carboniferous of marine origin. Such an opportunity presents itself below the northern basest edges of the Trias from Klausen onwards to the southern side of the quartz phyllites in Comelico, and of Forni Avoltri, or again along the fault of the Val Sugana and next to the eruptive rocks which are associated with the Adamello in the east and south, and in their probable continuation to the Sesia. Further, the basement is exposed in a 'window' near the middle of the southern border of this region at Recoaro, and in the Valli dei Signori. This term 'window' has been brought into use by our fellow geologists in Switzerland, and we shall adopt it in this work for those cases in which a subjacent tectonic element is brought to light by erosion—that is, where the local denudation has been sufficiently profound to cut through either a plane of unconformity or a thrust-plane. The superposition on the border of the Recoaro window has been made the subject of special study by Tornquist¹. Finally, at several localities in the east, and especially between the mighty limestone masses of the Menina and the Steiner Alps (north-east of Stein), schistose and gneiss-like rocks are exposed to view along faults and by erosion. The complicated structure thus revealed has been described by Teller².

At none of these numerous localities surrounding the peri-Adriatic region has a trace of marine upper Carboniferous hitherto been discovered. Nor is the lower Palaeozoic series of the Carnic mountains anywhere visible. To the north, in the Alps, we find in the Stangalp and the Steinacher Jock (Brenner) terrestrial plants which, according to Stur, are of upper Carboniferous age, but they are not known to me within the Dinaric boundary at a distance from the Carnic mountains; the outcrops of Assling, in upper Carinthia, belong to the neighbourhood of these ranges³, and those of Manno, near Lugano, are older, and are folded into the subjacent phyllites⁴.

C. The Trogkofel beds. These are light-coloured limestones, rich in fossils, and attain a thickness of about 400 meters in the Trogkofel. In these mountains they show a tendency to pass along a particular horizon into a breccia of angular blocks⁵. At more distant localities we often

¹ A. Tornquist, *Das vicentinische Triasgebirge*, 8vo, Stuttgart, 1901, 195 pp., map.; also A. Bittner, *Bericht über die geologischen Aufnahmen im Triasgebiete von Recoaro*, *Jahrb. k. k. geol. Reichsanst.*, 1883, XXXIII, pp. 563-634.

² F. Teller, *Der geologische Bau der Rogac-Gruppe und des Nordgehänges der Menina bei Oberburg in Süd-Steiermark*, *Verh. k. k. geol. Reichsanst.*, 1892, XXXIII, pp. 19-134.

³ D. Stur, *Obercarbonische Pflanzenreste vom Bergbau Reichenberg bei Assling in Oberkrain*, *Verh. k. k. geol. Reichsanst.*, 1886, pp. 383-385; Teller, *op. cit.*, 1899, p. 399.

⁴ C. Schmidt, *Allgemeine Darstellung der geologischen Verhältnisse der Umgebung von Lugano*, *Eclogae Geol. Helv.*, 1890, II, p. 6.

⁵ Geyer, *Jahrb. k. k. geol. Reichsanst.*, 1896, XLVI, p. 152.

find, in place of the thick limestone, nothing but this breccia. Stache had perceived its significance and determined its stratigraphical position at the very beginning of these investigations, and he named it the *Uggowitz breccia*. Since reefs in place are seldom met with, even within a very considerable distance, Teller unhesitatingly explains the breccia as due to breaking up of the limestone ¹.

The distribution of these Trogkofel beds and the Uggowitz breccia follows very closely that of the Auernigg beds; thus they extend eastward into the region of the folds of the Save, and do not broaden out any further to the south. The breccia, however, advances farther to the west. It was discovered by Hörnes near Sexten in Tyrol, about 100 kilometers west of the most westerly reef, and the sections which Geyer has given of the structure in this locality are in the highest degree instructive ².

Upon the quartz phyllite, which forms the south-west side of the band of Comelico, and at the same time represents the lowest member of the Carnic mountains, there rests at one locality a dark limestone which corresponds perhaps to division B.; at Matzenboden we see a distant but very small outlier of the quartz porphyry of Botzen, which occupies the north-west of the peri-Adriatic region. Over the porphyry lies the Uggowitz breccia, only 4–6 meters thick, and above this follow 150–200 meters of Verrucano, 200–300 meters of Gröden sandstone, gypsum, dolomites, and rauchwackes; and finally the Bellerophon limestone.

These facts enable us to fix the age of the porphyry, at least in part, with greater precision than hitherto. The outlier of the porphyry stream probably followed a line of depression; with this the considerable increase of the Verrucano and Gröden sandstone is in agreement; and the trifling thickness of the light-coloured breccia, which is not quite sharply separated from the Verrucano, becomes all the more striking.

D. *Verrucano* and E. *Gröden sandstone*. The Verrucano occurs in several scattered localities, while the Gröden sandstone broadens out over a wide area. We see it round the porphyry of Botzen and surmounting the heights of this rock (Ritten), in the Val Sugana, round about Adamello, and surrounding the window of Recoaro. Inside the Palaeozoic range, as for instance in the Achomitzer Berg, it rests directly upon the lower Silurian. There are few places in the whole region where the almost universal cover of Gröden sandstone is not visible, and even beyond the Dinaric boundary it forms the foundation of the Alpine Trias in the Gailthal Alps. It is towards the east only, namely in the direction of southern Styria, that it thins out.

¹ In particular G. Stache, *Die Stellung der Uggowitzer Kalkbreccie innerhalb der im Gailthaler- und Karawanken-Gebirge vertretenen Aequivalente der Permformation*, Verh. k. k. geol. Reichsanst., 1878, pp. 310–315; Teller, *op. cit.*, 1899, p. 410.

² R. Hörnes in E. von Mojsisovics, *Die Dolomit-Riffe von Süd-Tirol und Venetien*, 8vo, Wien, 1879, map, p. 297 et seq. Geyer, *Uggowitzer Breccie und Verrucano*, Verh. k. k. geol. Reichsanst., 1899, pp. 418–432.

The Gröden sandstone, however, is not a marine deposit. The only organic remains which it has furnished, and these chiefly at its base, are terrestrial plants, while above gypseous marls and gypsum frequently occur. The predominating characters are those of the Gobi series. They indicate a continental formation—deserts and pools without outflow.

The great overcovering by the Gröden sandstone corresponds to a period of retreat of the sea. It took place under conditions altogether different from those of the marine transgressions, and in particular under different relations to the relief of the land.

F. *The Bellerophon limestone.* When the sea returned later on conditions had completely changed, and the distribution of this stage differs therefore from that of the earlier marine deposits; the extension towards the east is more especially wanting.

The Bellerophon limestone does not enter the Alps; Diener defines the limits of its typical development as follows: to the west, Gröden; to the north, the Pusterthal; Recoaro and the Val Sugana to the south, and the neighbourhood of Tarvis to the east¹. I know of no locality where in the absence of the Gröden sandstones the Bellerophon limestone exists. Its distribution appears to be best explained by a southerly communication with the sea.

G. Between the Menina and the Steiner Alps, and further towards the east, in the direction of the folds of the Save, the transgressive series begins with the *Werfen shales*, as in the greater part of the north-eastern Alps.

At the head of a summary of the results so far obtained stands a general observation. *The Dinaric sheet may begin with any stage, from the Auernigg beds to the Werfen shales, but from the date of this horizon onwards up to a comparatively late epoch no tectonic discordance is visible.* Inequalities may have been caused by the flows of quartz porphyry, by the tuffs of the Wengen stage, and by other circumstances; but a general mountain movement is not perceptible within the series. The patches of Neocomian on the Croda d'Antruilles, for instance, are let down in a fault-trough, but they stand in concordant sequence with their normal foundation, and this concordant sequence extends throughout the Etsch gulf into the beds of Schio.

It is an obvious and very natural deduction that the *transgression took place over an uneven surface*. From the presence of the quartz phyllite in the window of Recoaro, and the absence of the upper Carboniferous transgression at this locality, Tornquist concluded that Recoaro, even in the Palaeozoic æra, must already have formed a high-lying mass, as compared with the northern areas, and this was perhaps prolonged into the Adriatic region. The age of the phyllite of Recoaro is unknown; but we

¹ Diener, *Ammoniten in Bellerophonkalk*, Sitzb. k. Akad. Wiss. Wien, 1897, CVI, p. 73, note.

can hardly avoid the conclusion that the mighty beds of Silurian and Devonian, the remains of which are preserved in the Carnic mountains, had already been denuded away over a considerable area at a very early period. Upon the quartz phyllites of Comelico lie the porphyry and the Uggowitz breccia, while on the other side of the valley the same quartz phyllites are covered by the Silurian. Nor must it be forgotten that in the west, near Manno, the plant-bearing middle Carboniferous is folded conformably into the phyllites.

The surface certainly appears to have presented considerable inequalities, and the northern region seems to have lain at a lower level. In the light of existing observations we may recognize the following order of events:—

First, the upper Carboniferous sea must have entered from the east between the range of Agram and the Bacher mountains, and have formed a long gulf in the northern part of the existing Dinarides, partly surrounding and partly covering the Carnic chain, which bore upon its ridges the flora of Ottweil, and furnished from its quartz phyllites the white quartz of the upper Carboniferous conglomerates. When the Trogkofel beds were in course of deposition (i. e. at the time of the fauna of Scacchinello), the situation must have been practically the same, and if we may suppose that the Uggowitz breccia at Sexten is their direct continuation, it follows that the gulf had been elongated towards the west, and a part of the quartz porphyry had already poured out over the country. Thereupon continental conditions obtained, and the mantle of Gröden sandstone and gypsum was formed as the floor of a desert. Next the sea of the Bellerophon limestone probably came in—apparently from the south—and this was succeeded by a preponderating, but not quite continuous positive displacement of the strand (during the deposition of the Raibl beds, for instance) which lasted for a very long period, and created the mighty sedimentary covering with its conformable sequence.

Thus although the unconformity may begin at various horizons, from the stage of *Spirifer supramosquensis* to the Werfen Shales, yet within this period no signs of any serious tectonic alteration can be perceived.

Later movements. From the conformable sequence of the covering, it is also clear that the dislocations by which it is at present traversed must be comparatively recent. They are indeed not of great age, but they are of different ages, and they are also of different kinds.

The question which first arises relates to the age of the tonalite cicatrice. Salomon has attempted, with no small degree of ingenuity, to show that the intrusion took place either during the Cretaceous epoch or at an early stage of the Tertiary æra, and has pronounced later in favour of its Tertiary age; whilst Lepsius does not regard the hypothesis of so recent a date as well founded¹. In the Adamello the only

¹ Salomon, *Periadriatische granitkörnige Massen*, p. 36; *Neue Beobachtungen*,

certain conclusion to be obtained from a close examination of the facts is that the tonalite is more recent than a considerable part of the Trias. In the east we learn a little more. If, as is probable, the porphyritic rocks of Prävali in Carinthia are to be regarded as contemporaneous with the tonalite, the intrusion, according to Teller, cannot have taken place before the latter part of the Jurassic epoch. Teller further shows that the Alpine limestone range of the north Karawanken breaks off transversely at its eastern termination near Windischgrätz, in southern Styria, and that the Gosau limestone rests against the fracture in a manner which shows that it is of later date. This fracture does not, it is true, quite reach the tonalite, and Teller draws no further conclusion with regard to its age, but the condi-

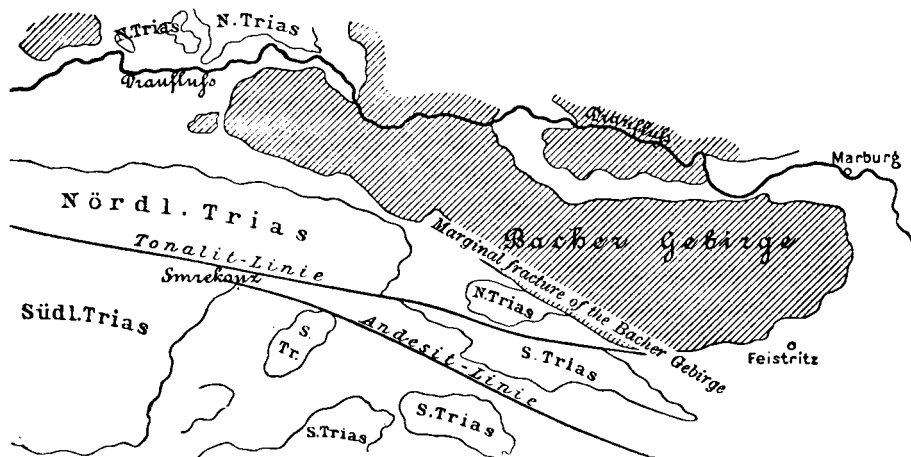


FIG. 17. Diagram to show the relationship of the tonalite-line to the Bacher Gebirge. (Based on F. von Hauer's sketch map of Austria and Teller's detailed map, sheet Prassberg.)

tions at the time of the Gosau limestone appear to have been already similar to those of the present day¹. Finally the andesite of Smekrouz lies directly upon the denuded surface of the cicatrice. This andesite is younger than the horizon of Castel Gomberto, and older than the Aquitanian lignites with *Anthracotherium magnum*; in the tuffs accompanying it *Anenchelum* is found. The andesite forms one of a long train of andesitic outcrops, which begins close to the tonalite, and, running to the south-east, cuts obliquely through the folds of the Save (Fig. 17).

That the movements are of various ages may be deduced from the behaviour of the Tertiary beds. In the midst of the eastern limestone

Sitzb. k. preuss. Akad. Wiss., Berlin, 1899, pp. 35, 38; L. Lepsius, Ueber die Zeit der Entstehung der Tonalit-Masse in Süd-Tirol, Notizbl. Ver. f. Erdk., Darmstadt, 1898, 4. Folge, 19. Heft, pp. 50-55.

¹ Teller, Erläuterungen zur geologischen Karte . . . Prassberg, p. 154; also pp. 68 and 146.

range we find ingressions, which presuppose valleys; as a rule they begin with the horizon of Castel Gomberto; in the fault-trough of Polschizzo, north-west of Krainburg, I have observed the underlying Laverda stage. Nevertheless, further east, Mediterranean beds have been carried high up and folded in the lines of the Save, like the Schio beds in the Etsch folds.

But apart from these divergent lines and apart from cross fractures of secondary importance, the whole region under consideration is dominated by two movements.

The first is the step-like subsidence towards the Adriatic, and the tendency to overthrusting in the same direction. We may add to the description already given of these movements (I, p. 236) that they are equally manifest north of the Asta faults, and on a grander scale than was then acknowledged. In particular Salomon has found that the whole mass of the Marmolata is driven in overthrust flakes to the south¹.

The second, and completely different movement, is seen in the north, especially from Sexten and Comelico to far away in the east. It has already been mentioned that the ancient Carnic range is intensely folded towards the north. We might almost imagine that the movement in this early direction had reawakened. It rules not only in the Archaean rocks of the Gail valley, but encroaches farther to the north; and the Alpine Trias of the Gailthal Alps everywhere exhibits, according to Geyer, the effects of its action². Even the eastern prolongations of the tonalite of the Rieser-Ferner, in the Deferegggen valley, are overthrust to the north³. The eastern continuation of the Carnic mountains (Stegunek) is also overthrust to the north; and there too the movement is continued northwards across the Dinaric boundary; the tonalite has assumed a gneissose structure, and at several places the Dinaric Trias is clearly thrust up from the south on to the tonalite. North of the tonalite, in the Vellach valley, near Kappel, the whole Alpine Trias is overthrown to the north. But in this valley, as we proceed towards the south, we perceive a knee-like bend in the Trias: the higher part is overthrust to the north and dips to the south; the lower part lies normally and dips to the north, so that at one place on the east side of the valley we see a dip to the north, and on the west side a dip to the south, as though the overthrusting had come from above and had only affected the upper beds⁴.

¹ W. Salomon, *Geologische und palaeontologische Studien über die Marmolata*, *Palaeontographica*, 1895, XLII, 110 pp., maps.

² Geyer, *Jahrb. k. k. geol. Reichsanst.*, 1897, XLVIII, p. 363 et passim.

³ Teller, *Porphyritische Eruptivgesteine*, *Jahrb. k. k. geol. Reichsanst.*, 1886, XXXVI, p. 736.

⁴ The knee-bend was described and figured in E. Suess, *Aequivalente des Rothliegenden*, *Sitzb. k. Akad. Wiss. Wien*, 1868, LVII, p. 289, pl. II, fig. 1; Teller has described the local contrast between the two sides of the valley in *Erläuterungen zur geologischen Karte . . . Blatt 20, XI, Eisenkappel und Kanker*, p. 77.

Thus for a distance of more than 200 kilometers the northern border of the peri-Adriatic region is dominated by the movement to the north in complete contrast to the movement towards the south which prevails elsewhere. I may here repeat the conjecture that the movement to the north stands in some causal connexion with the inter-Carboniferous folding of the Carnic range in the same direction. It nowhere appears to find expression far southwards of this ancient range and its eastern prolongations; on the other hand, it is undoubtedly propagated fairly far to the north, across the tonalite band into the neighbouring part of the Alps.

The question arises as to the mode of encounter of these two opposed movements, the peri-Adriatic and Dinaric movement directed towards the south, and the Carnic movement directed towards the north. We should expect to find a fan or something similar. But the actual arrangement is quite different.

At Pontebba we see merely a very steep contact between the upper Carboniferous and the Trias (Zirkelspitzen, I, p. 266, fig. 36) on the south border of the ancient range; and these formations are followed towards the south, on the other side of the valley, by the great peri-Adriatic limestone masses moved towards the south. This appears to be the case in the whole western half of the region; it is otherwise in the east. In order to describe the structure let us take a section from north to south through the middle of Teller's map of Eisenkappel.

