The Archæan Formation
of the
Abukuma Plateau.

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With Plates XXII-XXVII.

I. Introduction.

Dr. Edmund Naumann, in his excellent little work *Ueber den Bau und die Entstehung der japanischen Inseln*, has proposed a primary division of all Japan into Northern and Southern, by a remarkable, great, geotectonic line, a "*fossa magna*," which, as he says, traverses the whole breadth of the Main Island, from the Pacific Ocean to the Japan Sea.

In spite of a controversy that has arisen between Dr. Naumann and Dr. Harada, as to the existence or non-existence of that geologic moat, it must nevertheless be admitted that that division is in every way a most satisfactory one. The South was the cradle of our civilization, while the North was, down to the middle ages, the home of the Ainos. The climate of the South is sunny and mild, being influenced by the warm, genial Kuro-shiwo that washes the Pacific coast; while the North is chilly, for the polar current runs close by the shore.

That geotectonic line is also approximately the boundary of the vegetation of the *north subtropical zone*,[1] or the zone of *Pinus Thunbergii*, and *Ternstroemiaceæ* are rarely found to the north of that limit. Thus, from various sides, geologically, historically, and climatically, as well as phytogeographically, this line serves as the boundary for the great natural division of the Empire.

North Japan begins from the east side of the Hakoné mountains, running straightforwards, in almost meridional direction, towards Hokkaidō ; and along its Pacific side is to be seen a relic of a once gigantic Archæan realm, though disturbed in various ways. Between this pre-palæozoic band and the backbone of the island, longitudinal and radial valleys have been scooped out, those of the Abukuma-gawa, Toné gawa, Naka-gawa, and, lastly, of the Kuji-gawa.

The south end of the above-mentioned Archæan belt has been briefly sketched out by the present writer in one of his former papers,[2] *On the so-called Crystalline Schists of Chichibu*; the present one is an instalment of the results accruing from several occasional trips, since made in the northern prolongation of the same belt, *i. e.*, the Abukuma Plateau.

II. The Abukuma Plateau.

Proceeding northwards from Mito, in the province of Hitachi, once the resident-town of the princes of the same name, through Hamakaidō or the coast-road of Iwaki, to the mouth of the Abukuma, we there get a tolerably good view of the physical features of the plateau. The scenery is simple, but grand ; the thickly wooded, precipitous escarpment faces the sea, with an approximately meridional

[1] M. Fesca, Beiträge zur Kenntniss der japanischen Landwirthschaft, Allgemeiner Theil, Karte der Vegetationsgebiete, Tōkyō, 1890.

[2] This journal, Vol. II., p. 79.

trend. The general aspect vividly reminded me of the Sambagawan chain of Shikoku, as viewed from the Seto-uchi side. Below, down the steep declivity towards the plain, the precipitous wall is flanked on the east by the palæozoic sandstones and clayslates, which gradually submerge themselves under the tertiary and still later formations; the surface deposits of the lower plain, or rather of a raised beach, being a thick accumulation of granitic blocks and coarse sand.

The superficial covering of diluvial deposits, just referred to, is mainly composed of sand and gravels, with little or no clay that might keep hold of the percolating waters. Being of such a coarse and porous texture, the dry soil is no better than the pumice ground of Nasu, or the region around Volcano Bay in Hokkaidō. For this reason, we find here many lonely "haras," or prairie-like ground, 2-4 km. in breadth, along the shore, such as the Hara of Sōma, Harano-machi, and Chūka.

These sterile flats, together with the underlying tertiary strata, terminate abruptly at the water's edge, forming precipitous bluffs, interrupted only by occasional indentations of alluvial depressions.

The region lying to the west of these grassy deserts is the elevation of Abukuma. It extends over the provinces of Hitachi and Iwaki, stretching north and south for about 150 km. with an average breadth of 45 km. It is separated from the backbone of North Japan by the meridional valleys through which the rivers Abukuma and Kuji make their way; and its north and south sides are limited by these streams, which, after making an easterly trend, finally discharge their waters into the Pacific basin. The general outline of the plateau thus defined is consequently elliptical.

The *physical aspect* of the elevation presents a typical physiognomy of a plateau-character, with the mean height of 400 m. It is a broad, gently undulating surface, relieved only by some few prominent points, the highest being the Yomogita-yama (933 *m.*), with abrupt bluffs along main drainage-channels, usually in an east and west course. The hilly table-land faces the Pacific sea-board, as already mentioned, with a steep escarpment five to six hundred meters down to the plain below. On the west the slope is scarcely perceptible, and the plateau merges gradually in the fertile valley of the Abukuma river ; only in a few places is the fall very marked.

The field of my study does not comprise the entire plateau, but is chiefly confined to that portion between the cities of Taira and Tanagura (Plate XXII). As the stratigraphy of the Archæan formation of this country has not hitherto been systematically worked out, it was my desire to know something of the sequence of superposition of the schistose series ; and this point I have always had in mind during my trips. On the other hand, I cared but little about the topical distribution of special groups of rocks and their reciprocal boundaries, leaving these details to the mapping geologist, Mr. Ōtsuka, who is now prosecuting the field-work of this region.

III. Archæan Geology.

General Statement.