In the north lies the Alpine Trias; south of this follows a narrow zone of green schists, next comes the band of granitite, then the schists, altered by contact, and just a little east of this the tonalite also appears; continuing towards the south, we meet first a narrow band of Dinaric Trias, then the upper Carboniferous, followed by the unconformity, and beyond this the Silurian and Devonian of the ancient range, Stegunek-Seeberg, which belongs to the Carnic mountains. *All these zones are overturned towards the north.* Against the south side of the Stegunek-Seeberg range is laid the first of the broad limestone segments of the south. These are the *Steiner Alps*.

They form a typical limestone mass of Dinaric Trias, steeply bounded, about 2,000 meters high, and covering a square space of from 15 to 17 kilometers in the side. The great fragment of Trias shown in the southwest corner of Fig. 17 belongs to this mass. *Their broad northern side has followed the Silurian substratum, and shows the effects of the movement towards the north.* But *their southern side is overthrust towards the south*, so that the Trias rests on an overthrown Tertiary series, at the base of which *Ostraea fimbrioides* occurs¹.

¹ I have found this *Ostraea* in the strata of the fault valleys above Sidrasch, north of Ulrichsberg; it is usually accompanied by *Cerithium margaritaceum*. For the northerly movement, see Teller, Blatt 20, XI, Eisenkappel, pp. 4, 110.

On the north, therefore, this great limestone mass has been driven like the Carnic chain northwards; on the south, in the opposite direction, like the peri-Adriatic area. But in the process it has neither been extended nor compressed into a fan. *These movements cannot have taken place simultaneously.* The Steiner Alps were moved first as a fairly rigid mass towards the north, and then, at another time, towards the south. That this interpretation is correct appears from the fact that the northern boundary of the southward movement is not regular, so that west of the Steiner Alps, Teller has already found further to the north overthrusts directed to the south ¹.

The southward, peri-Adriatic movement was probably the more recent of the two, and it is extremely likely that the northward movement is even older than the transverse fracture of Windischgrätz against which the Gosau limestone is deposited. But it is also conceivable that the two movements occurred alternately.

These details show that the tonalite cicatrice, which coincides with the boundary between the Alpine and Dinaric type of the Trias, indicates undoubtedly very great mountain movements, but that nevertheless subsequent movements have not been impeded by it in the least degree.

¹ Teller, Das Alter der Eisen- und Manganerzführenden Schichten im Stou- und Vigunšca-Gebiete, Verh. k. k. geol. Reichsanst., 1899, pp. 396-418. Here Aquitanian plant-bearing sediments are folded together with those of the upper Carboniferous.

CHAPTER IX

NORTHERN EUROPE ¹

The watershed of Aral-Irgis. Relations of the Urals to the Caucasus. Ufa. Folded ranges between Ufa and the Arctic Ocean. The pre-Cambrian platform. Its continuation in the Baltic shield. Its continuation in south Russia. Relations with the Sayanides. The Caledonian lines. The Scandinavian overthrust. Theoretical considerations. Relations of Scandinavia to Scotland. Conclusion.

IN this chapter we shall endeavour to investigate the connexion which may exist between the trend-lines of northern Europe and those of Asia. The region we are about to study may be divided into three parts: the Urals, the Russian platform, and the faulted zone of Scotland and Scandinavia. Each has already been described, the Urals in particular (I, p. 501), but our conception of the region, even as regards some of its principal features, has been modified by subsequent investigations, and hitherto we have not been in a position to discuss the relations of the Urals to the structure of Eurasia in general. The Archaean foundation of the Russian platform has as yet been scarcely considered, and important questions were left open (II, p. 53) in regard to tectonic phenomena in the west of Scandinavia to which a more definite answer can now be given.

Of the three parts, the second—the central Archaean platform—is the oldest; the Baltic shield, Sederholm's Fenno-Scania, belongs to it. The glint round about the shield shows that its folds had already been denuded in pre-Cambrian times, precisely like those far away to the east on the margin of lake Baikal. In south Russia this ancient platform breaks up into fragments, between which the lines of disturbance described by Karpinski strike to the west-north-west (I, pl. V, m.m.); further west it sinks beneath the Carpathians (I, p. 187); still further on it is concealed by more recent sediments, and its relations with the outer border of the Variscan arc cannot be seen. But the platform is undoubtedly older than this border, and towards the north-west it disappears under the pre-Devonian undulations of western Scandinavia. The strike of the folds, except in the Caledonian fragment of Scotland, is everywhere directed towards the ancient platform. It is therefore uncertain how far the platform itself, which can be traced as far as Bornholm, may extend towards Belgium beneath more recent sediments. At the same time it has maintained its own pre-Cambrian folding, uninfluenced by any of the later movements which have taken place almost all around it.

This ancient platform, though its orographic features are never

¹ Revised by the Rev. Professor T. G. Bonney, Sc.D., LL.D., F.R.S., Fellow of St. John's College, Cambridge.

important, occupies a larger part of the surface of Europe than any other tectonic element.

The watershed of Aral-Irgis.—Karpinski's beautiful map of the east slope of the Ural mountains shows clearly that the Uralian rocks and folds, deprived by denudation of all the relief of a mountain range, still exist a long way towards the east, where they may be observed in the river valleys beneath a thin covering of sediments, chiefly of Tertiary age¹. This relation may be traced from the Tura to the Tobol, and if we refer to the observations of Krasnopolski, made along the course of the latter river, we shall find that the remnants of the Urals are exposed along the banks of the Ajat and Tobol almost as far as the confluence of these rivers, where they underlie Angara and Senonian beds².

In latitude 53° N. we can trace Uralian folding from long. 56° 20' E. to about long. 63° E., and, speaking generally, *no boundary has yet been discovered towards the east.*

In connexion with this great extension in breadth there is a divergence in strike, opening out towards the south. West of Orsk, Muschketow notes a strike to the north-north-east in the older rocks; in the Mugodjars the strike runs as a rule from north to south. In the basin of the river Ural, Stuckenberg observes frequent deviation to the north-north-west³; on the Tobol, above the Ajat, Krasnopolski records a strike to north-north-west (355° to 305°); the crystalline limestone at Troitzk runs, according to Melnikow, in a north-westerly direction⁴. This fact appears clearly enough on the maps, and again raises the question whether some connexion may not exist between the Urals and one of the branches of the Thian-shan virgation.

This conjecture is not new. Even in the eighteenth century the range of 'Alginsk' or 'Ayaginsk' was mentioned as the link connecting the Urals with the 'Soongar range coming from India.' But this is shown to be an error by the scanty observations of Bardanes, said to be the only traveller who has seen this range, as well as the place where it is marked by Georgi, between the rivers Irgis and Ulkai-jak⁵.

In more recent times Muschketow thought it probable that a broad fold, like that of the Tarbag-atai, occurs on the Aral-Irgis watershed (I, p. 501). Karpinski and Tschernyschew were inclined to regard as a slight indication

¹ A. Karpinski, *Geologische Karte des Ost-Abhanges des Ural*, 3. Bl., fol., 1884.

² A. Krasnopolski, *Account of geological researches in the mountainous regions of West Siberia in 1893*, *Gorn. Journ.*, 1894, II, p. 53, and *Geological researches in the basin of the Tobol*, *Djel. Dor.*, 1899, XX, 50 pp., map.

³ South part of sheet 139 of the geological map of European Russia; A. Stuckenberg, *Bull. Com. géol. Russie*, 1896, XV, p. 249, 1898, XVII, pp. 172, 175, &c., *passim*.

⁴ M. P. Melnikow, I, *Geological excursion on the rivers Uvelka and Uya in the circle of Troitzk*, *Mater. Geol. Russ.*, 1889, XIII, pp. 251-375.

⁵ J. P. Falk, *Beyträge zur topographischen Kenntniss des russischen Reiches*, 4to St. Petersburg, 1785, I, pp. 364 and 380.

of this kind ¹ some ranges of the Urals which strike to the south-south-east, among them the Ui-tash on the east side of the Ural-tau (lat. 54° 40' N.).

Let us now attempt to ascertain what indications of such a connexion are actually known to exist.

Towards the south, Borszczow has traced the diorite of the Mugodjars to the river Tshegan (about lat. 46° 30' N., north-west of the sea of Aral) ².

Towards the south-east, Muschketow has travelled along the whole line to the point where the Thian-shan begins to branch. He traced a series of exposures of syenite, granite, and ancient schists from the steppe which extends south of Orsk to the settlement of Karassai (about lat. 49° N., north-west of the town of Irgis). At that spot these traces of the Urals disappear beneath Cretaceous deposits, containing *Protocardium hillanum*, and bounded by a line which runs from the hill of Aigyr-Baital (north of the sea of Aral) into the neighbourhood of the town of Irgis and the village of Djalabil, situated to the south-west of this town. Rocks of Cretaceous age, wherever the Tertiary deposits are absent, form the lower substratum of the desert which extends towards the Sir-darya.

The continuity of the observations is interrupted by this desert. Beyond it, some 40 kilometers north of Kasalinsk, the Cretaceous formation reappears: it may be seen in the valley of the Sir-Darya between Kasalinsk and Karamaktshi, as well as on certain hills lying north of the river. Then follows, as far as Perovsk, the great marsh of Bakaly-kon, on the north side of the Sir-darya; and beyond it, east of Perovsk, we approach the mountains of Daut-Khodsha and Djitim-tiube, which are the most northerly spurs of the great Kara-tau, and therefore belong to the branch proceeding from the Thian-shan south-west of Aulieta (Pl. IV) ³.

The result of our inquiry is as follows:—

The southern parts of the existing Ural mountains represent the western portion of a very extensive folded region, which in the east is completely levelled by denudation and covered by the deposits of the west Siberian plain. Its folds run, towards the south, across the Gubernskii mountains and the Mugodjars, and north of lat. 46° N. sink, as they

¹ Karpinski and Tschernyschew, sheet 136, Mém. Com. géol. Russie, 1886, III, 2, 82 pp., in particular p. 73.

² Tchagan, Tchegan, or Tchassan, cf. I, p. 501; Geological observations by N. Sjwertzow and J. Borszczow in the western part of the Khirgiz steppe in 1857, Gorn. Journ., 1860, II, pp. 300–318, in particular p. 310; also Suess, The Face of the Earth, I, p. 501, note 1. Even north of the Caspian traces of naphtha are mentioned at several localities, especially on the Uil; Nikitin, Izvestija Imp. ross. Geogr. Obsch., 1893, XXIX, p. 630.

³ Muschketow, Turkestan, I, pp. 324, 327. Sjwertzow says that neither mountains nor hills are to be seen on the Irgis, but the rocky banks of a river valley, Bull. Acad. Imp. Sci. Saint-Petersb., 1862, IV, p. 484. Also Romanofski, Mater. Geol. Turkestan, 1880, I, pp. 45, 59, and Romanofski and Muschketow, Geologische Karte von Turkestan, sheet 1.

decline in height, beneath the steppe and the platform of Ust-Urt. Certain parts of the zones which succeed on the east, now almost completely planed down, are continued along the river Or, a little north-west of the town of Irgis. In the same direction, but separated by the Cretaceous formation and the desert, the spurs of the Kara-tau appear in the south-east. The watershed of Aral-Irgis marks the line of junction.

Hence, as is shown by Muschketow's observations, it is not impossible that one of the branches of the Thian-shan is deflected into connexion with the ranges of the Urals, which diverge one from another towards the south; it may even be regarded as probable, but under existing circumstances it cannot be directly proved.

It is still more difficult to hazard any conjecture in regard to the possible relations between the Urals and the much more remote folds of the Kirghiz. Krasnopolski's accounts of the gold-producing districts of the mountains south of Kokshe-tau show that the most ancient rocks in that region exhibit a fairly constant strike of from 40° to 60° to the east of north, and thus diverge from all the directions hitherto observed ¹.

We may regard it as an established fact that for a very long distance north of lat. 53° N. the Urals cannot be separated from the foundation of the Siberian plain, which is folded in the same direction as themselves.

Relations of the Ural mountains to the Caucasus. The apparent deflexion of the Kara-tau towards the watershed of the Aral-Irgis affords a striking contrast to the wide divergence between the directions of the southern Urals and the Caucasus. This contrast is still further heightened by the appearance of recent lines of disturbance, running from north to south, in the region between the Urals and the Caucasus. Nevertheless both the Kara-tau and the Caucasus must be regarded as radiating branches of the Thian-shan.

In the first place we must mention the folding of the *Yergeni* hills far away to the south-west, for a detailed description of which we are also indebted to Muschketow ².

We may regard them as beginning at the bend of the Volga near Zaritzyn. From this place an anticlinal fold, running almost from north to south, extends through about $2\frac{1}{2}$ degrees of latitude, turning, however, rather to the

¹ A. Krasnopolski, Geological researches in the provinces of Akmolinsk and Semipalatinsk, Djel. Dor., 1900, XXI, 317 pp., maps, in particular pp. 103 et seq. This important work did not reach me until I had gone to press. With regard to the bend of the Ishim we may refer to III, p. 162. I do not know the precise relations of the heights marked on Muschketow's general map of Turkestan, north of lat. 48° N. and north of the Sary-su; according to older data the Ul-tau consists of granite and contains lead ore; G. de Meyendorff, Voyage d'Orenbourg à Bokhara, fait en 1820, 8vo, Paris, 1826, p. 93.

² J. Muschketow, Geologische Untersuchungen in der Kalmtücken-Steppe in den Jahren 1884-1885, Mém. Com. géol. Russie, 1895, XIV, no. 1, 202 pp., maps.

south-east, so that it reaches the Manytch at the hill of Tshalon Chamur (long. $44^{\circ} 50'$ E.) with an easterly strike. At the same time several subsidiary folds diverging towards the south appear on the west side. Dark clay is exposed at the axis of the anticline, probably of early Tertiary age. The Sarmatian beds, at least in the south, are involved in the folding, which is older than the Aralo-Caspian sediments, and has an east-to-west strike.

The Caspian, at the time of its greatest extension, had for its western shore along the greater part of the distance between the Manytch and the existing site of Zaritzyn, the line of the Yergeni hills.

The folded range of the Yergeni is succeeded towards the east by a long chain of lakes, which begins with the Sarpa lakes near the Volga; the direction of this is first south-south-east, then south-east, and it ends by losing itself in the depression between Astrachan and the lower Kuma.

Another saddle appears on the Volga below Zaritzyn, near *Kammeni Yar* (Stony Bank). Here the clay, supposed to be lower Tertiary, forms a broad anticline with a denuded crown; it strikes at first towards the south, and then turns, exactly like the Yergeni, towards the south-south-east.

A little further down also, at *Tcherni Yar* (Black Bank) on the Volga, this older clay again crops out and indicates a connexion with the exposed Mesozoic beds which characterize those parts of the steppe lying more to the east.

We have already mentioned the difficulties which attend the hypothesis of a connexion between these isolated outcrops (III, p. 295, note 2). On the great *Bogdo*, which rises 171 meters above the neighbouring lake of Basskuntchak, lower Trias and upper Jurassic (or lower Cretaceous) are exposed. The little *Bogdo*, lying to the north-north-east, exhibits similar rocks. The hill of Tshaptshaptshi, further to the east, consists of gypsum surrounding a nucleus of salt.

Still further east rises the range of Bish-tshosho (Five Hills). This is formed by three series of ridges, some of them several versts in length. The middle series, rising to a height of 60 meters, coincides with the axis of an anticline striking to the north-east, and is formed of grey marl, not unlike the lower Mesozoic rocks of the *Bogdo*; the two other series are limbs of the anticline and consist of gypsum¹.

All these folds, from the Yergeni hills to the Bish-tshosho, whether they form a single system or not, are older than the Aralo-Caspian sediments which either rest against them horizontally or cover them. On the other hand, the Sarmatian beds in the south Yergeni are involved in the folding. We may recall the fact that the Sarmatian stage rests horizontally and

¹ J. Muschketow, *Geologische Untersuchungen in der Kirgisen-Steppe im Jahre 1894*, *Mém. Com. géol. Russie*, 1896, no. 5, 27 pp., map; on p. 21 a comparison with the Yergeni hills.

unconformably against the folds of Mangyshlak, which, on the east side of the Caspian, follow the direction of the Caucasus, while in the Caucasus itself this stage has been subject to mighty movements.

The southern end of the Yergeni certainly appears to swerve to the south-east, but we find it difficult to determine in what manner the more recent folds of the Urals and those of the Caucasus are related to one another, and whether they actually intersect.

Karpinski has raised a suggestive question in connexion with these more recent movements. Leaving out of consideration the Palaeozoic seas, it can be shown that the seas of Europe have reached the region of the existing Arctic Ocean sometimes by way of the western side of the Urals (Middle Jurassic, Volga stage, Neocomian), at others by an uninterrupted extension along the eastern side (lower Tertiary and perhaps even upper Cretaceous), and finally, during the glacial epoch, by a communication which was almost completely re-established on the western side. Hence it has been conjectured that the communication, now on the west, now on the east side, was produced by the development of long basins, sometimes parallel with the Urals, sometimes with the Caucasus, concomitantly with the formation of these two ranges¹.

By this conjecture we are confronted with a number of unsolved questions, and on that account we may expect to obtain fresh light from a further investigation. We must observe in the first place that, as Karpinski expressly points out, the origin of a considerable part of the Permian formation was not marine.

Herr T. Fuchs has drawn my attention to Stirling's description of the skeletons of great aplacental mammals, which are found covered with incrustations in the Australian deserts. This recalls the skeletons of Saurians similarly incrustated which Amalitzky discovered in the Glossopteris stage in the region of the Dwina². It also confirms the supposition that for this group of deposits the circumstances under which the transgression has occurred are completely different from those which commonly prevail. If we attempt to make a further comparison between the restricted peri-Adriatic region and the vast area of Russia, we perceive

¹ A. Karpinski, Survey of the physico-geographical conditions of European Russia during the geological periods. Discourse delivered at the public session of the Acad. Impér. des Sci. Saint-Petersb. on Dec. 9, 1886; supplement to vol. XXXV of the *Mémoires russes de l'Académie*, no. 8 (also a German translation in the *Beiträge zur Kenntniss des russischen Reiches*, 1887, 3rd series), and in particular, General character of the oscillations of the earth's crust within the limits of European Russia, *Bull. Acad. Imp. Sci. Saint-Petersb.*, 1894, 5th ser., I, pp. 1-19, maps.