The Archæan rocks of the Abukuma plateau, like those of other parts of the world, are separable primarily into two main divisions, viz.: an upper, chiefly schistose, bedded ; and a lower, of the granitic, dioritic, or syenitic type of mineralogical composition, but more or less gneissose in structure. In the (*a*) *upper* division there can be recognized at least two leading groups. One of these is developed in full advantage on the way from Taira to Takanuki, through the narrow gorges of Gozaisho. The other is found in its typical form in the region lying to the west of the former, and occurs between the base of the Gozaisho rocks and the Laurentian. The present paper is the first attempt that has ever been made to classify the oldest rocks within the confines of the Japanese islands. Being unable to correlate the series of the upper division with any with which I am acquainted in the geology of China and Corea, I propose now to name the first group the *Gozaisho series*,[1] the second the *Takanuki series*.[2] In the (*b*) *lower* division distinctions of stratigraphical sequence and relationship, if any such ever existed, have been obliterated. For this assemblage of rocks, viz., the lower division of the Archæan, the well-known term *Laurentian*, so named from the Laurentian Mountains in Canada, and not from the St. Lawrence River, is retained.

The leading divisions of the Archæan for this region may, from what has been stated, be arranged in the following scheme, according to the order of which the geological features of the region will be considered in detail:—

Archæan.....	*Upper division.*	α.	Gozaisho series.—(Huronian?)
		β.	Takanuki series.
	Lower division.—		Laurentian.

A more comprehensive statement of the results arrived at, will be given in the summary, after the facts, upon which these and other generalizations are based, have been set forth.

IV. Stratigraphical Relations and Structure—Sections.

Having sketched briefly the general aspect of the plateau, and pointed out my aim, I may now consider the stratigraphical composition of the series. It was found that it is usually disposed in

1 御在所,菊多郡,磐城國. 2 竹貫村,東白川郡,磐城國.

sharply folded troughs and in extensive, detached masses by frequent intrusions of all sorts of younger and older granites, which through horizontal pressure assume at times a gneissose structure. I have selected for discussion a number of lines of section where the whole complex so far as represented is favourably exposed. The first of these sections,[1] A-B in Plate XXV, is that lying furthest towards the south, and is taken along the road that joins the small port of Hirakata on the east, and Kawakami in the Kuji valley, for a distance of 24 km.

From Hirakata to Yamagoya, the road gradually ascends through paddy-fields. At Yamagoya, ochry sandstones and grey shales make their appearance, with thin seams of lignites which seem to be of tertiary age, as is indicated by the presence of a few fossil plants,[2] such as *Sequoia Langsdorfii* Brgt., *Juglans nigella* Hr., *Juglans acuminata* Braun., *Carpinus* sp., *Acer* sp., *Vitis* sp. This is underlaid discordantly by a black, coarse, massive rock (G B) with the aspect of a gabbro, covered with red soils and "niggerheads." As is usually the case, excellent exposures of this rock were not found, such as to disclose the relation with the adjacent complex. Under the microscope it is a typically coarse-grained rock, consisting of hornblende and feldspar, with but few remains of augite. The feldspar is grey, contains a number of rods, arranged in some determined direction, and is said to be the cause of schillerization, as is explained by Prof. Judd. The light-yellow augite occurs detached within the hornblende in the form of grains, as if it had been absorbed by the latter—a phenomenon very common in gabbro-diorites. Through weathering a portion of the feldspar has been removed, and the black components come into relief, so as to produce almost a slaggy aspect.

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1 The positions of this and other sections are indicated by thick lines, with corresponding letters on the map, in Plate XXII.

2 Explanatory Text (Japanese) to Section Kitsuregawa, published by the Geological Survey of Japan.

Next comes a peculiar, black rock (P Y), of massive appearance and more or less schistose in structure. It is almost entirely made up of large hornblende-individuals with some traces of feldspar and augite. This is evidently part of the gabbro-diorite, crushed and compacted to the present form, and accompanied by a new formation of hornblende, which occurs in lenticular spaces with tolerably perfect crystallographic outlines. How this is related to the diorite is as yet unknown to me. If this relation were thoroughly examined, some light might be thrown on the genesis of schistose hornblende rocks, which are of wide distribution in Abukuma and elsewhere.

The gabbro-diorite re-appears from Yōjigata as far as the place called Hirasodé, interrupted at its middle by a mass of hornblende-granite. On ascending the Hanatate pass to Saimaru, we see again the hornblende-granite, often containing detached masses of titanite-hornblende schist[1] and also small fragments of it (marked × in the profile), which produce the appearance of a breccia, cemented by a granitic material. The whole is frequently traversed by yellowish, fine-grained aplitic or pegmatophyritic dykes. The included amphibolite dips towards N. E. with the strike of N. 45° W.

We then proceed westward from Saimaru, through a thickly wooded, steep ascent of the Nakayama pass, locally known as "Nakayama Sanri," and finally come to the top, beyond which an interesting series of the Archæan schists may be seen. It is mainly an alternation of (*a*) the titanite-hornblende schist, (*b*) mica-schist, and (*c*) gneiss-mica schist; the second often approaching both in its composition and appearance to a true quartz-schist in losing either biotite or muscovite. The whole complex is included by the present writer under the *Takanuki series*, and considered by him to be the oldest

[1] This is the rock that largely enters into the composition of the upper horizon of the Takanuki series.

member of the upper Archæan group of Japan. Special descriptions of these rocks are given in another chapter.

As may be clearly understood from the profile, the whole of the Takanuki series is pinched in between hornblende-granite, and this fact serves as an example of undoubtedly irruptive granite, having literally taken up with it a part of the crust of the earth in its bosom, whatever may have been the nature of the irruption, whether passive or active.

As the schists are flanked on both sides by irruptive matter, and as all dip at very high angles, we can roughly estimate the breadth of the *lower member* of the Takanuki to be 5 km. We do not here take into account the thickness of the upper member, *i. e.*, the titanite-amphibolite (U T A), which makes up only an insignificant part of the section.

At Yama-no-Ogawa the gabbro-diorite (G B) again makes its appearance as a large boss. From here to the village of Kawakami, we find nothing but the hornblende-granite (H G), variously intruded into by the younger biotite-granite (B G) and pegmatophyritic dykes (*d*). Near the last-mentioned village, the hornblende-granite assumes a gneissose structure (G H G) with the strike north and south.

The second line of section selected, C-D in Plate XXV, is one drawn westwards from Kadōno, 12 km. west of Taira, across the ridge of Gozaisho to the west of Takanuki. This is the best profile one can get of the whole region, as the line goes approximately across the strike of the complex, which embraces nearly the complete series of the Archæan rocks to be studied, excepting the upper horizon of the Takanuki series. It is interesting chiefly as showing the stratigraphic relation in a clear manner in favourable exposures found along the transverse valley through which the brawling Samé-gawa makes its course ; and one of the ways of communication across the plateau is cut out of the rocks along the left bank of the river. This road we call the "Gozaisho dōri."

The basal member lies in a somewhat elevated portion of the plateau (Takanuki, 315 *m.*) on the west, while the eastern half of the section comprises the younger series. The bedding of the rocks is always disturbed, and that of the Gozaisho complex in particular, wherever it can be detected, as is frequently the case, is vertical. If we take into consideration, however, the enormous jamming together which the rocks have undergone, we can easily imagine as a result the complete parallelism of all the structural planes, affording a false appearance of a continuous section at right angles to the plane of deposition. Hence it is not safe to infer much from a twenty-three kilometers section of schists as to the original normal thickness. It is evident, however, that such thickness must have been enormous. The right half of the section, grouped together by me in one series as the *Gozaisho rocks*, seems to be tolerably free from great and irregular disturbances, and to be all tilted up in vertical position; and of these schists I venture to advance figures for the thickness, which is probably not less than 10,000 meters.

The thick mass of the Gozaisho schists terminates on the east near Kadōno, being there covered by nearly horizontal layers of the tertiary shales and sandstones. At no great distance from this spot, brown coals are now being profitably worked in the same bed. At Negishi, a greenish, fine-textured, rather massive schist crops out along the banks in a vertical position with a slight inclination towards the east. It has the aspect of a clastic rock, and is like a hardened deposit of volcanic ashes, with here and there, not infrequently, white, garnet-bearing quartzite (marked Q in the section C-D).

This is followed to the west by alternate bands of green and white schists, intruded into at times by a hornblende-granite (H G).

From near the Gozaisho temple, the green schists become more fissile, and intercalated with a black mica-schist (marked M.) To the westward, in the vicinity of the district-boundary of Higashi-Shirakawa and Kikuta, the green schists gradually disappear and give place to a black, crystalline hornblende schist, which occupies the basal portion of the series. The thick complex of schists which we have hitherto traced from Kadōno to Ishizumi is very persistent and monotonous in character throughout.

Having briefly considered the lithological succession of the voluminous, schistose hornblende rocks, of which the whole gorges and the solitary ascents of the Gozaisho road are composed, I shall add a few words on their nature. These rocks strike north and south dipping eastwards with very high angles, and being usually on end, or vertical. Such being the case, it is quite impossible to form a definite idea as to the sequence of superposition within short distances; but viewing the whole series at large, I cannot help thinking that those lying eastwards must be stratigraphically younger than the schists on the west.

The rocks at the west end of the Gozaisho Narrows, consequently the lowest of the present series, bear, as I have already had occasion to note, the unmistakable physiognomy of a genuine crystalline schist. They are laminated, perfectly fissile, evenly planed; in short, they present none of the signs that would show them to have been formed from some antecedent rock or rocks through metasomatic and paramorphic changes so profound, that their original characteristics would have been effaced beyond recognition. But the higher we ascend towards the horizon, the rocks become less fissile in structure, appear more compact and clastic, and eventually pass into a green slate, made up apparently of the ashes and mud of volcanic ejectamenta, subsequently changed to the present form through varied dynamic metamorphism. It is practically impossible to draw a hard and fast line between the varieties they present; but altogether they form a lithological continuity and a harmonious whole, although, when their extremes are compared side by side, they appear at first sight to have nothing in common with each other. As I have elsewhere pointed out, it is very interesting to note that at the higher horizon are found the light-coloured and rather hard, more compact and chloritic varieties, resembling an altered trap; while the less hard, perfectly fissile schists crop out at the basal portion. The gradual changes which are observed between multifarious varieties appear to be due to the operation of some cause, of the nature of which nothing certain can be at present made out.