² E. C. Stirling, The physical features of Lake Callabonna, *Mem. Roy. Soc. South Australia*, 1900, vol. I, part 2; V. Amalitzky, On the excavations of the remains of vertebrates in the Permian deposits of North Russia, *Travaux Soc. Nat. Saint-Petersb.*, *Procès-verb.*, April-May, 1900, pp. 177-198.

at once the greater simplicity of the Dinarides, where the desert deposits were followed by a long, continuous, and conformable, series of marine sediments.

The gaps in the Russian series, however, were not confined to Russia, and the transgressions which are observed there are repeated almost without exception in distant parts of the world. But during the negative phases—or more correctly, up to that moment at which in a given place the strand-line has returned to a given distance from the centre of the earth—the form of the dry land is being altered (*a*) by tectonic processes, which also extend beyond the strand-line, and (*b*) by denudation, especially by the wind and the erosion of great river valleys; these processes being confined to the solid land. It is true that *b* is largely dependent on *a*, but it also does its work when tectonic processes are altogether absent.

Therefore every new transgression (regression), in so far as the encroaching line of breakers itself has not denuded the land, will encounter an altered relief. The new outlines will be influenced by *a* and *b*, or by *b* alone. Many communications of the sea, which previously did not exist, may be opened up by a renewed transgression, or ancient communications may be closed by tectonic processes.

The distinction between the influences *a* and *b* is in each case a geographical problem which demands an exact knowledge of the local conditions. Many facts support the hypothesis that during the middle of the Jurassic epoch the west side of the Urals formed a coast line to a long gulf, and through this the transgression from the far north passed across Darvaz and Afghanistan to that sea which has left traces of a higher level of the strand-line at so many places around the Indian Ocean. The transgression itself is a general phenomenon of another kind, and not dependent on the existence of this connexion; the submergence of the corresponding part of Russia may have been caused by *a* and *b*.

Ufa. In front of the western border of the Urals, extending northwards from lat. 55° 15' N., lies a district designated by Valentine von Möller the plateau of Ufa, and its profound influence on the structure of the Urals has since become more and more clear¹.

It assumes in the south the form of an anticline 90 versts broad and about 360 meters high; on the denuded summit the upper Carboniferous is exposed beneath the Artinsk stage. Towards the east, i. e. facing the Urals, it presents a steep escarpment, while towards the west its slope is gentle. It extends northwards for as much as 200 versts, but before its termination the breadth of the plateau is diminished to about 7 versts.

The folds of the Urals have been driven from east to west, and are dammed up against the plateau of Ufa. Such is the influence of this obstacle

¹ V. von Möller, Letter in N. J. f. Min., 1870, pp. 648-650; here the plateau of Ufa is already compared with the Timan mountains. On the question of the plateau of Ufa, Bull. Com. géol. Russie, 1886, V, pp. 235-237.

that for almost three degrees of latitude the western outline of the range curves backwards, and its folds are more densely crowded together. Not only the border ranges of Devonian quartzite, but also the crystalline Ural-tau which succeeds them in the east, are concave towards the west. South of the plateau of Ufa, however, where it terminates suddenly, cut off almost at right angles across its entire breadth, we see on the beautiful map of this district prepared by Karpinski and Tschernyschew how the folds of the Urals, bending almost at a right angle as they advance to the west, follow the south border of the plateau and then return to an almost north-and-south direction. Only those folded ranges which lie quite in the east, beyond the Ural-tau, retain an undeviated direction from north to south¹.

The most important of these ranges of the Urals, which are deflected to the west along the south border of the plateau and indicate the termination of the obstruction, is the Kara-tau. This presents steep slopes of Devonian sandstone facing the plateau. The same upper Carboniferous and Artinsk beds as those which form the plateau also share in the folding, not of this, but of other ranges of the Urals. Thus the Kara-tau cannot have formed a coast in upper Carboniferous or Artinsk times, and the plateau behaves like a fragment of a concealed foreland, against which the outer border of the Urals is dammed back, or over which it may even be thrust².

There can be little doubt that this checking of the folds, which though local is considerable, has influenced the divergence, mentioned above, of the southernmost branches of the Urals. The Devonian zone of the Urals surrounds the plateau of Ufa, advances, and reaches the river Ural west of Orsk; the long crystalline range of Ural-tau which, as we have seen is concave towards the west along the breadth of the plateau, joins it in the east, and then, striking from north to south, reaches the river Ural. Then follow towards the east other meridional zones of great length; sometimes formed of diabase porphyry and tuffs; sometimes characterized by granite ranges, or again by Palaeozoic sediments.

Towards the east the zones have been so completely planed down by denudation that their limit in this direction cannot be seen, either across Vercho-turje or towards Shadrinsk, or on the Tobol. In this way the Urals diverge from the plateau of Ufa towards the south as far as those regions where we have sought in vain for their traces upon the watershed

¹ A. Karpinski and T. Tschernyschew, General geological map of European Russia, sheet 139, *Mém. Com. géol. Russie*, 1886, III, no. 2, map; and Tschernyschew, sheet 139, *Beschreibung des Central-Urals und des West-Abhanges*, op. cit., 1889, III, no. 4; also Karpinski, *Geologische Karte des Ostabhanges des Urals*, 1884, 3 sheets fol.

² Tschernyschew, Section through the Kara-tau in the *Guide des Excursions du VII^e Congrès Géologique Internationale*, 1897, III, p. 9, and *Geological Map of European Russia*, sheet 139, p. 379. The overthrusting of the foreland would render it no longer necessary to suppose that the folding in the Kara-tau terminated earlier than in the adjacent chains striking to the north-east.

of Aral-Irgis, and where we have seen the Mugodjars disappear as they sink beneath the Ust-Urt.

It is difficult to say with certainty how far the effect of this obstruction has made itself felt in front, i. e. towards the west. Pawlow has conjectured that the deflexion of the Kara-tau on the south border of the plateau of Ufa may be represented even far to the west-south-west by the remarkable dislocation which is visible at Stavropol. Here the *Djeguli* mountains give rise to the sharp bend of the Volga. On their north side they are cut off by a fault running to west-south-west. This dislocation is visible for about 140 versts, and is believed to be connected towards the east-north-east by way of Bugulma with the folds which advance on the south border of the plateau of Ufa. It is of later date than the Eocene¹.

Perhaps we might carry conjecture so far as to include the Yergeni mountains and the other disturbances on the lower Volga, and to sketch lines which would follow a course like that, for instance, of the Vachsh. Then the recent folds of the lower Volga would resemble those of Kêlif or Chodshent, the position of Ufa would correspond with the re-entrant angle of the Karsh or the Aryss, and a system of intermediate lines would lie between the Urals and Caucasus similar to that of Bokhara and Ferghana. Here, however, we will be content with the two inferences; first, that in this region also the dislocations most remote from the obstacle, the free ends (Yergeni), so to speak, are the most recent; and secondly, that one result of the damming back at Ufa is to heighten the contrast between the direction of the Urals and that of the Caucasus.

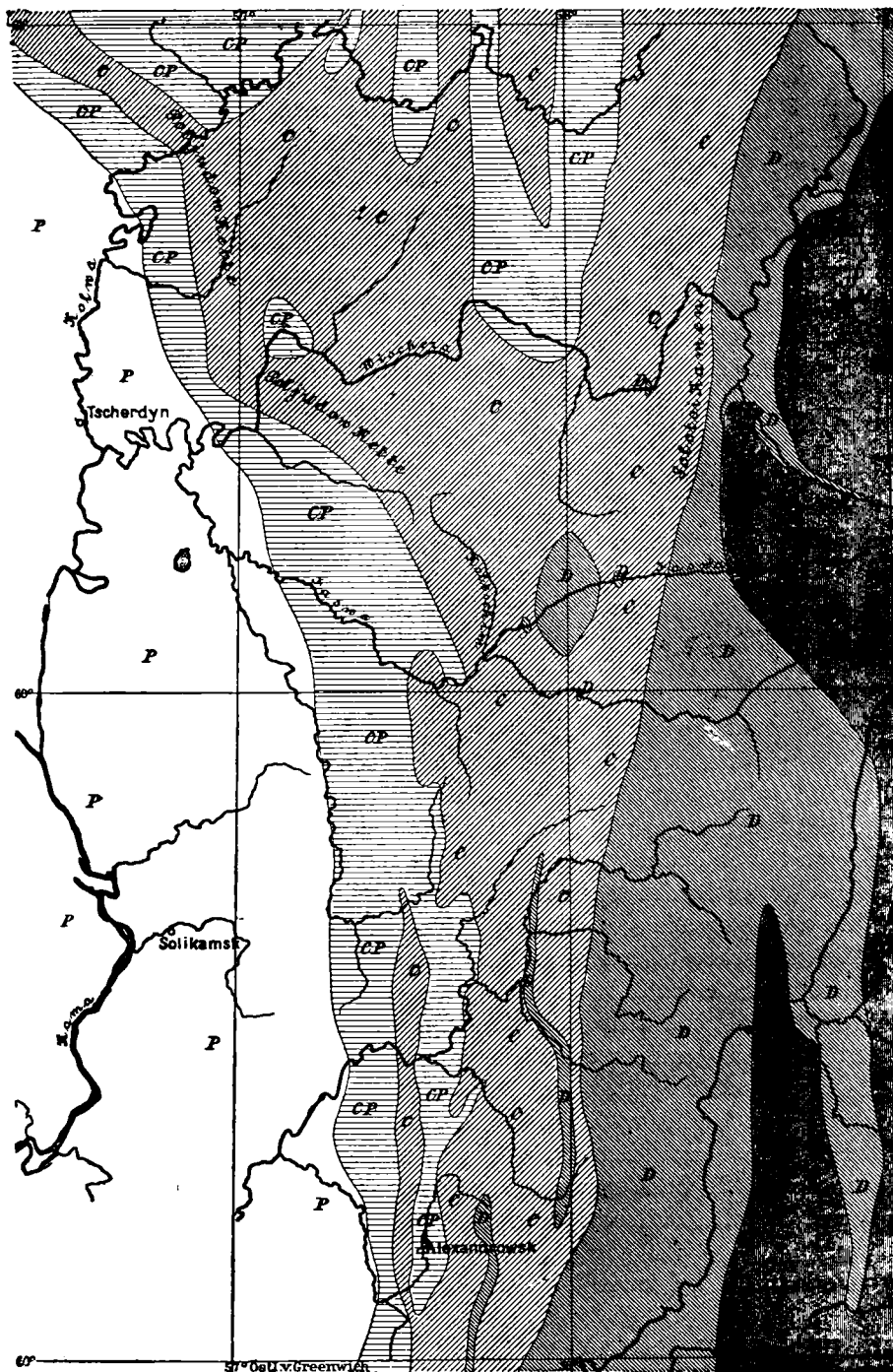
Folded ranges between Ufa and the Arctic Ocean. Möller has compared the plateau of Ufa to the Timan range; Tschernyschew thought it had but slight orographic importance; Stuckenberg inclines to Möller's view, but only in regard to the tectonic relations².

North of this plateau the folds of the west side of the Urals proceed in a north-westerly or north-north-westerly direction, and if we conjoin Krasnopolski's map of Perm-Solikamsk with that given by Krotow of the western border of the mountains extending to lat. 61° N. we see that in this region several branches of ancient crystalline rocks are detached successively at an acute angle in the form of coulisses. This indicates the existence of a deep-seated subdivision or dismemberment of the chain³.

¹ A. Pawlow, The peninsula of Samara and the Djeguli's, *Mém. Com. géol. Russie*, 1887, II, No. 5, 63 pp., map; p. 55 et seq., for the hypothetical line of connexion.

² A. Stuckenberg, Geological map of European Russia, sheet 127, *Mém. Com. géol. Russie*, 1898, XVI, No. 1, pp. 5 and 506; Philippson has represented the relations with the Urals in a diagrammatic sketch in *Sitzb. niederrhein. nat. Ges., &c., Bonn*, 1898.

³ A. Krasnopolski, Geological map of European Russia, sheet 126, Perm-Solikamsk, *Mém. Com. géol. Russie*, 1889, XI, No. 1, and 1891, XI, No. 2; P. Krotow, Geological investigations on the west slope of the Urals in the regions of Tscherdyn and Solikamsk, *op. cit.*, 1888, VI, No. 1 and No. 2, map. On the diagrammatic figure of the dislocations



The Bassegi, Kvarush, and the Poljudov Chains

After Krotow and Krasnopski

M, Metamorphic schists ; D, Devonian ; C, Carboniferous ;
CP, Permo-Carboniferous ; P, Permian

Of these coulisseries two are especially striking. The first begins between lats. $58^{\circ} 30'$ and 59°N. , in the crystalline schists of the lofty mountain range of the Bassegi which advances towards the west in an arc, and is separated north of lat. 59°N. by a long band of Devonian from the axis, or rather from the west border of the following coulisse; it then returns to the strictly meridional direction and terminates in about lat. $59^{\circ} 40' \text{N.}$ as a long spur of crystalline schists. The second coulisse terminates in lat. $60^{\circ} 25' \text{N.}$ in the lofty range of *Kvarkush*; this also is bounded in the east by an intercalation of Devonian.

Krotow's description shows that a similar disposition occurs in the neighbouring region of Devonian and Carboniferous; and more especially we may observe that the *Poljudov chain which forms the beginning of the Timan range is also only a divergent coulisse* (I, p. 504).

Possibly the long anticline of Devonian which begins east of Alexandrovsk corresponds with this coulisse in the south. Krotow lays stress on the parallelism between the *Kvarkush* and *Poljudov*; north of the *Jasva* the latter detaches itself from the range of the *Soioti Kamen*, loses in height, and is thus interrupted for a short distance, then becomes completely independent, and assumes further to the north-west the name of the *Timan range*.

Our knowledge of this range, or rather of this group of parallel ranges, has been considerably increased by Tschernyschew. His investigations are the first to show that no such syntaxis with the range of the peninsula of *Kanin* as had been previously supposed to occur to the north of the *Timan range* on the *Sula* really exists (I, p. 505), but that the *Kanin range* must be regarded as the direct continuation of the *Timan* ¹.

We are also made acquainted with the following facts:—

Tschernyschew shows that the *Timan range* certainly consists of a series of parallel anticlines and synclines, which form marked orographical features, but that unconformities occur within these folds. The oldest rocks are sericitic schists. Near the sea-coast, the upper Silurian rests unconformably upon them, and a little further south the discordant superposition begins with the upper Devonian, which everywhere forms the most prominent parts of the *Timan range*, especially the anticline on the upper *Sula*. It is associated with eruptive rocks. The Devonian is followed by Carboniferous, and the Permian also is involved in the folding.

We learn from Grewingk's diary, describing his very successful journey

of the *Urals* which *Karpinski* has given in *Bull. Acad. Imp. Sci. Saint-Petersb.*, 1894, No. 1, p. 13, we recognize the emergence of spurs which are directed to the north-west.

¹ T. Tschernyschew, *Investigations carried out in the Timan mountains in the year 1889*, preliminary report, *Bull. Com. géol. Russie*, 1890, IX, pp. 41-84, map; also *Investigations in 1890*, op. cit., 1891, X, pp. 95-147, map.

to Kanin in 1848 published in 1891, we learn that the sericitic schists of the Timan range are continued to cape Miklukin, through two little islands which separate, so to speak, the gulf of Tchesskaia from the Arctic Ocean; in fact they form in the peninsula of Kanin a range running to the north-west from cape Miklukin to Kanin Noss, precisely as Keyserling represented it many years ago on the map of the Petchora region ¹.

The northern parts of the Timan range are to a large extent buried under the sediments of the latest circumpolar transgression of the Arctic Ocean. Kanin also is mantled over by a vast sheet of similar sediments and other débris; for this reason it is impossible to discover what rocks immediately follow upon the ancient schists in this peninsula; Carboniferous and Permian have been observed only at some distance from them.

These facts show that the line of Puljudov, Timan, and Kanin was already determined before the upper Silurian, and that posthumous folding occurred as late as the Permian epoch. The general map of Russia, published by the Comité géologique in 1892, shows, however, among other things, that the ancient schists of south Timan may not correspond exactly with the continuation of the same anticline in the north, and that the Timan, as we have said, represents a whole group of parallel folds.

The surveys of Fedorow show that the main stem of the Urals, north of Puljudov, possesses a purely meridional direction and a structure which recalls the geometric regularity of the Lushai mountains (I, p. 453, note 2) ².

Fedorow describes a coulisse which dips beneath the surface and disappears near lat. 63° N. on the east border; in the south it consists of lower Devonian; further north the zones of *Stringocephalus Burtini* and *Rhynchonella cuboides* occur, and finally on the river Nayssa plant-bearing beds of Carboniferous type ³. In like manner smaller independent anticlines rise on the western border: Tima-Is. in lat. 63° 20' N., Mertwaja-Parma in lat. 64° 10' to 64° 24' N. Fresh divergent coulisses appear further west of

¹ K. J. Grewingk, Travels in the peninsula of Kanin, edited by Tschernyschew, Karpinski and Nikitin, supplement no. 11 to the LVII volume of the Mémoires russes of the Académie Impériale des Sciences, Saint-Petersb., 1891. On the map accompanying this work Tschernyschew has coloured geologically the north part of the Timan range according to the results obtained by the expedition of 1890.

² E. Fedorow, Geological explorations in the north Urals in the years 1884-1886, Gorn. Journ., 1890, I, p. 196 et seq. (refers to lat. 60° 40' to 62° 20' N.); also Syenite gneisses of the north Urals, Bull. Com. géol. Russie, 1888, VII, pp. 15-31 (chiefly the range Tshistop, 61° 25' to 61° 35'); also New data for the geology of the north Urals, op. cit., 1889, VIII, pp. 7-17 (to lat. 63° 45'), further in many places in the Gorn. Journ. and in particular the geological map of the north Urals from lat. 61° to 64° 45', Gorn. Journ., 1897, III. In the earlier of these works Fedorow supposes that the north-and-south direction of the existing Urals preceded in certain parts of the north other east-and-west folds of great amplitude (cf. Bull. Com. géol. Russie, 1888, VII, p. 24); since this view is not republished in his later works I have not discussed it here.

³ Bull. Com. géol. Russie, 1889, VIII, p. 7.

the principal chain, and the map of the Comité géologique shows a very long Carboniferous anticline which, quite 120 kilometers west of the Urals, between lats. $65^{\circ} 40'$ and $66^{\circ} 40' N.$, or thereabouts, makes, in the region of the Ussa, the same bend to the north-east as is described in these latitudes by the principal chain of the Urals. This fold, where intersected by the upper Ussa, is called the *Adak* range by E. Hofmann, and his map even indicates a little chain lying further west, the *Pise-To*, which also runs to the north-east¹.

These ranges and the curve which they describe parallel to the Urals show that what we can see of the principal range of the Urals is only a small part of a far broader zone of folds.

Much further north still, beyond the back of the Samoyede upland, formed of Mesozoic and glacial deposits, Keyserling and the 'general map' show between longs. 56° and $57^{\circ} E.$, near the Arctic Ocean, a Putkov Kamen formed of ancient schist; but I possess no detailed information concerning it².

East of this lies the great bay of Chaipudyrskaja of the Russian maps. Schrenk writes the name *Hayodepadara*. The Samoyedes apply this word to one of those small isolated groups of trees, which maintain themselves under favourable local circumstances in the desert, north of the limit of forest growth. The Samoyedes, however, regard these green islands as spots specially favoured by nature. They are to them holy groves, whither they bring their dead for burial from great distances across the Tundra³. At the same time, when we recall the instability of the forest limit, and the persistence of such traditions associated with localities, as well as the extraordinary variations of climate which man has experienced during the glacial epoch, we may ask ourselves whether similar green islands may not have existed even at that time beyond the forest limit, and whether the native tribes of the present day may not connect with these sacred spots one of the tenderest recollections of the childhood of the human race, a recollection far older than that of the flood.

To the north-east, beyond the bay, lies Sinjkin Noss, where Iwanow, Lutke's companion, found beneath the horizontal Mesozoic beds low rocky cliffs on the border of the sea. This fact, together with a statement by

¹ Map to The North Urals and the coast range of Pae-choi, studied and described by an expedition equipped by the Royal Russian Geographical Society, 4to, St. Petersburg, 2 vols., 1853 and 1856. (The text by E. Hofmann, the map by Kowalski and others.) The Adak mountains also in Keyserling and Krusenstern's Journey into the Petchora country, Atlas, vol. I, p. 374, section of an anticlinal wing in $64^{\circ} 20' N.$

² Mentioned in A. G. Schrenk, Reise nach dem Nord-Osten des Europäischen Russlands durch die Tundren der Samojeden zum arktischen Uralgebirge, 1848, I, 8vo, Dorpat, p. 554 (Putkov Kamen).

³ A. G. Schrenk, Reise, I, p. 314; the corpse is laid on its left side and the implements and weapons which are placed with it are rendered useless; this custom was once very general in Europe, op. cit., 524.

Linschoten in the year 1594, that the island of Mauritius (Dolgoi) is rocky¹, as well as the name Goletz, which is borne by one of the islands, led Schrenk to conjecture that a rocky range runs parallel to the mountains, striking towards Vaigatz in a north-westerly direction from Sinjkin Noss across the long series of islands—Selenetz, Dolgoi, Matvejev, and Goletz².

This conjecture has been confirmed. Feilden and Pearson found that the island of Dolgoi, 50 kilometers in length, consists of limestone and conglomerate, which dip regularly to the east at an angle of 45°³.

Thus we must ascribe to the Pae-choi as well as to the Urals a far greater breadth than was formerly supposed.

Considering the great length which these ranges attain, it is not impossible that the Adak range passes in a great curve, concave to the west, beneath the more recent sediments, forming the mainland hills of the Samoyedes, and reaches Sinjkin Noss, thus uniting the Pae-choi and the Urals; but on this point we have no information.

As regards the relations of the Urals and the Pae-choi, I have thought it necessary (I, p. 502), chiefly on the evidence furnished by E. Hofmann, to suppose the existence of a syntaxis near Konstantinov Kamen (lat. 68° 29' N.); though another view is supported by the distinguished authors of the general map of the Comité géologique. On this map the Pae-choi slants away from the Urals somewhat south of lat. 68° N. and runs, from a point situated south of the summit of Gnetju, across the watershed between Kara and Ussa to the Yugor Shar. Thus the Kara district should indicate the separation between the Urals and Pae-choi. Since the above-mentioned watershed is covered with glacial débris, and the Pae-choi itself breaks up into low ice-polished hills, we cannot at present go beyond conjecture, but I do not hesitate to adopt this more modern view because it presupposes a junction similar to that known in the case of the Timan range⁴.

It would be interesting under these circumstances to know how far the Urals extend to the north. Near lat. 68° N., in the mass of the *Gnetju* (1,307 meters, Hofmann) talcose clay-slates prevail, striking to the north-north-east; this is also the general direction of the range and is

¹ Linschoten in J. C. Adelung, *Geschichte der Schiffahrten und Versuche, welche zur Entdeckung des nordöstlichen Weges nach Japan und China unternommen wurden*, 4to, Halle, 1768, pp. 155, 156; Dolgoi is the name employed here for Moritz island.

² Schrenk, *Reise*, II, 1854, p. 42. We may mention here that, according to Feilden, the depth of the sea from the continent to Kolgужew never exceeds 30 fathoms, and that Kolgужew according to Trevor-Battye and Feilden is only an accumulation of glacial débris and recent marine sediments, *Quart. Journ. Geol. Soc.*, 1896, LII, p. 52 et seq.

³ H. W. Feilden, *Visits to Barents and Kara Seas with Rambles in Nova Zemlya*, 1895 and 1897, *Geogr. Journ.* 1898, XI, pp. 333–364, map; in particular p. 350.

⁴ Geological map of European Russia, edited by the Comité géologique, 6 sheets, St. Petersburg, 1892.

continued further towards the Arctic Ocean by the mountains of Anaraha, Arkapai (Hofmann,—Horamagha, Schrenk), a little west of this, Minisejpai (the terminal dome rock), and close to the latter the oft-mentioned round quartzite ridge of Konstantinov Kamen (I, p. 505). The Pae-choi, as we have seen, does not come into direct contact with the Urals, but its deflexion near the Yugor Shar from north-north-west to north-west, and finally, as it approaches the Urals, to west-north-west, is recorded both by Hofmann and Schrenk.

The Konstantinov Kamen descends sheer to the northern Tundra and is surrounded by Tundra lakes¹: its distance from the seashore amounts only to 30 or 35 kilometers. The indefatigable traveller, Sujew, crossed this Tundra as early as 1772². E. Hofmann has described it in great detail. North of the Konstantinov Kamen there rise from it, one after the other, 'rocky hill ranges, stretching from east-south-east to west-north-west, and attaining a height of at least 150 feet above the surrounding Tundra.' Here we see clay slates, chloritic rocks, and schistose greywackes, but the exposures do not permit us to determine the strike. Towards the sea hard pepper-coloured sandstone appears. 'These ranges of hills, which lie almost at right angles to the longitudinal axis of the Urals and nearly parallel to the seacoast, may be compared to a series of dunes with intervening plains³.'

It follows from this that fragments of mountains are still visible beneath the Tundra north of the Konstantinov Kamen, but whether they belong to the Urals, or are oblique continuations of the Pae-choi, I hesitate to decide. Hofmann states that at this place the sea casts up fragments of coal and of sandstone with plant remains. Schrenk conjectures that the Urals are connected with the peninsula of Yalmal; this peninsula lately received a passing visit from Nordenskiöld's expedition, but is almost completely unknown⁴.

On the east side of the Urals, beneath the Tundra which extends between the Obi and Kara bay, Finsch has encountered rocks in place between lats. 67° 15' and 68° N., about 40 kilometers from the foot of the mountains; among them are limestone and diabase and on the watershed (Yangana-pai, 100 meters), between the rivers Shtutshaia and Podorata, quartz-porphyry. All these rocks, as well as the quartzites of the Urals and Pae-choi, probably belong to the Devonian system, which, together with the lower Carboniferous, forms the greater part of all these mountains. They indicate that here also the range is still very broad⁵.

¹ E. Hofmann, *Der Nord-Ural*, II, frontispiece.

² Sujew in Pallas, *Journey through various provinces of the Russian kingdom*, 4to, St. Petersburg, III, 1776. On p. 288 he mentions 'black schistose beds dipping obliquely.'

³ E. Hofmann, *Der Nord-Ural*, II, p. 264.

⁴ Schrenk, *Reise*, II, p. 68.

⁵ O. Finsch, *Der Isthmus zwischen dem Karischen Meere und dem Ob*, *Peterm. Mitth.*, 1877, pp. 216-220, map; *Reise nach West-Sibirien*, 8vo, 1879, pp. 436-447, 466. Erman

In describing the *Pae-choi* we mentioned its deflexion to the north-north-west. An imposing secondary range, the *Padaia*, lying to the west is separated from the main body by the river Velikaia which discharges itself into the Yugor Shar. The range of Sinjkin Noss-Dolgoi, lying still further west, must be regarded as a foothill.

Vaigatz is described by Feilden as 300 feet high and formed of limestone and shales or slates; the baset edges of the steeply upturned beds, striking to the north-west, extend over the surface of the island. Nordenskiöld has stated that the vertical beds of cape Grebeni have a north-west strike. Tschernyschew and Jakowlew have collected all the facts relating to this island; and their investigations show that the fossils of cape Grebeni, which had been assigned to the upper Silurian, are really Devonian¹.

Tschernyschew's journey to *Nova Zembla* brought to light the unexpected fact that a broad depression extends across the south island from Möller's bay (lat. 72° 20'–30' N., north of North Geese cape) on its western side to lat. 72° N. on the east coast; it is possibly a fault-trough and is occupied by deposits belonging to the Artinsk stage².

From south to north we may trace the following directions of strike: *Vaigatz*, upper Silurian (Devonian) lat. 70° N., strike north-west according to Feilden and Nordenskiöld; the island in the mouth of the river *Nechvatova* with the greater part of the *Kostin Shar* (shale or slate, Devonian limestone, also porphyry) lat. 71° 10'–20' N., strike 330°, also 345° (north-west to north-north-west), dip steep, north-east to east-north-east, according to Lehmann³; *shores of Gooseland* in the bay of Rogatshev and of the adjacent islands (Devonian, also intercalations of augite porphyry and amygdaloid rock) lat. 71° 30' N., strike north-north-west according to Hoefer⁴; in the low-lying zone between Möller's bay on the east coast (Artinsk stage) lats. 72°

has ascended the eastern foothills in lat. 67° 12' N.; he found diorite divided into vertical plates strike N. 35° E., and at a greater height hornblende rocks with transitions to gneisslike talc schists; A. Erman, *Reise um die Erde*, div. I, vol. I, 8vo, 1883, pp. 692 et seq., 702, 708, Atlas, pl. III; also in Erman's *Archiv*, 1842, II, p. 769. K. M. Derjugin describes the ascent to the summit Suchar-keu in the *Travaux Soc. Nat. Saint-Petersb.*, Zool. div., 1898, XXIX, p. 58.

¹ T. Tschernyschew and N. Jakowlew, *Die Kalksteinafauna des Cap Grebeni auf der Waigatsch-Insel und des Flusses Nechwatowa auf Nowaja-Semlja*, *Verh. russ. k. min. Ges. St. Petersburg*, 1898, XXXVI, pp. 55–99, in particular p. 56 et seq.; cf. also Lindström in *Bihang k. svenska Vet.-Akad. Handl. Stockholm*, 1882, VI, no. 18, p. 4.

² T. Tschernyschew, *The expedition to Nova Zembla*, *Izvestija Imp. ross. Geogr. Obsch.*, 1896, XXXII, pp. 1–26, map; also in Ymer, *Stockholm*, 1896, pp. 129–149, map.

³ Lehmann in Baer, *Expédition à Novaja-Zemlia et en Laponie*, *Bull. Scientifique Acad. Imp. Sci. Saint-Petersb.*, 1838, II, p. 154; Tschernyschew and Jakowlew have published the instructive description of the river *Nechvatova* from Lehmann's Diary and established the Devonian age of the fossils, *Die Kalksteinafauna*, &c. p. 84 et seq.

⁴ H. Höfer Graf Wilczek's *Nordpolfahrt im Jahre 1872*, II, Über den Bau Nowaja Semljas, *Peterm. Mitth.*, 1874, p. 303.

20'–30' and 72° N., strike 335° (= north-north-west) according to Tschernyschew; *Matotchkin Shar* (older Palaeozoic rocks, ancient schists, gneiss; on Black island also an alleged boss of protogine) lats. 73° 15' to 73° 25' N., general strike 345° to 360° (north, to a little west of north) according to Lehmann, confirmed by later observations; *Pachtussoff* islands (probably upper Silurian) east coast, lat. 74° 24' N., dip west, (strike about north) according to Feilden; *Behrends islands* (upper Carboniferous, according to Toula, possibly Permian also ¹) lat. 76° 16' to 76° 25' N., beds vertical, strike north-east according to Hoefer. These islands form only one part of a Carboniferous zone, which accompanies the north-west border of the island and is known in places from *Berch island* (lat. 75° 55' N.) to cape Nassau (lat. 76° 30' N.). Upper Carboniferous or Permo-Carboniferous, according to Nordenskiöld, also crops out on the outer margin of the island much further south, and even in the north part of Gooseland².

Two independent strikes, according to Tschernyschew, occur on Nova Zembla, one running to the north-west and one to the north-east. The uniform bending of the principal directions of strike from north-west and north-north-west in Vaigatz to an almost or completely meridional direction in Matotchkin Shar and the Pachtussoff islands, and finally to north-east in Behrends islands corresponds with the view already expressed, that a uniform arc, corresponding in strike with the trend of the mountain chain, extends from Pae-choi through Vaigatz to the north-east extremity of Nova Zembla.



FIG. 18.

Thus from a study of these observations we are led to recognize three elements: (a) the *Urals* with two branches, namely (b) *Timan-Kanin*, and (c) *Paechoi-Vaigatz-Nova-Zembla*.

The range of the Urals, recurved to the north-east in lat. 65° N., and folded along its whole length by a pressure acting from east to west, is dammed back in the neighbourhood of Ufa. But south of this region its folds advance, diverging widely in their course, and extend perhaps as far as the Yergeni, while in the north we see successive *Parmaes* (coulisses) detach themselves from it; *Timan* is a coulisse of this kind and perhaps *Pae-choi* also. The development of these frontal chains is not everywhere the same. In the north, at least in *Timan*, it appears to be predetermined in

¹ F. Toula, *Eine Kohlenkalk-Fauna auf den Barents-Inseln* (Nowaja-Semlja N. W.). Sitzb. k. Akad. Wiss. Wien, 1875, LXXI, pp. 527–608.

² A. E. Nordenskiöld, *Redogörelse för en expedition til mynningen af Jenissej och Sibirien*, Bihang k. svenska Vet.-Akad. Handl. Stockholm, 1877, IV, no. I, p. 24; these outcrops may possibly be connected with the region described by Tschernyschew. The facts concerning Nova Zembla known up to 1886 have been collected by A. Wichmann. *Zur Geologie von Nowaja Semlja*, Zeitschr. deutsch. geol. Ges., 1886, XXXVIII, pp. 516–550.

a much older substructure, while in the south no indications of this kind can be discerned. But in neither case do we see any such sharp contrast between the mountains and the foreland as exists, for instance, on the northern border of the Alps and Carpathians. On the contrary, as we shall see immediately, the oldest visible parts of the foreland strike in a similar direction to the mountains. The folds of the Urals, in spite of the obstruction at Ufa, and notwithstanding frequent overfolding towards the west, are not isolated secondary folds which are checked by alien horsts and bent like the Banda arc. No sharply defined boundary is perceptible on their eastern flank, and in their western parts we still find a certain

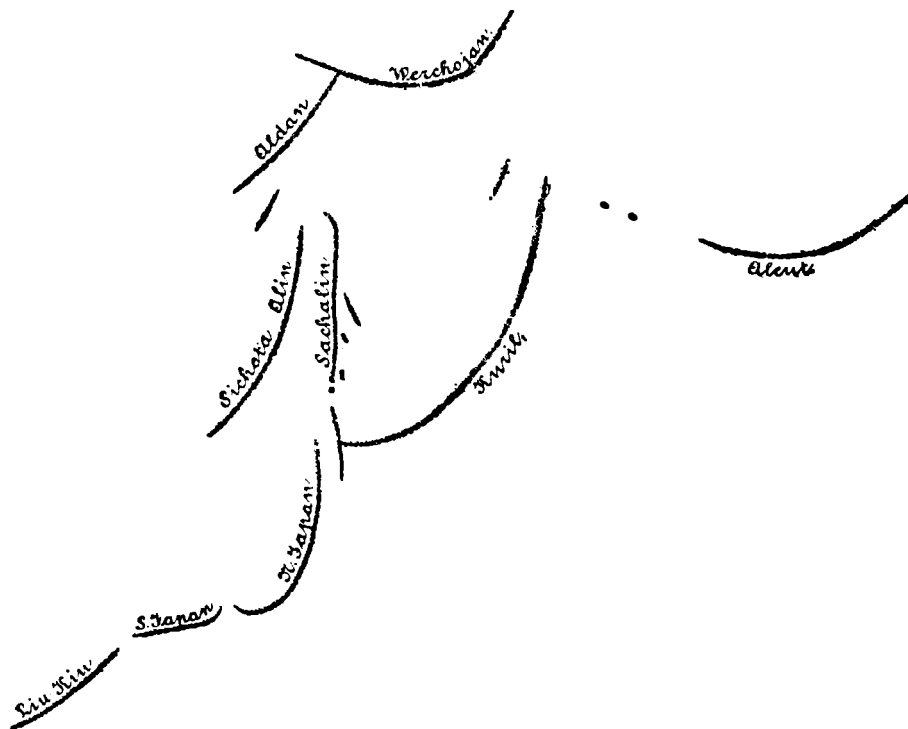


FIG. 19.

resemblance to the foreland (I, p. 504). They are, as it were, the inner members of a common whole, of a greater and more ancient unit. The Ural chain, in its position and length, recalls the peripheral folds of eastern Eurasia, such as the Djugdjur, Sikhota Alin, and perhaps also the Great Khingan. In fact, in this part of North Europe we recognize trend-lines which present no small resemblance to certain parts of the island groups of eastern Asia.