I am not bold enough to assert freely that such basal, crystalline members are the dynamo-metamorphic products of massive, syenitic or dioritic rocks, crushed and remodelled to the present form, as has been done by many great authorities, who claim excessive and profound effects for pressure-metamorphism. For them there are properly no gneisses and mica-schists, but those derived by pressure from massive rocks. Taught by the modern school of dislocation-metamorphism, I was at first misled, while travelling through the Abukuma plateau, last summer, to consider the amphibole schists, and even the gneisses and mica-schists to be crushed products; the first derived from dioritic and syenitic rocks, the second and third from granites. But gradually I became convinced that *at least a part of the hornblende schists of the Gozaisho series is of primary origin* (though its exact mode of formation remains unknown), *and not a product of the crushing effect of a mass-movement of the earth's crust.*

In this connection, something may conveniently be said on the mode of formation of those gneisses and schists that come below the *Gozaisho complex*, and which are now included by me in the *Takanuki series* and the *Laurentian.*

There are in this region numberless modifications of granites, syenites as well as gabbros, that are more or less schistose. This once seemed to me an invincible circumstantial evidence of the crushed-rock origin of schists and gneisses, and apparently harmonized well with all the facts, then observed in the field. But being unwilling to come to a hasty conclusion, I visited the plateau again during the last Easter-holidays, and this time I found some of my former conclusions to be illusory. There are of course *schistose granites*, spoken of usually, though very improperly, as granite-gneiss or gneiss-granite, which are really connected with the massive granite of irruptive origin, and these I consider to be of the age of Laurentian. There are again, *forming another group, gneisses and mica-schists*, at one time included by me without distinction in the same class as the Laurentian gneisses. They are intercalated between bands of a coarse crystalline limestone, near Takanuki, for example.

Overwhelmed by the array of facts continually presented to my eyes during field-work, I paid little heed to the interbanded limestones, which besides give little hope of affording fossilized remains. Now, Reyer says, in his *Theoretischen Geologie*, that carbonate rocks may reasonably occur inserted between granites through interrupted up-welling of a plastic magma by subsequent pushes (*Nachschub*). Examining closely the mode of occurrence of these rocks, I found the schistose granite to be really granite (Laurentian) with that special structure, due surely to the effect of pressure; while the limestone-bearing gneiss, and the mica-schist (Takanuki series), both having a distinct parallel arrangement of component minerals, are, so to speak, primary rocks, and should not be confounded with the foliated granite. The two classes of rocks are quite distinct in origin, and are not issues from a common stock of granite. No geological continuity is ever found between them; on the contrary, the Laurentian granite and the foliated granite intrude into the overlying, genuine gneisses of the Takanuki series. Good exposures of their contact will be frequently mentioned when explaining the profiles in the sequel.

We now return to the section which we left at Ishizumi, in Gozaisho.

Going westwards for a short distance, we arrive at the upper edge of the rapids, whence the Samé-gawa takes a narrow and swift course down from the plateau to the lowland, which lies further to the east. Here is the boundary of the districts, Higashi-Shirakawa and Kikuta. As may be clearly understood from the profile (C-D), the above mentioned Gozaisho series are brought to a sudden close by an outcrop of granites. The massive rocks are dome shaped; the peripheral, schistose hornblende-granite with its enclosed patches of the titanite-amphibole schist has a schistose plane which here dips eastwards with high angles, but on the other side has westward inclinations. The nuclear part is a young biotite-granite (M G) with much quartz and less mica; this hard rock hangs over the deep gorges of the Samé-gawa.

The rock which we first meet with in coming from the east is the ragged form of an old hornblende-granite, over which the road makes many crooked turns. It is a schistose modification of that granite. Examined under the microscope, it is seen to be made up of biotite, hornblende, plagioclase, orthoclase and, lastly, quartz. Biotite and hornblende, are present in about equal quantities; oligoclase, but little; clear, well-finished apatite, abundant. The orthoclase shows well-marked undulatory extinctions, and is remarkable for the zoning. The nuclear part seems to differ greatly in chemical composition, as may be seen from the usually decomposed state of its interior. It is a syenitic or dioritic granite. Misled by its rudely schistose structure, I once looked upon it as an intermediate stage between syenite and the amphibole schists of the Gozaisho series; and then thought I might be able to trace the gradual passage from one extreme to the other. During my second visit to this district, however, I discovered a spot where the amphibolite comes in direct contact with the schistose granite, the former being sharply cut by the truly irruptive granite with schistose structure, well exposed on an abraded cliff at the water's edge. Looked at from a distance a marked contrast in colour and structure soon suggests something quite heterogeneous, and on close examination the junction is still very clearly defined, the effusive granite cutting in obliquely, independent of the schistose plane of fissile rocks, while the latter is often convulsed and caught up in pockets within the granite. This, therefore, affords most conclusive evidence as to the heterogeneity of the adjoining rocks as regards genesis.

Having thus traced out, as closely as field conditions will allow, the limiting edges of the granitic boss and the Gozaisho series, we may now proceed to examine the mode of occurrence of the underlying Takanuki series to the westwards. The last-mentioned complex is widely separated by the irruptive mass, of which we have already spoken, from the overlying Gozaisho series, and this holds true of other sections which we have had occasion to study. The two series of the Upper Archæan are, therefore, always separated, so far as I am aware at present, by the intervention of some foreign mass, usually granite; and no line of their direct contact has been ever observed either in Abukuma, or in the upper course of the Tenrū-gawa in the province of Shinano.