The two figures, 18 and 19, roughly indicate this resemblance. But we must observe that in Fig. 18 the lines of the Urals, the junction of

which cannot be correctly given on this scale, lie in much higher latitudes than those of Asia, and that the representations of them on our ordinary maps are thus very much distorted. We must also observe that in Fig. 19 the arc of Verkhoiansk occupies an exceptional position and has not yet been described. Liu-kiu is probably cut off from south Japan. In the same way the Kuriles are probably cut off on Yezo, but the volcanic line enters the intersecting arc in the group of Optateshike (III, p. 138).

The pre-Cambrian platform. In front of the Urals there extends the vast Russian plain. Its ancient foundation is not visible till we proceed a considerable distance to the west and south-west. In the folds exposed, both on the eastern slope of the Urals and in the river valleys of west Siberia, Devonian and probably lower-Carboniferous share in the folding, and on the western border of the chain still more recent sediments are involved. The folds of the foundation of the plain are far more ancient, and in the region surrounding the gulf of Finland we perceive that they were already planed down in pre-Cambrian times.

Notwithstanding this difference of age we recognize a remarkable correspondence between the direction of these ancient folds and that of the folds of the Urals.

Karpinski, in his instructive treatise on the structure and geography of Russia, has endeavoured to represent the meridional (Ural) trend-lines of the country as opposed to the east-and-west (Caucasian) lines. The first of these lines is drawn from the Mugodjars along the Urals, then to the north-west in the direction of the Timan range towards Kanin Noss. This line, slightly concave to the west, is followed on Karpinski's sketch by similar lines, extending with a gradual transition to the meridional direction to Finland and the Dnjepr¹.

The contrast, not only with the Caucasus but also with the Crimea, the Carpathians and all the trend-lines of Central Europe, is very clear and deserves close investigation.

The east of the Baltic shield. The line from Kecholm on lake Ladoga to the north-east corner of the gulf of Finland separates the ancient rocks of this region from the recent sediments of the level country which extends southwards across the whole breadth of lake Ladoga and the gulf of Finland to beyond St. Petersburg. This line is regarded as a fault. The island of Hogland is regarded by Ramsay as a horst². Nevertheless the gneiss has been reached beneath St. Petersburg at a depth of from 195 to 200 meters³.

¹ A. Karpinski, Uebersicht der physiko-geographischen Verhältnisse des europäischen Russlands während der verflossenen geologischen Perioden, Beiträge zur Kenntniss des russischen Reiches, 3rd series, 1887.

² W. Ramsay, Om Hoglands geologiska byggnad, Geol. Fören. Stockh. Förh., 1890, XII, pp. 471-490, map.

³ A. Inostranzew, C'est le gneiss qui forme le sous-sol profond de Saint-Petersbourg, Travaux Soc. Nat. Saint-Petersb., XXIII, pp. 45-51.

Ladoga and Onega are also united by recent sediments, and from the gulf of Bothnia to the White sea the Baltic shield appears to be separated from the region to the south as if it were a horst. Yet there can be no doubt, according to Karpinski's statements, that the Archaean rocks cropping out in the south of Russia are continuations of the ancient rocks of the north¹.

Sederholm separates the pre-Cambrian rocks of Finland into three independent groups. The most recent of these, the *Jotnian* division is scarcely folded or not at all; it lies unconformably on the older members, and consists chiefly of sandstone. The second or *Jatulian* division, formed of quartzite, schists, dolomite, and basic eruptive rocks, is folded. It probably corresponds as a whole with the so-called 'Algonkian.' Below this there follows, also separated by an unconformity, the *Archaean* group of which the greater part consists of granite gneiss².

We will begin north of lake Ladoga.

In these regions the prevalent strike is north-north-west with local deviations to the north-west. Miklucha-Maklay encountered a strike to north-west, 315° to 330°, in the ancient schist³. Berghell records the same direction on the north coast⁴. At the north-east end of lake Ladoga, however, the western boundary of a great Archaean region begins; it runs along the west coast of the Pjälis-järvi and the eastern end of the Uleå-järvi to the north-north-west. East of this boundary the Archaean rocks, according to Sederholm, are thrown into folds striking to the north-north-west for a distance of 800 kilometers and over a breadth of 500 kilometers. The observations made more to the east by Russian geologists show that they extend over even a greater area.

Lisitzin has observed the prevalence of the north-north-westerly direction on the Pjälis-järvi, and further away to Nurmes⁵, and Tigerstedt has

¹ In addition to the exposures in the government of Pskov (II, p. 229) Cambrian and lower Silurian sediments have been described near Ravanitchi (between Minsk and Mohilev) at a much greater distance from the Baltic shield. Bork has found lower Silurian at Vishny-Volotchek (government of Tver); A. Karpinski, *Mélanges géologiques et paléontologiques*, from the Bull. Acad. Imp. Sci. Saint-Petersb., 1892, I, pp. 139-145 (Bull., nouv. série, III, p. 1).

² J. J. Sederholm, Ueber eine archaische Sedimentformation im südwestlichen Finland, Bull. Com. géol. Finland, 1899, no. 6, pp. 1-254, maps; for previous interpretations, Om Bärgrunden i Södra Finland, Fennia, 1893, VIII, no. 3.

³ M. N. Miklucha-Maklay, Geologische Skizze des Kreises Olonetz und der Inseln des Ladoga-Sees in der Umgebung von Walaamo, Matér. Géol. Russ., 1897, XVIII, pp. 171-264, map, r.

⁴ H. Berghell, Geologiske iakttagelser längs karelska järnvägen, Fennia, 1892, V, no. 2, map.

⁵ G. Lisitzin, Några geologiska iakttagelser gjorda i trakterna norr om Ladoga Sjö sommaren 1889, Meddel. fr. Industristyr. i Finland, Helsingfors, 1891, XIV, pp. 127-154, map. At Pitkäranta on the east shore an extent of massive rocks makes it difficult to determine the original strike; cf. Törnebohm, Om Pitkäranta malmfält, Geol. Fören. Stockh. Förh., 1891, XIII, pp. 313-334, map.

recorded it to the west and south-west of the Pjälis-järvi, where bands of diorite, from 20 to 50 kilometers in length, run in the same north-north-west direction through ancient quartzite¹. Finally Rosberg has traced the strike of the rocks between the meridians 31° 30' and 32° 30' E. from lat. 63° N. onward to the shores of the Tuoppa-järvi in lat. 65° 45' N. At Kallionemi (lat. 62° 45' N., long. 31° E.) the gneiss shows a divergent strike of N. 50° E.; this soon turns to a north-and-south direction, then somewhat more to the west, and the direction north-north-west to north, or in places north-west, prevails even up to the Tuoppa-järvi. On the south-east border of this lake, however (lat. 65° 28' N., long. 33° E.), a strike of N. 10° E. appears².

These observations serve as a link with the extensive investigations carried out by Inostranzew between lake Onega and the White sea³.

In this region, where the ground is not covered by glacial deposits, we find the same rocks as in Finland. Gneiss accompanied by bands of granite, which follow the same strike, as well as talc and chlorite schists, forms a large part of the foundation. Above it lies a quartz conglomerate, quartzite, and quartz schist, then dolomite. According to Inostranzew, the superposition of the quartzites is unconformable, but nevertheless they are folded in the same direction. This indicates discontinuous mountain formation in extremely remote times. That these rocks correspond with Sederholm's Jatulian stage⁴ can hardly be doubted.

Inostranzew's results may be summed up as follows:—

The north-north-westerly direction observed by Rosberg is continued through the whole western part of the mining district of Povjanetz and is most conspicuous in a great tract of quartzites, which, accompanied by ranges of eruptive rocks, runs to the south-south-east, across the Segosero and the region lying to the west of it. These, further to the south-south-east, are replaced by crystalline schists, which, also in association with eruptive ranges, form the shores of lake Onega for long distances. Gneiss also occurs north and east of the lake to beyond the Pudoshgorskii Pogost; here, too, the strike is directed to the north-north-west, and in one place even

¹ A. F. Tigerstedt, *Om traktens mellan Höytiänen och Pjälisjärvi geologiska och topografiska byggnad*, Fennia, 1892, V, no. 10, maps.

² J. E. Rosberg, *Ytbildningar i ryska och finska Karelen med särskild hänsyn till de Karelska randmoränerna*, Fennia, 1892, VII, No. 2, maps, in particular pp. 17–27.

³ A. Inostranzew, *Geological survey of the regions between the White sea and lake Onega*, 8vo, St. Petersburg, 1871, map; *Geological investigations in North Russia in the years 1869 and 1870*, 8vo, 1872; *Geological sketch of the district of Povjanetz in the government of Olonetz*, 8vo, 1877, maps (here in particular, p. 495 et seq.) also W. J. Koltenko, *Geological description of the Cis-Onega region*, *Matér. Géol. Russ.*, 1885, XII, pp. 23–104, map.

⁴ An older statement concerning the discovery of a Devonian coral in Olonetz gave rise to differences of opinion, but this discovery has not been confirmed. R. Ludwig, *Die Gegenden am Ssuna- und Semtsche-Flusse im Olonetz-Gouvernement*, *Bull. Soc. Imp. Nat. Moscou*, 1874, II, pp. 108–127, map.

to the west-north-west. But almost north of the town of Povjanetz on the little lake of Matkosero (about lat. $63^{\circ} 10' N.$) the direction changes and turns to the north-north-east. Glacial deposits no doubt mask large areas of the country to the north, but where the rocky foundation appears a strike to the north-north-east prevails, almost to the shores of the White sea. Talc and chlorite schists occur at the northern extremity of the great Bygosero, and gneiss on the whole seashore, both on the coast of Pomoria in the south, and up to the mouth of the Kem in the west. Here the north-easterly direction appears, even in the graphitic gneiss of the island of Warbarlud.

The archipelago of Solovetskii, lying off this coast, affords nothing but glacial deposits.

It is highly probable that the direction to the north-north-east, of which Rosberg found indications at the end of the Tuoppa-järvi, ought to be assigned to the region of Pomoria. This region, however, does not embrace the whole border of the gulf. West of the mouth of the Onega, on the Kusheretzkaia, the gneiss shows a strike to the east-north-east (260°), further away becoming 285° , but on the Kij Ostrov near Onega, which was visited by Murchison, we again encounter as in Finland the widely prevalent direction to the north-west or north-north-west (320° – 345°).

The question now arises whether the north-north-east strike of Pomoria is maintained in the gneiss and amphibolite gneiss which forms the greater part of the peninsula of Kola. Ramsay has published a table of the directions of strike. Only at one place on the east coast, Karabelnaia Navolok, not far from Ponoj, does he mention a strike to $N. 10^{\circ} E.$; at Ponoj it is north and south; further north, on the Swjatoi Noss and as far as Jokonsk, that is to beyond long. $40^{\circ} E.$, it is north-north-west. Then, further west, the direction again becomes north-west and west-north-west. At Kola the prevalent strike is west-north-west and, according to Kudriazow, the rocks between Kantalaks and Imandra also follow the same direction¹. The band of granulite, probably the greatest known, which crops out west of lake Imandra, at first follows this direction to the west-north-west, and continues to do so as it proceeds north of lat. $68^{\circ} N.$, over a wide area through Sodankylä, where it has been described by Tigerstedt and Rosberg²:

¹ W. Ramsay, *Geologische Beobachtungen auf der Halbinsel Kola, Fennia*, 1890, 111, no. 7, map; gneiss however occurs, strike $N. 20$ – $30^{\circ} E.$, on the eruptive mass of the Umpjavr. Ramsay, *Das Nephelin-Syenit-Gebiet von Kola, Fennia*, 1894, XI, no. 2, p. 70. Rabot's studies on lakes Imandra and Enare, so important for a general knowledge of the country, contain no information about the strike: *Explorations dans la Laponie Russe ou presqu'île de Kola*, Bull. Soc. géogr. Paris, 1889, 7^e sér., X, pp. 457–547, and Rabot et Velain, op. cit., 1891, XII.

² A. F. Tigerstedt, *Beskrifning af de geologiske formationerna i sydöstra delen af Enare samt nordöstra delen af Sodankylä socknar*, Sällskap. f. Finland's Geografi, 1884, pp. 1–24, map; J. E. Rosberg, *Nordöstra Sodankylä*, Geograf. Fören. Tidsskr., 1891,

then its northern border meets the south-west end of lake Enare and bends further west in a very conspicuous curve to the north, maintaining this direction, according to Jernström, up to the Tanajoki in lat. 70° N.¹

The investigations of Jernström have contributed largely to our knowledge of these northern regions. Sederholm, who visited the district south of lake Enare in 1898, confirms Jernström's observations; Herr Sederholm also informs me that the Jatulian quartzite, coming from Kittilä continues towards the south-east and reaches the river Kitinen north of the church of Sodankylä. *It therefore runs in the same direction as the southern border of the granulite range*, which is very clearly shown on Sederholm's map of Finland.

Thus in a great part of Finland and in the adjoining region north of lakes Ladoga and Onega up to the islands of the White sea, both in the Kola peninsula and in the barren regions between lakes Imandra and Enare, we see that the oldest rocks, including the discordant Jatulian series, are thrown into long folds, and already find it possible to recognize the trend-lines of some of these folds together with the ground plan of the primitive mountain ranges which they represent. In a general way we may say that the north-north-westerly strike prevails from the gulf of Bothnia to the south-east end of the Tuoppa-järvi, beyond Ladoga and Onega, and somewhat north of Povjānetz, and that it reappears, after being hidden under glacial deposits, near the mouth of the river Onega. In the interval, however, is a region in which the strike is almost without exception north-north-east. This extends from the points mentioned on the Tuoppa-järvi, and north of Povjānetz, to the coast of Pomoria, and nearly to the mouth of the Kem. Perhaps a trace of this strike reappears on the east coast of Kola, but in the interior of the peninsula the strike turns at once from the north-north-east to north, further west to north-north-west, and then west-north-west to beyond lake Imandra, and it remains west-north-west in the granulite band to the south of lake Enare, where it again turns to the north.

pp. 1-51, map, in particular p. 25. The older description of the parish of Kuusamo by Holmberg does not indicate the directions of strike: Hydrographische und orographisch-geognostische Beobachtungen im nördlichen Finnland in den Jahren 1847, 1848, and 1849, Verh. russ. k. min. Ges. St. Petersburg, 1855-1856, pp. 1-62, map. The band of gneiss which Hummel thought he recognized in 1875 along the Swedo-Russian frontier (Geologisk öfversigtskarta öfver den kända delen af Norrbottens län, 1875, in his Underdänig berättelse om malmfyndigheter inom Gellivare och Jukkasjärvi socknar af Norrbottens län, Sver. geol. Undersökn., 1877) is not so clearly shown on the more recent maps of the region of the Muonio by Svenonius and Stjernvall. Vast outcrops of granite make it difficult to determine the strike: F. Svenonius, Bergrundet i Norrbottens Län, in Sver. geol. Undersökn., 1892, no. 126, map and H. J. Stjernvall, Bidrag till finska Lappmarkens Geognosi, Meddel. fr. Industristyrelsen i Finland, 1892, XIV, pp. 71-125, map.

¹ A. M. Jernström, Material till finska Lappmarkens Geologi; I, Utsjoki och Enare Lappmarker, Bidrag till Känned. af Finlands Nat. och Folk, 1874, XXI, pp. 93-229, map; and II, Kitinendalen i Sodankylä socken, op. cit., 1875, XXIV, pp. 49-76.

The directions mentioned above are the same as those of the Urals and the Pae-choi.

The north-north-west strike which prevails north of lakes Onega and Ladoga and in central Finland, and sometimes approaches very closely to the meridian, corresponds with the dominant strike of the Urals south of the Töll pass. The north-north-east strike of Pomoria, into which, according to Inostranzew, the north-north-west strike probably is gently bent north of lake Onega, is thus comparable to that in the more northerly part of the Urals.

We have seen that in the peninsula of Kanin upper Silurian beds rest unconformably on sericitic schist, the strike of which is parallel with Pae-choi. Now the granulite range of northern Lapland repeats in a remarkable manner the Nova Zembla curve. Tschernyschew has already pointed out the correspondence between Pae-choi, Timan, the northern border of the Scandinavian horst and of the peninsula of Kola¹. The plan of the granulite range of Lapland takes us still deeper, even into the structure of the Archaean platform itself. It is as though the plan of a broader arc, which would find a place in Fig. 18, had been already sketched out in pre-Jotnian or pre-Cambrian times. As, however, the question has a more direct bearing on the study of the island arcs, it may suffice to have suggested a closer examination.

The middle and west of the Baltic shield. Let us return to the boundary line of the granite-gneiss, to the north-east of lake Ladoga and the Pjälis-järvi. This granite-gneiss is doubtless the oldest rock visible in Finland, and Sederholm compares it to the 'Jerngneis,' or iron gneiss, of western Sweden. It never sends off veins into the adjacent rocks. The stratified rocks which rest upon it towards the west, first a broad zone of hornblende-schist with intercalated limestones, then mica-schist, quartz-schist, and the like, gradually approach the normal sediments. Rocks resembling gneiss are also present, and the strike of the folds appears at first to be fairly uniform and to extend towards the north-north-west into northern Sweden².