The *Takanuki series* is so named from a village in the vicinity of which that complex is typically developed. The whole series is divisible into two parts; the (*α*) *upper* (U T A), embracing the multifarious alternations of the titanite-amphibole schist and biotite-gneiss; the (*β*) *lower* (L T A), being composed of a thick mass of various gneiss-mica schists and gneisses. The occurrence of the lower subdivision has been already alluded to in examining the line of section of the Nakayama pass,[1] where the beds stand vertical, but dipping in the peripheral portions of the series towards the middle point, so as to produce a fan-shaped structure of the Mont Blanc type. Here, however, the schists make a low arch with their main axis in the north-south direction, and the line of section runs obliquely across the strike of this dome-shaped mass.

The rock first met with in coming westwards from the granitic area of the district-boundary is the upper member, which forms a small synclinal at Shimo-Matsukawa, and is intruded upon by another boss of hornblende-granite. At Shimo-Matsukawa we find still the titanite-amphibole schist (U T A) with a dip towards the east at low angles ; and not far from this point, the lower member (L T A) finally makes its appearance, keeping the same dip and strike as the upper. A highly quartzose, brownish, granulitic gneiss, accompanied by a micaceous schist with plenty of garnet, is found all along the road for a distance of 6 km, until we come to the west of Takanuki. Often the whole complex has been so disturbed, in various ways and at numerous points, by the intrusion of biotite-granite, as to make one almost believe the granite to be

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[1] See p. 203.

a normal member of the gneiss-mica schist, petrographically somewhat similar to it. At Kami-Matsukawa, the schists are nearly horizontal with a dip towards the north at very low angles, and just at the west end of Kami-Matsukawa, a highly coarse-crystalline limestone, about 70 cm. thick, is interbanded between the granulitic schist, having the strike W. 20° N. and dip 30° N. E. At Kamada we meet again with the titanite-amphibole schist, now with the strike N. 40° E. and dip N. W.

The line of section, E-F, Pl. XXV, from the small hamlet of Kami-Misaka to Ishikawa, is very similar in general features to the sections A-B, and C-D. But here only a part of the *Gozaisho belt* (G Z) is to be seen, for a distance of not more than $\frac{1}{2}$ km. in breadth, flanked on either side by a granitic boss. The lower member of the *Takanuki series* is concealed from view in the present line of section, owing probably to a great dislocation line, whose southern prolongation at the west of Takanuki may be traced in the last profile; and this fault has probably brought the upper member in direct contact with the granite.

As may be seen from Fig. 8, Pl. XXIV, the above mentioned small belt of the Gozaisho rocks at the east end of the profile, is pinched in between granites B G and H G, and consequently the mode of arrangement is very much disturbed. Near a small water-mill at Naka-Misaka, a tourmaline-bearing *hornblende-salite schist* (*b*) of a rather black, massive appearance seems to abut against the neck of an amphibole-picrite (*d*), but the exact relation between them could not be made out. The *peridotite* is, on the east, in direct contact with the hornblende-granite, which is itself more or less gneissose in structure (*gn*) near the line of contact. The peridotite is followed, to the west, by bands of spotted chlorite-schist, alternating with a garnet-chloritoid-quartz schist (*c*), said to contain the unique mineral piedmontite,[1] which is of very wide distribution elsewhere in Japan, especially in the island of Shikoku. The chlorite schists are followed by another band of platy epidote-amphibole slate (*a*), which is tilted up in vertical position like the overlying rocks, and is partly corrugated at its junction with the biotite-granite (B G), indicating that the latter has broken through the former, and brought it to its present form.

Beyond the small ridge of Komori-zuka[2] (574 m.), the hornblende-granite makes its appearance, often interrupted by a later eruption of the biotite-granite, and also by the formation of aplitic dykes (*d*). Between Jūmoji and Kodaira, we meet with a detached mass of the titanite-amphibolite (U T A) of tolerably large dimensions. This soon gives way to the hornblende-granite, which is more or less gneissose (G H G), with the plane of schistosity inclining towards the east, having just the same dip as the last-mentioned patches of amphibole schist. At Nakagura the granite has acquired a peculiar habitus (Nakagura type), owing to the predominance of somewhat large grains of quartz, which gives to the rock a blotchy appearance. Farther to the west the line of contact of the granite with schists is observed, in which the irruptive nature of the former through schists is clearly marked. Not far from the line of contact, a dyke (L P) of about 2 m. thickness is found in a vertical cleft. The material of the dyke is of a dark-greyish colour with brown spots. Microscopic analysis, the details of which are given in a separate section, proves it to be an augite-dioritic lamprophyre.

From Nakagura to Sōri, through Ōtsuka and Nakata, the rocks exposed are multifarious alternations of thin bands of titanite-amphibole schists, and gneiss-mica schists (U T A). Of the amphibole

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1 This journal, *Some Occurrences of Piedmontite in Japan*, Vol. I. p. 303; also *On the so-called Crystalline Schists in Chichibu*, Vol. II. p. 93.