Then the state of things is changed.

The region of the 'Jerngneis' mentioned above, namely the broad, monotonous region of the Swedish granite-gneiss, in part hornblende-gneiss, lies much further west. It is bounded on the east by a long meridional line, already recognized by Erdmann. This line begins on the south

¹ Tschernyschew, Nowaja-Semlja, Izwestija Imp. ross. Geogr. Obsch, 1896, XXXII, p. 25. Beyond Nameless bay Tschernyschew has observed another strike which is a return to that of the Urals. The reasons why the whole of Nova Zembla is considered to be the continuous fragment of an arc have already been mentioned.

² J. J. Sederholm, Ueber eine archaische Sedimentformation im südwestlichen Finland, p. 211 et seq.

coast near Sölvisborg, and runs, almost following the meridian $15^{\circ} 20'$ E. towards the south end of lake Wetteren, by the east side of lake Wenern, and then in the direction of the Klar-Elv to the glint. *Its length amounts to more than five degrees of latitude.*

The district west of this line, namely, the eastern part of the gneiss region, is traversed by numerous long dykes of hyperite, running from north to south, and the difference east and west of the long boundary is so striking that Nathorst once conjectured that it might possibly represent a great and very ancient fault with a downthrow on the western side ¹.

The nature of this boundary has not, however, as yet been satisfactorily determined. Detailed observations of recent date are in my possession only for a small part of the extreme south. After de Geer had discovered a conglomerate in the mica-schist near the supposed boundary north of Sölvisburg, Bäckström showed that in this place at least the boundary is not so sharply defined as it is stated to be in the north. A band of amphibolite undoubtedly strikes along the boundary, while the hälleflinta and the conglomerate-bearing series clearly diverge from it, but isolated bosses of granite-gneiss occur yet further east without any sign of a meridional fracture; possibly the latter lies further west. If there is a fault, Bäckström thinks the downthrow is on the east ².

Between these two lines, so remote from one another, i. e. between the lakes of Ladoga and Wetteren, there lies, in the middle of the Baltic shield, a region of divergent structure. While outside them, both to the east and the west, the most ancient gneiss and a uniform structure prevail, in the interval between them considerable variety exists, produced by the occurrence of eruptive rocks, dating from various phases of the pre-Cambrian period, and by unconformities, also pre-Cambrian. The back of a great granite batholite occupies the middle of Finland, a second lies in Småland, a third to the north of it; between the last two granite masses we see a band of gneiss striking from east to west; smaller eruptive regions also occur. As in many other ancient abraded districts the strike is affected by the form of the batholites, and frequently we seem to have before us an arrangement like the concentric coats of an onion rather than the remains of original folding.

Cohen and Deecke ascertained that similar granites form the foundation

¹ A. G. Nathorst, *Ett försök att förklara orsaken till den skarpa gränsen mellan södra Sveriges vestra och östra urterritorium*, Geol. Fören. Stockh. Förh.. 1886, VIII, pp. 95-102.

² G. de Geer, *Om ett Konglomerat inom urberget vid Vestanå i Skåne*, Geol. Fören. Stockh. Förh., 1886, VIII, pp. 30-54, map (German translation by Wahnschaffe, in *Zeitschr. deutsch. geol. Ges.*, 1886, pp. 269-294); also *Bladet Bäckaskog*, the detailed geological map of Sweden, II, O. 40 and text; H. Bäckström, *Vestanåfältet en petro-genetisk studie*, K. svenska Vet.-Akad. Handl. Stockholm, 1897, XXIV, no. 4, 127 pp., map, in particular p. 104.

of the island of Bornholm, and concluded from this that the meridional boundary line is continued west of Bornholm¹.

We seek in vain for traces of the ancient plan in the diversified region between lakes Ladoga and Wettern, and can only hope again to meet with it in the gneiss of south-west Sweden beyond the western boundary. Since this central region includes a number of rocks which are more recent than the gneisses of the east and west, we must regard it in a tectonic sense as lying lower, whence it follows that the boundary line in the west, if it is neither a fracture nor a flexure, must yet show a general inclination of the surface of the gneiss towards the centre, as is the case in the boundary of Finland.

In south-west Sweden the prevalent strike of the granite-gneiss itself is to the north; this direction appears not only along the boundary line, in connexion with the dykes of hyperite which have that strike, but also in the west, from west Scania through Bohuslän, and Dalsland to Wermland². On Norwegian territory, however, the Finland strike to the north-north-west reappears and persists up to the fault-trough of Christiania, to lake Mjösen, and northwards to Trysil (Klar Elv)³; thus bringing us near to the ancient eruptive mass of the Dovre-fjeld. West of the fault-trough, however, in Christiansand, granite again predominates.

South Russia. In Volhynia and Voronesh we see at first only completely isolated outcrops of ancient rocks, widely separated from one another by a covering of recent sediments. They are laid bare here and there at the edges of the river valleys; then the exposures become more or less continuous, not so much in the north as on the upper courses of the rivers which flow southwards in the government of Cherson, between the Bug and the Dnjepr, but there they again disappear not far south of lat. 48° N. North of the Dnjepr they are only visible at a few places, and the bend of this river separates a western from an eastern region which is better exposed and extends north of the sea of Azov.

The rocks are the same as in the north; gneiss intimately associated

¹ E. Cohen and W. Deecke, Ueber das krystalline Grundgebirge der Insel Bornholm; in the IV. Jahresb. d. geograph. Ges. zu Greifswald, 61 pp., in particular p. 38 et seq. At Stockholm the strike is still due east: Svednark. Geol. Fören. Stockh. Förh., 1885, VII, p. 708.

² G. de Geer, Om algonkisk bergveckning inom Fennoskandias gränsområden, Geol. Fören. Stockh. Förh., 1900, XXI, pp. 675-693. The author considers the fact that a mass of Jotnian sandstone extends from north to south in Dalsland to be an argument for a completely different conception of the structure of the country. According to this view, it was the granite masses of the centre that produced those alterations (*Umorientirungen*) which gave their existing character to the gneiss regions in the east and west. This work served to elicit a very instructive discussion, op. cit., 1900, XXII, pp. 116-142.

³ T. Kjerulf, Geologie des südlichen und mittleren Norwegen, German trans. by A. Gurlt, 8vo, Bonn, 1880, p. 89.

with granite, and frequently described as granite-gneiss, forms the oldest member, with which more recent stratified rocks are infolded, in particular, quartzites accompanied by iron ore; massive rocks also appear, granite, syenite, gabbro, and others.

North of Shitomir, as well as between this town and Kiev, the river valleys contain ancient massive rocks described as labradorites, for which Chrustschow has created the term perthitophyre¹. The most westerly outcrop of Archaean rocks, so far known, lies at Shepetovka (about long. 27° E. between the rivers Gorin and Slutsh); not far from there on the Slutsh, Laskarew found gneiss striking N.W. (300°)². At Ostropol, in Volhynia, according to Miklucha-Maklay, vertically upturned hypersthene-gneiss strikes north and south; then, south-west of Shitomir, to the north-north-west, and nearer this town to the north-west³.

South of the Dnjepr, Domher found that the strike of the gneiss in the government of Cherson was north-west, 'or more correctly north-north-west⁴,' and the gneiss, according to Sokolow's surveys, may be observed to strike north and south with deviations to the east, but much more frequently to the west, so that north-north-west is given as the prevalent direction⁵. Further away, on the shore of the Dnjepr between Novo-Georgievsk and Ekaterinoslav the Archaean rocks strike, according to Pjatnitzki, almost without exception to the north-west⁶.

The quartzites and talc schists of Krivoi-Rog, on the Inguletz, which are associated with iron ores, afford important evidence in regard to this strike. They lie in very long and narrow synclines wedged into the gneiss;

¹ K. v. Chrustschow, Ueber die sogenannten Labradorite Wolhynien's, Tschermak, Petrogr. Mitth., 1888, new ser. IX, pp. 470-527; the strike is said to be directed to the north-west, except in a long strip on the river Uz where it runs to the north-east, but we have passed over these data because they concern massive rocks, in part also dykes.

² W. Laskarew, Geological observations on the watershed between the upper course of the Goryn and that of the Slutsh, Bull. Com. géol. Russie, 1899, XVIII, pp. 161-194, in particular p. 189.

³ M. N. Miklucha-Maklay, Geological description of the districts of Novograd-Volinsk and Shitomir in the government of Volhynia, Matér. Géol. Russ., 1890, XIV, pp. 1-91, map, in particular, pp. 13, 14, 16.

⁴ W. A. Domher, Preliminary report on the geological observations made in the summer of 1883, Bull. Com. géol. Russie, 1884, III, pp. 183-214, in particular p. 190.

⁵ N. Sokolow, Hydrogeologische Untersuchungen im Gouvernement Cherson, Mém. Com. géol. Russie, 1896, XIV, no. 2, p. 227 et passim, map.

⁶ P. P. Pjatnitzki, Preliminary report on an excursion to the banks of the Dnjepr from Novo-Georgievsk to Ekaterinoslav, Travaux Soc. Nat. à l'Université de Kharkow, 1886, XX, pp. 104-110. In the neighbourhood of Kamennopototzk an exceptional strike to north-east prevails; at Krementchug, according to Lewakowski, both directions, north-east and north-west; at the rapids between Krementchug and Ekaterinoslav chiefly north-west according to Krotow, Tektonik des Dnjepow'schen Krystallinischen Gesteinsstreifens, Krichtafovitsch, Ann. géol. et min. de la Russie, 1897, I, pp. 30-37.

and their richness in ore has led to a precise investigation of their course. Near the town of Krivoi-Rog they appear to bend gradually from a north to a north-north-east direction; according to Sokolow the bands separate towards the north, the majority curving to the north-north-west. As Monkowski has remarked, a meridional strike prevails north of the Krivoi-Rog, and an arc slightly concave to the west exists as a result of pressure acting from east to west on the Archaean rocks. These observations extend from north to south over a distance of about 60-70 kilometers¹.

Near Alexandrovsk, on the bend of the Dnjepr, the strike of the rocks, according to Sokolow, oscillates between north-north-west and north-north-east².

To this observer, who has so greatly enlarged our knowledge of south Russia, we are indebted for a map of the western part of the Archaean land lying to the north of the sea of Azov. It represents the strike as running generally, though not invariably, to the north-west or north-north-west. The ore-bearing quartzites also appear in this region, and their strike, south-west of Berdiansk near the sea of Azov, is north-north-west³.

Further east, in the district of Mariupol, Morosiewitsch found widely distributed massive rocks, especially syenite; he also made the unexpected discovery of lava flows of basalt and andesite, together with andesite tuffs. They lie, with one exception, on the boundary between the Archaean region and the coal-bearing sediments of the basin of the Donetz; outliers of Palaeozoic sediments rest upon andesite laccolites. These post-Carboniferous eruptive rocks mark a zone of dislocation along the boundary of the Carboniferous. The gneisses west of this region are broken up into horsts and fault-troughs⁴.

¹ Krivoi-Rog has been frequently described; I need only cite N. Sokolow, Geological observations in the north part of the ore-bearing region of Krivoi-Rog and along the river Sholtaja, *Bull. Com. géol. Russie*, 1896, XV, pp. 201-223, map; and T. Monkowski, *Zur Geologie von Krivoi-Rog*, *Zeitschr. f. prakt. Geol.*, edited by Krahmann, 1897, pp. 374-378 (trans. by K. Milkowski; a little map in the text, p. 182). Monkowski thinks that the northern ranges may possibly have been displaced towards the west by a fault (flaw?). The map by Chimanowski, *Gorn. Journ.*, 1892, IV, pl. ii shows a strike to the north-north-east.

² N. Sokolow, Hydrogeological investigations in the district of Alexandrovsk, *Bull. Com. géol. Russie*, 1896, XV, pp. 157-223.

³ N. Sokolow, General geological map of European Russia, sheet 48, Melitopol, Berdiansk, Perekop, Berislavl, *Mém. Com. géol. Russie*, 1889, IX, No. 1; Note on the deposits of iron-ore in the district of Berdiansk, *Bull. Com. géol. Russie*, II, pp. 123-144.

⁴ J. Morosiewitsch, On the lithological composition of the crystalline mass in the neighbourhood of the district of Mariupol in south Russia, *Bull. Com. géol. Russie*, 1898, XVII, pp. 27-167; Geological observations in the district of Mariupol, *op. cit.*, pp. 287-295, and Geological observations in the district of Beriansk, *op. cit.*, 1899, XVIII, pp. 371-382.

Summary. From this mass of details we arrive at the following results :—

The Russian platform, composed of denuded, pre-Cambrian folds, extends from the Arctic ocean to the sea of Azov, and as far as long. 27° E. Beyond this its western limits are indefinite. From its southern part northwards up to lake onega and beyond, its strike is chiefly north-north-west or north-west; indeed in Finland and the north generally the more nearly meridional direction to north-north-west predominates. But towards the coast of Pomoria on the White sea a north-north-east and even east-north-east strike appears. The granulite range of lake Enare presents a crescentic outline, which in position and trend resembles Nova Zembla.

The general disposition of the trend-lines is similar to that which occurs in the much more recent range of the Urals, and *these mountains may be described as a posthumous system formed on the ancient plan.* This is also true of the Timan-Kanin series.

The southern portion of the platform is traversed by more recent dislocations, which, abandoning the ancient directions, run to the west-north-west in parallelism with the Caucasus. Karpinski not only recognized this contrast long ago, but also perceived that the isolated Archaean fragments of the platform, standing like horsts, influence the course of the more recent folds, and that the horst of Azov in particular has determined in all probability the bend from the Caucasus to the Crimea¹.

These prolongations of the fractures running to the west-north-west are called Karpinski's lines (I, p. 469, Pl. V, m, m). We recognize in them movements which are later than the Cretaceous period. That we are dealing with dislocations extending to a great depth is shown by the unexpected occurrence of anamesite at Rovno in Volhynia, and the presence of more recent volcanic intrusions on the north-east part of the boundary between the horst of Azov and the Carboniferous of the Donetz.

The Caledonian lines. A fragment of extremely ancient foreland borders the Atlantic ocean, west of the great Caledonian overthrusts (II, p. 75). It includes the western Hebrides, especially the island of Lewis, together with some of the promontories of western Scotland and several intervening islands (II, p. 78, Fig. 10).

The most ancient rock of this region is the Lewisian gneiss. In loch Maree its folds are partly formed by ancient schists which have been correlated with the 'lower Algonkian.' These folded rocks have undergone great denudation and on their irregular surface rests with a well-marked unconformity the red Torridon sandstone, with no trace of folding. Thus its position is similar to that of the Swedish Dal sandstone, the Jotnian

¹ A. Karpinski, On the general character of the oscillations of the earth's crust within the limits of European Russia, Bull. Acad. Imp. Sci. Saint-Petersb., 1894, V, ser. 1, in particular p. 18, note 20.

series in Finland, and perhaps Barrande's stages *A* and *B* in Bohemia. In Sutherland and Ross, valleys of erosion may be seen, 2,000 to 3,000 feet deep, in which this sandstone has been deposited¹.

Innumerable dykes, formed chiefly of basic rock (strike west-north-west), traverse the oldest gneiss, and indicate a general splitting-up of the region into strips. These dykes are followed by another group of very basic dykes (strike from east to west), and these again by intrusions of granite and syenite. All these injections are more recent than the folding of the gneiss and the ancient schists, and older than the Torridon sandstone².

The Caledonian flakes, described in the previous volume, are thrust over this foreland of the Hebrides. They were driven from south-east to north-west. On the whole, the thrust-planes, on which this movement took place, are only slightly inclined towards the horizon but are sometimes suddenly upturned. From the fact that one thrust-plane is sometimes intersected by a second, and that volcanic intrusions took place in the intervals, it has been concluded that the movements were intermittent³.

An important advance was made in proving that *within the Caledonian ranges rocks occur which have been produced by a transformation of the rocks of the foreland*. Charles Lapworth was the first to show that the eastern or Caledonian gneiss is a complex formed of the Hebridian gneiss, of

¹ Report on the recent work of the Geological Survey in the north-west Highlands of Scotland, based on the field-notes and maps of Messrs. B. N. Peach, J. Horne, W. Gunn, C. T. Clough, L. Hinxman, and H. M. Cadell; communicated by A. Geikie, Director-General, Quart. Journ. Geol. Soc., 1888, XLIV, pp. 378-441; further, B. N. Peach and J. Horne, *The Olenellus Zone in the North-West Highlands of Scotland*, op. cit., 1892, XLVIII, pp. 227-242; A. Geikie, Annual Report of the Geological Survey for the year ending Dec. 31, 1892; 4th Report of the Science and Art Department, 1893, p. 259 et seq.; Annual Report . . . for 1893, p. 262 et seq.

² A. Geikie, *The History of Volcanic Action in the Area of the British Isles*, Anniv. Address Geol. Soc. for 1891 and 1892; *The Ancient Volcanoes of Great Britain*, 2 vols. 8vo, London, 1897.

³ Report on the Recent Work of the Geological Survey in the North-West Highlands of Scotland; Quart. Journ. Geol. Soc., 1888, XLIV, pp. 412, 436. At first only overthrust flakes and no folding or overfolding were encountered; from this it was concluded that different processes had occurred here from those observed on the borders of other folded regions. But subsequently great foldings were observed, especially on loch Carron; Annual Report for 1892, p. 261; on this point cf. Cadell, Trans. Roy. Soc. Edinburgh, XXXV, p. 342; Marcel Bertrand, *Les Montagnes de l'Écosse*, Revue générale des Sciences, III, 1892, pp. 817-824; A. Rothpletz, *Geotektonische Probleme*, p. 100; A. Penck, *Geomorphologische Probleme aus Nordwest-Schottland*; Zeitschr. Ges. f. Erdk. Berlin, 1897, XXXII, p. 161 et seq. Discontinuity is naturally produced with the greatest ease along beds offering less resistance which correspond at first with the direction of the thrust. Geikie has shown that such discontinuity may even occur along intrusive dykes when their inclination is favourable, and that in this case these dykes may be crushed and the sedimentary rocks spared.

sedimentary rocks and later volcanic rocks, altered by the movements¹. In like manner it has been shown by the Geological Survey that parts of the Torridon group have been forced in between the Caledonian flakes, that they pass into the 'Moine schists,' and contribute to the formation of the Caledonian rocks of the east².