2 See the line of section E-F, Pl. XXV.

rocks we have to mention as chief varieties the *titanite-biotite amphibolite*, *titanite-salite amphibolite*, *titanite-feldspar amphibolite*, and lastly, *biotite-amphibole gneiss*. Those of the second category show the following modifications, viz., the *gneiss-mica schist*, *two-mica schist*, *garnet-biotite schist*, and also *hornblende-biotite schist*. The whole complex has been variously faulted in parallel lines, giving rise to a so-called stair-case structure ; at other times horizontal pressure seems to have produced a compressed arch. Again, in one case at Ōtsuka, a mass of hornblende-granite must have been squeezed along a fault-line, considerably disturbing the adjacent rock on the east, while on the other side schists seem to overlie conformably the granitic basis (Fig. 7, Pl. XXIV). This boss affords an excellent example of the schistosity of a granite. The peripheral portion is highly gneissose in structure in conformation to the surrounding rock, and little by little it gradually passes to a normal granular variety at the centre. How such structure has been brought about is not an easy question to answer. It may perhaps be the result of a crushing during epigenetic movement of rocks, or may have been produced, as Reyer[1] assumes, during upwelling of a semi-fluid magma by constant pushes (*Nachschub*), by lateral compressions.

The amphibolites and gneisses, lying to the east of the last-mentioned irruptive mass, have acquired a specially great fissility, cleaving easily into a papery slab ; and owing to its loose texture, the rock falls into a bluish-black, ashy-looking powder on weathered surfaces.

The structure of the Archæan belt at this part is undoubtedly a very complicated one, as has been suggested in the foregoing lines. The rocks are mostly brought to a vertical position, or dip at angles rarely less than 80°, with the strike of N. 20° W. Considering their present position as a result of pressure, the recurrence of

1 loc. cit.

the same zone in the section is by no means unlikely. But, making a small deduction for the breadth of the eruptive rock and a correction for the dip, we can estimate the probable thickness of the formation, and this was found to be $5\frac{1}{2}$ km. for the upper horizon of the Takanuki series.

At Sōri, where the road bifurcates, one leading to Takanuki, the other to Kodaira, an important tectonic line was accidentally discovered. Here an insignificant isoclinal valley comes from the east, through the villages of Kodaira and Nakagura, along which the present line of section was drawn. A precipitous wall on both sides of the rivulet is wholly composed of alternate bands of the titanite-amphibole schist and the two-mica schist; all of them dip westwards at very high angles with the strike north and south. A ridge along the west side of the valley, forming a naked whitish precipice, at once gives information of its being composed of a granitic material, contrasting greatly in colour and habitus with the black, schistose rock of the opposite side (Fig. 11, Pl. XXIII)[1].

If we adopt the view of the excessive effect of dislocation-metamorphism, and in accordance with it attribute the formation of banded gneisses and amphibolites to the crushing of dioritic and granitic rock by strong pressure, it is not yet easy to conceive of such sudden changes of structure at so short a distance. Therefore, I examined very closely the spot where possibly the line of junction of the schists and granite might occur high up on the cliff; and in doing so, I found actually the place where two geological bodies of entirely different origin come in direct contact, side by side, having nothing in common either in appearance or structure. The granite is the hornblende-bearing variety with an imperfectly schistose structure and its plane of schistosity inclining towards the west; and the streaky,

1 In Fig. 11, Pl. XXIII, Nakagura valley is erroneously spelled as *Nagura*.

lenticular nodules of a dioritic habitus, produced by differential movement of a granitic magma, dip with their longer axis towards the same point. The complex of amphibolite and mica-schist has also the dip in the same direction ; but it is sharply separated from the other by a nearly perpendicular line of fault, which seems to continue southwards for a long distance, with the bearing N. 30 E.

From what has been said, it is evident that the granite and schists are geologically different bodies, brought to their present situation side by side by a down-thrust of the schistose member, and *they are by no means structural phases of one irruptive stock.* Although the section now examined seems at first sight quite insignificant, and to have no bearing of geological importance, nevertheless it has been of great use to me, by showing clearly the two sets of rocks to be of heterogeneous origin. Some gneisses and amphibolites approach in their outward aspect to the schistose modification of granites, and confounding them together is very liable to occur during field-work. This in itself is to a certain extent reasonably allowable, but it would be a gross error to consider the two kinds of rocks as different phases of primarily only one species of rock. For some distance to the west, the same schistose granite with streaky nodules continues to appear along the road as far as Ishikawa, where it gradually passes into a normal granular variety, containing likewise blackish nodules of a more or less dioritic habitus. We see here a number of reddish, fine-grained pegmatophyre dykes (*d*), running N. 30° E. with N. W. dip.

The last line of section (G-H) that will be examined is drawn from Ishikawa to Shimo-Kawabe on the right bank of the Abukuma-gawa. This traverses the region from S. E. to N. W., and stretches for about 6 km. The chief interest attaching to the present section is not, however, in the bedded formations of the series, but in the irruptive rocks which, mixing with each other, cause a very complicated tectonic condition. The effusive rock that comes here into consideration is mainly granite. It is to be separated into an *older*, hornblende-bearing (H G), and a *younger*, biotite-bearing (B G) variety. They intermingle with one another in such a confused manner as to try the patience of even careful observers ; and many have entirely ignored the heterogeneous origin of the two kinds of massive rock (Fig. 1, Plate XXIV).

On the way from Ishikawa to a small height where the road ascends towards Shibukawa, we meet with the continuation of the granite-mass, already referred to in the preceding profile. In one spot a mass of dioritic habitus occurs of tolerably large dimensions. Examined under the microscope, it is found to be mainly composed of feldspar and needle-shaped hornblende, with a little biotite and orthoclase. Macroscopically it approaches in its external aspect to the so-called "needle-diorite" (marked × in the section). Not far from this point, another exposure of a similar kind makes its appearance in a road-cutting. Blackish dioritic patches of various sizes are enclosed in normal hornblende-granite, as if a dioritic scum had floated on a granitic paste, and then been torn asunder by some movement in the semi-fluid mass. The patches seem to have been once a part of the same granitic magma, slightly different in chemical composition (Fig. 8, Pl. XXIII). These should not be confounded with the caught-up fragments of amphibolite in hornblende-granite, or the hornblende-granite in biotite-granite, as the enclosed and enclosing rocks in the latter two cases differ both in age and composition, and the patches have angular outlines.

Just on the top of the hill, two large dykes (d) traverse the granite in the E.-W. direction. The material of the dykes is a pegmatic mineral aggregate with large orthoclase crystals twinned on the Baveno type. Large, opaque biotite, smoky quartz, and muscovite are other ingredients of this aggregate. A dull, brownish beryl is said to have been found in it.

The rest of the region represented in the section is entirely composed of old and young granites, which appear successively along the lines of fault after the manner of ruin-marbles. Sometimes aplitic dykes traverse the rocks irrespective of the nature of the granite. The hornblende-granite assumes at times a gneissose structure in the usual manner, as is indicated on the west end of the section G-H. From Nakano a quartz-bearing augite-andesite covers the eroded edge of the underlying rock. Near Shimo-Kawabe (*i*), fleams of a hornblende-biotite gneiss of the lower member of the Takanuki series are enclosed within the mass of hornblende-biotite granite of schistose structure, and the whole is traversed by coarse pegmatic dykes (Fig. 5, Plate XXIV).

V. Petrography of the Laurentian Rocks.

Generally speaking, the granites of the extensive region of Abukuma may be classed in two categories; the *first group* is a rather greyish-looking, medium-grained variety, in which the long prisms of hornblende (8 mm.), and the broad, hexagonal scales of biotite could be easily recognized within the admixture of the white ingredients of the rock. It is hornblende-granite. To the *second group* belong those common, coarse-granular granites of a lighter colour, built up of a flesh-coloured orthoclase, and a grey, vitreous, allotriomorphic quartz, mixed with black mica.

These two groups differ greatly in many respects ; the grey rock contains, as is usually the case, more of the plagioclases when compared with the light-coloured rock, although none of the last named rock is free from the presence of the striped feldspars. The most common rock of this region is undoubtedly hornblende-granite. It may be seen all over the district wherever exposures of granites are to be found, being often cut sharply by wide dykes of the *biotite-granite* in a most confused manner, as is represented in Fig. 1, Plate XXIV. Therefore the biotite-granite must be of later age than the hornblende-bearing variety. When such dykes of the younger granite appear repeatedly within a short distance it is often not easy to say which is the foreign mass and which the intruded one. It is not necessary to point out the localities of such occurrences, as these perplexing cases are inevitably met with during field-work.

A. Amphibole-Granites and Biotite-Granites.

The dominant rock of the region, the amphibole-granite, has, as is already stated, a very uniform composition which varies only through local fluctuations in quantity of the several ingredients. All the rocks included under the present group contain, therefore, *quartz*, *orthoclase*, *microcline*, *plagioclase*, *amphibole*, *biotite*, *titanite*, *apatite*, *zircon*, and *opaque iron ores*. To these may be added the usual, secondary accessories, such as *epidote*, *chlorite*, *muscovite*, and *iron-glance*.

Before we enter into the detailed description of the individual occurrences of granites, it may be well to speak of the minerals which enter into the composition of the rocks. Although their properties do not differ in essential points from those of other granites, still it seems well to give here some consideration to them as likely to prove of some use for the mapping geologists of our Geological Survey.

The *feldspars* are of three varieties, viz., orthoclase, microcline, and plagioclase. The secondary muscovite, resulting from decomposition, is common to all of them ; while epidote is very rarely observed, indicating that the plagioclase is of an acid nature, and consequently poor in lime. In regard to dimensions, there occur large and small individuals which, although belonging to the same generation, still differ a great deal in size even in the same rock. The orthoclase and plagioclase are both of large dimensions; but the latter is the smaller of the two feldspars, and is idiomorphic in comparison with the monosymmetric variety, while the microcline is usually of an allotriomorphic form, and is the latest in its formation[1] and the smallest in its size.

The *orthoclase* is a greyish-white form, usually devoid of well-defined crystallographic outlines ; it becomes flesh-red in slightly decomposed specimens. In the field, observers might be easily misled to consider such an orthoclase to be a different variety, and consequently would make a quite distinct type by calling the rock which contains it a red granite in contradistinction to the common grey one ; but in truth both form one and the same mass. As already stated, orthoclase is proportionally large in its size, and usually encloses a more or less idiomorphic plagioclase ; but I have never met with the reverse case. Prof. Rosenbusch repeatedly asserts most definitely, in his *Mikroskopische Physiographie, that the dogma, that orthoclase falls more easily a victim to decompositions than the other feldspars, is not based on ascertained fact* ; but I generally find orthoclases to be more dirty, crooked, and fissured, and much more decomposed than the other members of the same group, when viewed side by side in the same portion of a slice. The monoclinic feldspar is fissured in all directions, and is also characterized by the presence of abundant liquid-inclusions and other foreign interpositions, especially when compared with the other feldspars. Well-defined crystals of a brown mica, indeterminable, colourless needles looking like sillimanite, crystalloids of hornblende,