At a greater distance from the outer border of the Caledonian flakes, the Scotch horsts are formed chiefly of dynamically metamorphosed rocks, which strike from the north-west of Ireland to the North Sea. Archibald Geikie has given them the general name of 'Dalradian'³. In recent years a series of Silurian stages has been distinguished in these highly altered rocks. The series, however, contains numerous intercalations of diorite, epidiorite, hornblende schist, 'green' schist, and intrusive dykes of diabase. The potstone which occurs here resembles that of Trondhjem, and here as there is used for building purposes.

The presence of a great quantity of eruptive rocks, chiefly basic, within the lower Palaeozoic beds, and the decrease of these rocks from the upper Silurian onwards, is characteristic of these formations in Great Britain. In this they present a striking contrast to the flat-lying Palaeozoic beds on the Baltic shores.

The Scandinavian overthrust (II, pp. 51-65). Great advances have been made during the last few years in the study of the region which now comes under discussion, and it becomes necessary, for the sake of completeness, to repeat many facts which have already been mentioned.

It is generally agreed that the Caledonian folds are continued through the Orkney and Shetland islands to Norway. Judd, who investigated the marginal fractures of north-east Scotland, even thinks it possible that the separation of Scandinavia from Great Britain took place after the appearance of man. Reusch, to whom we are indebted for an admirable map of the islands on the south-west coast of Norway, thinks that the Norwegian and Scotch folds certainly form a single system interrupted only by the subsidence of the North sea⁴.

A glance at the map of Norway certainly shows that we can scarcely expect to find, at least in the southern part of the country, any continuation of the outer zone of Eriboll, but only of such parts of the Caledonian structure as lie to the east of it. These Norwegian ranges certainly exhibit many points of correspondence with those of Scotland,

¹ Charles Callaway, who at first regarded the eastern gneiss as an independent formation, afterwards adopted this view; *The Present State of the Archaean Controversy in Britain*, Geol. Mag., 1889, p. 323.

² *Annual Report for 1893*, p. 264.


³ A. Geikie, *Anniv. Address Geol. Soc. for 1891*, p. 72.

⁴ Judd, *Address British Association, Sect. C, Aberdeen, 1885*, p. 1008; H. Reusch, *Bömmeløen og Karmøen med omgivelser geologisk beskrevne, udgivet af den geologisk Undersøgelse*, 8vo, Kristiania, 1888, maps, in particular, p. 240.






Overthrusting in Central Scandinavia

After A. E. Törnebohm

Basement rocks in the South-east. A, Archaean; Da, Dal Sandstone; Sp, Sparagmite; Si, Silurian;  Gabbro of the Jötun mountains.

Folded mountains and overthrust flakes. A, Archaean; Sp, Sparagmite, ar, Åre-schists (forming together the Seve group); Rör, Røros schists. Overlying Cambrian and Silurian beds are not indicated by letters.

Elm, Ekne group (Devonian?);  Younger Granite;  Eruptive greenstones;  Brek schists.

Heights in Meters.

while there are also contrasts which are difficult to explain. On the whole, they have suffered more from denudation than the Scotch mountains, but yet are not so completely levelled down as the folds of the east Urals; indeed the denudation has been carried just so far as to afford hopes of finding some evidence of the relations, so seldom visible, between a folded range and an adjacent platform. The great merit of having paved the way to a better understanding of this subject is due to A. E. Törnebohm, who has put forward a remarkably bold interpretation of the facts¹.

A girdle of horizontally stratified Palaeozoic deposits, beginning with the Cambrian, runs from the gulf of Finland across the Åland islands and Upland, through Dagö and Oesel, Gotland, Oeland and the western coast of Kalmar sound. The same girdle, broken up into fragments, appears in Scania (II, p. 47, fig. 5); blocks of it are let down in the fault-trough which extends from Christiania to lake Mjösen. Pre-Cambrian rocks are exposed further inland, but among them a Palaeozoic fragment appears here and there, preserved by subsidence from the general denudation, a fact which shows that the Cambrian and Silurian beds once covered the whole shield. Fracture and subsidence are often visible, but not folding, with the exception, perhaps, of a gentle anticline in the Åland islands². Then, after crossing a large part of the breadth of the peninsula, we reach the glint, which runs from north to south throughout its length, i.e. for more than ten degrees of latitude, forming an escarpment of imposing appearance, although much broken up by erosion.

Fossils prove the presence of Cambrian sediments in the glint for the whole of its length, or at least from Hardanger - Vidda (lat. 60° N.), into the Lappmarken beyond lat. 68° N.; Silurian beds are known to overlies the Cambrian at many places, especially in Jemtland. Between lats. 61° and 64° N. the succession, according to Törnebohm's precise statement (II, p. 53) is as follows: 1. At the base, sparagmite, i.e. sandstone containing felspar, reaching between Gudbrandsdal and the Glommen, a thickness of 900 meters, but from here onwards decreasing rather rapidly in thickness. 2. Above this the Biri limestone, often dolomitic, attains 300 meters, and in places even 500 meters. 3. Then the upper sparagmite, which in Rendal is 1,000 meters thick. These three members, which, in all likelihood, are more recent than the Dal sandstone covering the most ancient formations east of the glint,

¹ A. E. Törnebohm, *Om fjällproblemet*, Geol. Fören. Stockh. Förh., 1888, X, pp. 328-336; *Om hogfjällsquartsiten*, op. cit., 1891, XIII, pp. 37-44; *Försök till en tolkning af del nordligaste Skandinaviens fjällgeologi*, op. cit., 1893, XV, pp. 81-94, and 1894, XVI, p. 161 et passim, and in particular the comprehensive work—*Grunddragen af det Centrala Skandinaviens Bergbyggnad*, K. svenska Vet. Akad. Handl. Stockholm, 1896, XXVIII, no. 5, 212 pp., maps.

² C. Wiman, *Ueber das Silurgebiet des Bottnischen Meeres*, Bull. Geol. Inst. Univ. Upsala, ed. by Hj. Sjögren, I, 1892-1893, pp. 65-75.

have as yet yielded no organic remains. Above them comes the blue-quartz conglomerate, which is closely associated with fossiliferous Cambrian beds, and this is overlain by the Silurian series. The last-named has been studied by Högbom and Wiman in Jemtland: its subdivisions extend into the upper Silurian, and even into the graptolite slates which lie above the *Pentamerus* limestone of Christiania¹.

It may be said that the Cambrian and Silurian sediments, exposed at the foot of the glint and in its outposts, present the same characters as the contemporaneous deposits of Christiania and lake Mjösen, as well as of the Silurian girdle of the Baltic, but include, at their base, great masses of sediments devoid of fossils. In the above-mentioned girdle, the beds lie flat; this is also the case in front of and beneath the glint, and the series in both places rests unconformably upon the ancient formations of the shield.

Upon this normal succession of strata a second and very different series rests horizontally. It was formerly regarded by some observers as representing a coast at the foot of which the normal Silurian beds had been deposited (II, p. 53); but this view has not been confirmed. It consists of quartzite and phyllite, often identical in all respects with the sparagmite, but also, over great tracts, of mica-schist, hornblende-schist, and gneiss. Törnebohm regards the latter as sparagmite altered by pressure, and names it the Åre group, calling the whole overlying series the *Seve group*.

The superposition of these highly altered rocks upon normal Palaeozoic sediments is placed beyond doubt by numerous observations (II, p. 64, note 3) extending for a distance of 9 degrees of latitude and across a breadth of 90–100 kilometers².

¹ On this section see also C. Wiman, *Kambrisch-silurische Faciesbildungen in Jemtland*, Bull. Geol. Inst. Univ. Upsala. III, (1896–1897), pp. 269–301, map.

² Several examples of the succession in the glint were given in II, p. 51 et seq. The following fresh data may be added: 1. Hardangervidda (lat. 60° N.) primitive formations (granite and gneiss); 45–50 meters Alum schists, which have furnished the *Dictyograptus flabelliformis* of the Huulberg=Cambrian, zone 2e of Christiania; 40 meters blue quartz; 10 meters marble, probably=Orthoceras limestone=lower Silurian, stage 3; 220 meters greenish grey phyllite, probably=Bjørlykke's graptolite schist of the Gausdal=lower Silurian, stage 4; overlying this, as much as 300 meters thick, hälleflinta, mica-schist, hornblende-schist, gneiss; towards the north-east also sparagmite and quartz conglomerate. W. C. Brögger, *Lagfolgen på Hardangervidda*, Norges Geol. Undersög., 1893, no. 11, and K. O. Bjørlykke, *Graptolitförende skiferne i vestre Gausdal*, op. cit., 1891, pp. 1–10. 2. From the *Storsjön* towards Offerdal and the Kallsjön (lats. 63° and 64° N.) primitive formations; Cambrian and Silurian up to the *Pentamerus* limestone and the graptolite schists of Scania, horizontal or dipping towards the west, at Offerdal cleavage and traces of pressure; upon this further west the Seve group (Åre schist, garnet gneiss, &c.), and upon these two great masses of sandstone and slates which are compared with the western Silurian of Trondhjem. A. G. Högbom, *Geologisk Beskrifning öfver Jemtlands län*, Sver. geol. Undersökn. Afh., 1894, Ser. C, no. 140, 4to, 106 pp., map. 3. In *Norbotten* from lat. 66° to 69° N. the series is similar. On the eastern

The anterior border of the glint is frequently broken up into buttes (pl. VI), which are crowned by the Seve group. Sometimes the Seve group is interrupted by erosion or by inequalities in the foundation; then gaps or windows are produced through which the normal succession of the basement beds is visible. In Jemtland, for instance, such windows form the hill-range of the Mull-Fjäll, west of Kall-Sjön, and south-west of this the long range which terminates in Skarsfield. In the Åreskutan, on the east side of the Kall-Sjön, the Åre schists of the Seve group, formed of hornblende-schist and rocks resembling gneiss, are 1,200 to 1,500 meters thick, and both in the east and west are seen to rest on fossiliferous Silurian. The Åreskutan is thus an overthrust flake.

Törnebohm has expressed the opinion, founded on these undisputed facts, that *the whole mass of the Seve group has been thrust by an extensive tangential movement, from the folded range lying to the west over the normal Palaeozoic sediments of the east.*

Generally speaking, the rocks of the glint exhibit, as we have said, horizontal bedding. An exception occurs near the Storsjön in Jemtland, where the Seve group has been denuded away over a wide area; here the normal Silurian of the foundation is closely folded; these sharp folds are even overfolded towards the south-east. But a consideration of the section, published by Högbohm, showing the south border of the Ansätten flake in Offerdal (north-east corner on plate VI), impresses us with the belief that this folding has itself been produced by the movement of the superimposed flake (Dachschleppung, charriage).

South of Gudbrandsdal the great ancient gabbro mass of the Jötun range produces complicated conditions, which are not yet explained, but here also the normal Palaeozoic sediments of the glint are met with. They reach the sea in the neighbourhood of Stavanger in the south. Thus they approach a second Palaeozoic series, which first emerges from the sea to the south-west in the island of Karmö, and presents all the essential characters of the great folded western range.

Ramanvare above the primitive formations there are 50 meters of Scolithus sandstone; 15 meters greyish-green schistose rock with Hyolithus (Cambrian); 30 meters black clay slates, also quartz sandstone and phosphorite conglomerate; 90 meters so-called Raman schist. Above it, chiefly receding towards the west, mica-schist and quartz-schist in great thickness, next light hälleflinta gneiss and common gneiss, then a dark zone with hornblende rocks, then, forming the main mass of the hills, a phyllitic series associated with calc-mica-schist, &c. At the summit, hornblende rocks with eclogite-like schist, gneiss, and white marble. Bands of olivine rocks are intercalated. F. Svenonius, Om Berggrunden i Norbottens län, Sver. geol. Undersökn. Afh., 1892, ser. C, no. 126; also W. Petterson, Om de geologiska förhållandena i trakten omkring Siangelis kopparmalmsfält i Norbottens län, Geol. Fören. Stockh. Förh., 1897, XIX, pp. 296-306, map et passim; for the intercalations of olivine rocks, Svenonius, op. cit., 1885, VII, pp. 205 and 1893, XV, p. 16; for the microscopic structure of the Åreskutan mass, H. Reusch, En dag ved Åreskutan, Norges Geol. Undersög. Aarb. 1891 pp. 22-32.

While the Cambrian and Silurian beds of the glint present the Baltic facies, the western series is distinguished by a vast development of green eruptive rock, mostly gabbro-like, and of green tuffs. The more remote this renders their resemblance with the sediments of the glint, the closer it brings them to their representatives in Scotland. But a comparison of the faunas is very difficult, since, owing to extensive dynamic alteration, fossils are rare and their preservation imperfect.

From Karmö dioritic rocks and green stratified rocks extend northwards across the islands towards Bergen. Reusch has described them, and has been led by fossils discovered at Bömmelö and Storen to place them in the middle or upper Silurian. Acid eruptive rocks also crop out. At the same time gneiss and mica-schist follow a divergent strike to the north-north-east in the direction of the Hardanger fjord. At Bergen a semi-circular bend of the strike occurs (II, p. 64)¹. Further north, west of the Jötun mountains, recent observations are wanting. On the northern border of the Jötun we reach the region which forms the subject of Törnebohm's latest memoir (pl. VI).

A broad zone, the ruins of a great folded range, which extends from the Dovre towards the north-north-east, and beyond the end of the Snåsen Vand, has been described by Kjerulf as the *Trondhjem-fältet*. The only indication of the original trend is afforded by the roots of elongated synclines. Their axes, or the core lines, as Törnebohm calls them, converge to the north-north-east. One of these synclines lies north of Bettstatt fjord and Snåsen Vand. The second is visible between Bettstatt fjord and Trondhjem fjord, and intersects the first where it noses out. The third, which is smaller, lies in the west-south-west arm of the Trondhjem fjord. The fourth runs from the shore of this fjord to the west-south-west, and merges in its northern part, east of Trondhjem, with the great main syncline which extends from the Grömminger, east of Snåsen Vand, to the south-west into the neighbourhood of the Jötun range.

Between the synclines rise broad, flat, dome-like masses of Archaean rocks. It is an instructive fact that, notwithstanding the rounded outlines of these broad masses, the mountains must nevertheless have been arranged, as appears from the synclines, in the form of coulisses. In the narrow synclines the rocks have been strongly compressed and generally stand almost vertical; in the great main syncline they apparently assume a more or less fan-shaped arrangement, the axis of the fan lying towards the eastern border of the syncline.

The group of the Åre schists forms the lowest horizon of the folded rocks. Above them lies the Röros schist, which is sometimes a phyllite,

¹ H. Reusch, *Bömmelöen og Karmöen med omgivelser geologisk beskrevne*, udgivet af den geol. Undersøg., 8vo, Kristiania, 1888, maps; a good general map in the N. J. f. Min., 1887, supplement vol. V, p. 53.

sometimes a siderite mica-schist or mica-quartzite, locally contains sheaves of hornblende, and then forms a garben-schist. It is also encountered outside the folds, forming, for example, the overthrust flake of the Ansätten mass. I am unable to give a detailed account of the several members of the mighty series of shales and sandstone, or of the limestone in the upper Silurian which rests upon the Röros schist. Gabbro, containing biotite and hypersthene, occurs in the Seve group; and it attains greater importance in the lower Silurian, which also exhibits a considerable development of green schists. These rocks are again met with, but more sparingly, in the upper Silurian. They have also been influenced by the folding. No such dynamic influence is exhibited by the isolated outcrops of recent granite (marked black on pl. VI), which occur within the great syncline.

At a few places we see patches of greenish-grey sandstone (Törnebohm's Ekne group) resting unconformably upon the folds; they are more recent, but their position is none the less disturbed. Possibly they are of Caledonian age, and represent the Caledonian unconformity.

We have already discussed in detail the continuation of the folded mountains towards the north (II, p. 54). Vogt has ascertained that, from lat. 65° N. onwards, white marble, associated with mica-schist, plays a much larger part in the structure of the folds than might be supposed from the nature of the country around Trondhjem. Bands of this marble, sometimes 1,000 meters in thickness, appear with a north-north-east or north-east strike in lat. $65^{\circ} 20'$ N. on the Val fjord, and extend into the mountains as far as Vefsen; they then run past Ranen through Dunderlandsdal, east of the Svartisen, cross the inner part of the Salten fjord west of Sulitelma, and again in lat. $68^{\circ} 30'$ N. following the same strike, cut obliquely across the head of the Ofoten fjord¹.

North of lat. 67° N. we obtain an exceptionally clear conception of the facts, for here the field of Sjörgen's investigations near Sulitelma² joins, towards the east, that of the extensive observations of Svenonius³, which were carried into the extreme north of Sweden; Holmquist has described in detail the whole transverse section along the line Bodö-Sulitelma-Kvikkjokk⁴.

¹ J. H. L. Vogt, Norsk marmor, Norges Geol. Undersög., no. 22, 1897, maps; also Dunderlandsdalens jernmalmfelt, op. cit. no. 15, 1894, et passim.

² H. Sjögren, Om Sulitelmakisernas geologi, Geol. Fören. Stockh. Förh., 1894, XVI, pp. 394-437, and Nya Bidrag till Sulitelmakisernas geologi, Geol. Fören. Stockh. Förh., op. cit., 1895, XVII, pp. 189-210, map.

³ F. Svenonius, Om Berggrunden i Norbottens Län, Sver. Geol. Undersökn. Afh., 1892, ser. C, no. 126, 43 pp., map; Öfversigt af Stora Sjöfallets och angränsande fjälltraktens geologi, II, Geol. Fören. Stockh. Förh., 1899, XXI, pp. 541-570.

⁴ P. J. Holmquist, En geologisk profil öfver fjällområdena emellan Kvikkjokk och norska kusten, Geol. Fören. Stockh. Förh., 1900, XXII; also Sver. geol. Undersökn. Afh. ser. C, no. 185, 100 pp., map.

According to Holmquist, a syncline of the first order, or, using the expression adopted in this work, a coulisse valley, formed of mica-schist, and of extraordinary breadth, strikes inland of Bodö to the north-north-east straight across the Salten fjord. At a distance of only 50 kilometers east of the sea we first reach the parallel anticline; it is a band of marble. This is followed by another syncline up to the shores of the Langvand. We now reach Sulitelma (1,877 meters) a mighty mass of olivine-gabbro. Near its southern foot the strike of the folds has turned from north-north-east to due east, and here the stalks of Crinoids were found in the schists. Beyond the Swedish frontier we enter the region of overthrust, represented by a great mass of mica-schist and quartzite. Though the overthrust mass is not so broad as in the south, yet its eastern margin, the glint, in the neighbourhood of Kvikkjokk, is about 180 kilometers from Bodö. Here it is divided into numerous flat-lying overthrust flakes, and the thrust planes are inclined contrary to the movement, which thus followed a rising direction. In the flake between Sulitelma and Kvikkjokk the movement was probably directed rather more from north to south, and has produced an east-to-west strike in the neighbourhood of Sulitelma.

Once more we find along the glint, beneath this overthrust mass, the flat Cambrian beds of the eastern type (*Hyalolithus* series), and they rest upon the gneiss and granite of the shield.

Some further details have already been mentioned. Vogt found the fragments of a great eruptive region in the *Lofoten islands*. The island of Flakstad, parts of Mosknäsön, and of Vestvaagö, a great part of Langö with Oeksnäs, and some parts of Hindö are formed of olivine-gabbro, labrador-rock and augite-syenite. The comparison drawn between the Lofoten islands and the western Hebrides, which was based on older observations (II, p. 56), is therefore unfounded. These parts of the archipelago, of considerable size, rather resemble the olivine gabbro of Sulitelma, and in all likelihood the Lofoten islands also belong to the coulisses of the great folded range¹.

A horizontal and unconformable covering of sandstone, devoid of fossils (Gaisa system of Tellef Dahll) extends from lat. 69° N. onwards, and conceals more and more completely the folded formations. It forms the greater part of the coast, from the Alten fjord up to the Varanger fjord².

Relations of Scandinavia to Scotland. Törnebohm's interpretation of the structure of the western Scandinavian mountains as due to a great overthrust has raised the objection that an almost horizontal movement

¹ Vogt, *Norsk marmor*, pp. 176-184.

² It is to this sandstone that the observations of Reusch and Strahan on the inclusion of glacial boulders refer. H. Reusch, *Skuringsmerker og morænegrus eftervist i Finmarken fra en periode ældre end istiden*, *Norges Geol. Unders.*, Aarbog for 1891, and A. Strahan, *On Glacial Phenomena of Palaeozoic age in the Varanger Fjord*, *Quart. Journ. Geol. Soc.*, 1897, LIII, pp. 137-146.

of one flake of the earth's crust upon another for a distance of nine to ten degrees of latitude, and in places over a breadth of 100 kilometers, exceeds all our conceptions of the dynamic processes which affect the earth. But our conceptions must conform themselves to facts, and in this matter there is scarcely any important difference of opinion. On the contrary, we see clearly that what we have before us is only the ruins of a still greater structure. Brögger points out that the highest-lying rocks are frequently the most profoundly altered¹, and Herr Törnebohm draws my attention to the fact that at Sjiangili, south-west of Lake Torneå, a series of schistose rocks, with a violently squeezed granite at the very summit, rests upon the primitive formations of the shield, and on sparagmite, which presents scarcely any trace of compression. This shows that a weighty load of superimposed mountain masses has been removed. We know not how far the glint has been driven westward by denudation since the Devonian period, and thus we cannot measure the full breadth of the overthrust, nor its complete length either to north or south.

But throughout the whole region in which the facts are visible the overthrust parts tend to pass westwards into a folded range formed of long coulisses with a general direction to the north-north-east. In this range the anticlines and synclines of the first order (coulisses) are fairly broad, but accompanied by many secondary folds, and affected by dynamic metamorphism to a very high degree. In the overthrust part also we see compression, but indications of an extraordinary extension of the rocks (rolling out) predominate over large areas.

Holmquist, whose section from Bodö to Kvikkjok we have already mentioned, has attempted a hypothetical explanation of the phenomena: this is illustrated in the diagrams given below (figs. 20 to 23)².

In the north the fundamental rocks of the shield plunge more or less steeply beneath the glint. The windows, which occur further south (pl. VI), lie, for the most part, nearer the eastern border. In the west, in the deep valleys of the folded mountains and on the sea-coast, the shield is nowhere exposed. The dip of the beds in the coulisses, which, as shown by the bands of marble, is often very steep, suggests that its continuation must lie deep down beneath the existing west coast.

Holmquist's hypothesis starts with a trough-like symmetrical subsidence with mutual approximation of the two limbs (figs. 20 and 21).

Since, however, the folding is known to become gentler in the west, towards Trondhjem, and since throughout the peninsula the strongest dynamic effect is produced towards the east, an asymmetrical subsidence seems to be more consistent with the facts (figs. 22 and 23). From this Holmquist

¹ Brögger, *Lagfolgen på Hardangervidda*, pp. 138 et seq.

² P. J. Holmquist, *Bidrag till diskussion om de skandinaviske fjellkedjans tektonik*. Geol. Fören. Stockh. Förh., 1901, XXIII, p. 51-71.

concludes that, owing to the continuous subsidence of the eastern part (i.e. of the shield or foreland) *the overthrusting practically becomes an underthrusting*¹.

Strictly speaking, however, this explanation does not solve the problem, but only removes it to an unknown depth beneath the surface. This becomes clear if we attempt to apply the natural scale (100 kilometers) to the horizontal parts of figs. 22 or 23. Nevertheless, the representation harmonizes perfectly with the otherwise almost inexplicable subsidence of the entire mass in a single mighty curve directed to the north-west, such as has been described north of lat. 69° N. (II, p. 58, fig. 6). If, then, to

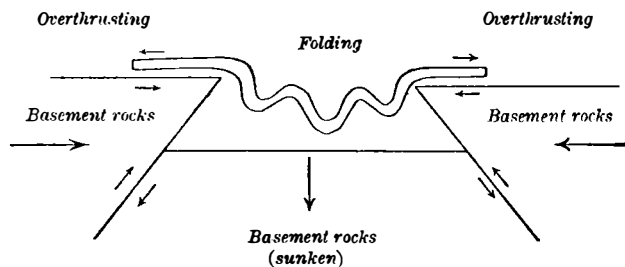


FIG. 20.

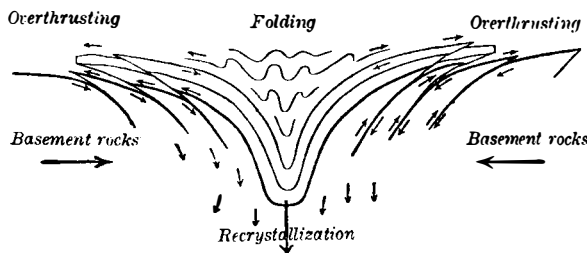


FIG. 21.

Hypothetical explanation of the Scandinavian overthrusts, after Holmquist.
Symmetrical movement.

the older ideas, we add Törnebohm's hypothesis, that Rismaalstind and Hattevarre are masses moved horizontally to the east, then it certainly appears as if the movement had come from below, or, as Holmquist thinks, that subsidence and underthrusting of the foreland have occurred.

The movement to the east-south-east, which is exhibited by the Scandinavian overthrusting, is contrary to all the great movements which have occurred in western Eurasia. In its extension to the south-south-west in Scotland, it has, however, turned completely round into the opposite direction—to the west-north-west. Here it becomes the *first step in the repeated*

¹ Holmquist, tom. cit., p. 67.

reconstruction of Europe and at the same time forms a part of the encircling frame, within which the more recent foldings describe their curves (II, p. 130).

If we are prepared to push Holmquist's theory still further, we must either imagine a fault-trough, the eastern part of which is visible in Scandinavia, the western in Scotland; or a second asymmetrical and inverse subsidence; or finally a single contorted plane of dislocation extending over the whole region.

The pre-Cambrian gneiss mountains of the western Hebrides are completely separated by this zone of disturbance from the pre-Cambrian rocks of the Baltic shield. The Eriboll strike-lines, if prolonged, run far

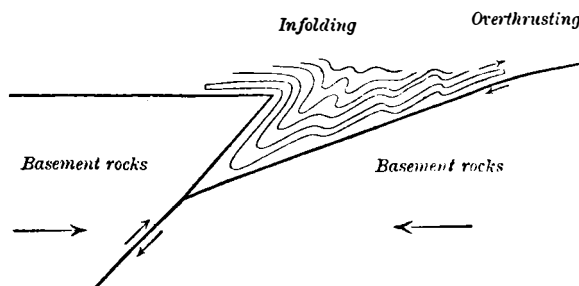


FIG. 22.

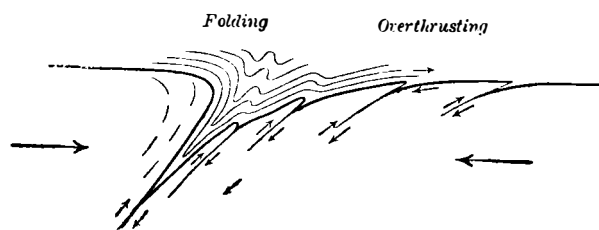


FIG. 23.

Hypothetical explanation of the Scandinavian overthrusts, after Holmquist.
Asymmetrical movement.

west of the Scandinavian glint into the North sea. But the great fractures south of the glint, which divide up Scotland (II, p. 78, fig. 10) although in part of more recent age, assume a similar direction. Thus our knowledge of the inner structure of the Scotch horsts acquires a new significance. In the most southerly of these horsts, the Southern Uplands, Lapworth has succeeded, after long-continued investigation, in classifying the rocks, notwithstanding the great mechanical disturbances they have undergone; and a detailed description of the structure of this mass has been given by Peach and Horne¹.

¹ B. N. Peach and J. Horne, *The Silurian Rocks of Britain, I, Scotland*, Mem. Geol. Surv., 1899, 8vo, 749 pp., map, in particular p. 71 et seq.

The strike in the Southern Uplands is not quite parallel to the fracture which runs south of Edinburgh, but is directed somewhat more to the north, corresponding with the general Caledonian strike. These Uplands, in their northernmost part, consist of the lower divisions of the lower Silurian, their central part of the upper divisions, their south border of upper Silurian. All the beds are very closely folded; some members, folded more or less vertically on themselves, attain a breadth many times greater than their thickness. The thicker beds of the lower Silurian form in the north a fan open above, the parts of which dip from north-west and from south-west towards the axis, and nearer the middle region a second fan which opens downwards. Associated with these beds are many intercalated layers of volcanic rocks, which have also suffered from pressure.

These altered Silurian beds are continued towards Ireland, and the peculiar lava-flows and Radiolarian beds of the Arenig group may be traced towards the south-west as far as Slieve Bernagh (north of Limerick, lat. $52^{\circ} 45' N.$). The dynamic alteration of the rocks by the Caledonian movement extends thus far without diminution; then follows, stretching right across Ireland, the outer border of the Armorican mountains.

It is true that in these inner and southern parts of the Caledonian system, Cambrian and pre-Cambrian rocks are not entirely absent. But opinions differ in regard to many outcrops described as gneiss, and there is nothing corresponding to the great gneiss ranges which are encountered elsewhere on the inner side of important regions of folding and overthrusting. The Southern Uplands, on the other hand, as well as the western couliesses of Norway are a good example of a folded region, formerly believed to consist of much older rocks, where patient investigations have succeeded in recognizing fossiliferous sediments in compressed folded zones¹.

This fact may perhaps be cited in favour of Holmquist's view. It may be taken as proved that throughout their course from the Armorican border in the south-west of Ireland (lat. $52^{\circ} 30' N.$) across the whole of Scotland and Scandinavia, and as far as those traces which are visible beneath the unconformable covering of sandstone in the most northerly fjords (up to lat. $70^{\circ} 30' N.$) the pre-Devonian movements must be regarded as manifestations of a single tectonic phenomenon, which maintains a constant strike to the north-north-east, notwithstanding the fact that the movement is directed in Scandinavia to the east-south-east, and in Scotland to the

¹ e. g., C. Callaway, *The Present State of the Archaean Controversy in Britain*, *Geol. Mag.*, 1889, 3 Dec., VI, pp. 319-325; On the Origin of the Gneisses of Anglesey, *Quart. Journ. Geol. Soc.*, 1897, LIII, pp. 349-357; Grenville A. J. Cole, On Metamorphic rocks in East Tyrone and Southern Donegal, *Trans. Roy. Irish Acad. Dublin*, 1900, XXXI, pp. 431-472.

west-north-west. Alike in the south and in the north, its end is buried out of sight, and it may not impossibly be continued into Spitzbergen, where the Devonian unconformity appears in the Liefde bay system (II, p. 68).

Results. In Asia we have distinguished: 1. The *pre-Cambrian vertex*, which is prolonged eastward as far as the Pacific ocean in younger peripheral arcs, harmoniously arranged. 2. The *Altaides*, which proceed from the more recent vertex, the Altai, surround with their eastern branches the ancient vertex in the south, apparently fuse further to the east with the peripheral arcs of the ancient vertex, but split up towards the west in the virgation of the Thian-shan. Finally, 3, the *southern marginal arcs*, the most easterly of which, the Burman arc, receives a branch of the eastern Altaides.

In eastern Europe the southern marginal arcs (3) find their continuation in the Tauro-Dinaric arc. The Caucasus belongs to the branches of the Thian-shan (2). *It thus appears that the Russian platform is a part of the ancient vertex (1), and, indeed, of the Sayan moiety.*

All its more important features point to this: its general position, its pre-Cambrian age, the constant Sayan strike of the folds which run to the north-west or north-north-west in the south, and to the north-north-west in the north, until still further north they pass into a north-north-east direction, and finally its resemblance to the island arcs. *The ancient foundation, which disappeared from sight on the banks of the Yenisei, now once more comes into view.* At the same time we are again impressed by that extraordinary constancy of the strike which distinguishes the oldest parts of the earth's crust and contrasts so remarkably with the diversity met with in later formations. This constancy attracted Richthofen's attention in China; it was remarked by Tscherski in the mountains of lake Baikal, and Karpinski found it no less clearly displayed in the Russian platform.

The western part of the vertex lies on the whole further north than the eastern part. Towards its southern border the ancient structure suffers from disturbances produced by the branches of the Thian-shan or completely disappears from sight.

We sought in vain to discover whether the bordering mountains, arranged in coulisses advancing from the northern banks of the Hoang-ho, form a junction with the Great Khingan, or, in other words, whether this branch of the Altaides bends back into the eastern regions of the ancient vertex. Equally in vain did we follow Muschketow's footsteps in his investigations as to a possible continuation of the great Kara-tau along the watershed between the Aral and the Irgis. In each case the question is really the same. Our object is to determine whether a branch of the Altaides, the Kara-tau, turns back into the ancient vertex. But whatever the future solution of this question may be, it is certain that the Urals present a structure in harmony with the folding of the vertex, that in the valleys

of the upper Aiat, Tobol, and other rivers, these mountains disclose far to the east their denuded folds, and that towards the west they give off coulisses which show that on this side also there exists a certain unity in the substructure.

The Urals are a group of posthumous folds of the ancient vertex. As in eastern Asia, the folding movement is directed towards the east, and in the boundary arcs towards the south, so in the Urals it is towards the west. Yet the Urals can scarcely be described as a peripheral formation, because a considerable mass of pre-Cambrian—the Russian platform—lies to the west, that is, outside them. It is true that we do not know what is the structure of the floor of the Pacific ocean where it lies between the island arcs, and if the Russian platform and the fluvial region of the Petchora were now submerged beneath the sea, as they once were during a long period, the Urals would completely resemble one of the peripheral arcs of the east, and Nova Zembla or the peninsula of Kanin would recall still more closely the island arcs of the Pacific margin.

A great part of the ancient vertex of Eurasia is buried beneath the more recent sediments of the Obi; it reappears in Europe; in the extreme west we encounter the Scandinavian overthrusting. Strange as the question may appear, it may yet be asked, whether the eastern Carpathians, if denuded to an equal extent, would not likewise reveal through their windows either the ancient platform or its horizontal Silurian covering (I, p. 188), and in the western Alps the relations of the compressed synclines of the Briançonnais to the recumbent sheets may well suggest a comparison with the tectonic phenomena of Scandinavia.

In this way the vertex in the north, sloping out of sight beneath the surface, and the tonalite cicatrice in the south, bound the space from which one after the other the two terminal branches of the Altaides emerge in the west, first the Variscan-Armorican and then the Alpine branch.

Thus, though it puts on one side a number of open questions, and is still vague or incomplete in many important respects, our description of the trend-lines has at last reached these regions. This part of the earth's surface does not coincide with the last prolongations of the western Altaides nor, as a consequence, with the western end of the Eurasian structure. It does not lend itself to a general survey of the whole of this great tectonic unity, but it marks at least the entrance to regions, where the trend-lines are better known and have already indeed been thoroughly established. We can, therefore, proceed more rapidly with our study of the remaining parts of the plan, and shall be able to turn occasionally to questions dealing less with the plan itself than with the further development of the folds; until our return to the north of the ancient vertex, and the junction of the ranges of Verkhoïansk with those of Alaska again renders it necessary to enter into fresh details.