1 Dr. Dathe, when speaking of the order of crystallization of feldspars in the biotite-gneiss of the Eulengebirge, says:......*scheint nach meinen Beobachtungen an diesen und zahlreichen anderen Gneissen und Granuliten der Plagioklas zuerst, hierauf Mikroklin, schliesslich Mikroperthit und Orthoklas sich ausgeschieden zu haben.* Jahrb. d. königl. preuss. geol. Landesanstalt für 1888. p. 318. Whether the same rule may or may not be applied to an undoubtedly irruptive granite like ours, is a question for the future.

zonally constructed zircon, red iron-glance, opaque iron ores, and lastly, apatite, are the usual guests. A bluish schiller, so common in the Swedish granites, is not observed.

In the advanced stage of decomposition, the mineral resolves itself into pseudophitic scales, whose tufts and aggregates are arranged at right angles, and also parallel, to the c-axis. The epidotization seems here to have not taken place; but if it does occur amidst the feldspar-substance, then the material for its formation must have been surely derived from the hornblende, evidence in favour of this being easily deduced from the presence of ropy strings of chloritic matter directly connected with the degenerating amphibole, and penetrated and infiltrated in the feldspar along the clefts in the latter. The polarization-colour is languid and dull, ranging from yellowish-brown to grey; a prominent feature is, however, the presence of the parallel-fibrous structure in crystals in a somewhat advanced stage of decomposition.

The *microcline* is present only in small quantities. Macroscopically, it can not be distinguished from orthoclase, as their colours and lustres are quite similar. Under the microscope the microcline nature can only be recognized by its characteristic reticulated or cross-hatching structure. The mineral is usually of a small, irregular form, filling the interstices of other components, and also forming the outer zone of the plagioclase or orthoclase. It is generally fresh, and pellucid, and is poor in liquid-inclusions; consequently it can not be supposed to have been produced by the albitization of orthoclase, like that of granite in Socotra.[1] It belongs to the latest generation. At times larger grains seem to occur in the rock-mass, and these are partly changed into muscovite. Small microcline forms, together with grains of quartz, a part of the rock, producing thereby what is called the

1 A Sauer, Zeitschr. d. deutschen geol. Gesellschaft, vol. XL. p. 146.

mortar structure, or with the same, a micropegmatic intergrowth; the latter is developed on the peripheral zones of other feldspars, and the stalks of quartz, which are disposed in regular orders, stand at right angles to the faces of the enclosed mineral.

The *plagioclase* occurs in the fresh state. Muscovite is always the mineral formed from it when weathered ; no epidote crystal is ever found, a fact which speaks in favour of the acid character of the feldspar, of its being poor in lime. The quantity of the plagioclase is greater than that of the orthoclase and microcline. The plagioclase is usually of a large size, and with quartz it forms a part of the micropegmatic intergrowth. The twinning lamellation is distinctly developed, yet not so finely as in that of the labradorite series. Well-outlined clinopinacoids are seldom met with, as is usually the case in such granular rocks as granites, and the direction of extinction could be very rarely measured on that face ; some opportunities were, however, afforded for such an observation, and it then extinguished light in the positive sense at about 8° with the edge P/M. Sections with twinning lamellations make an extinction-angle of 4° symmetrically with reference to the trace of the twinning sutures. From this it may be inferred that the plagioclase in question is of an oligoclastic nature, or else is closely allied to oligoclase, perhaps albite. A feature which characterizes this variety of feldspar is its zonal structure, and the presence of this feldspar could be readily recognized by the zoning, even without examining for the existence of the polysynthetic twinning. The plagioclase is rich in crystalloids of hornblende, lamellæ of biotite, round-edged needles of apatite, and nearly ellipsoidal crystals of zircon.

The *quartz* occurs, as is usually the case in granites, in a xenomorphic, angular form. Macroscopically it seems not to have taken an important part in the composition of the rock, and in some varieties it sinks into so small a quantity as to give to the specimen the appearance of a dioritic syenite. The colour of the quartz is light-grey, and when it contains abundance of liquid-inclusions, and also stiff, bent, and broken trichites, it becomes more or less bluish in shade. These trichitic bodies come indifferently in quartzes of the granite-mass, and in the veinlets which variously traverse the quartz.

Notwithstanding the scarcity of macroscopic quartz, it is largely represented microscopically in the rock, and forms, with microcline or plagioclase, a fine aggregate between the larger individuals of feldspar, hence the mortar-structure of Törnebohm. Under polarized light between crossed Nicols, the variously coloured mosaics consist partly of the intergrowth of quartz and feldspar, radially arranged around the feldspar individuals, forming a sort of delicate fringe, and bringing about, in consequence, the pegmatophyritic[1] structure. The latter is chiefly confined to the fine-grained variety, containing richly zoned feldspar, but having only a small quantity of quartz-grains. The liquid-inclusions are abundantly present, forming band-like swarms, and the quartz containing them resembles a smoky quartz. Hexagonal scales of biotite and rounded crystals of zircon are also found as enclosures. Undulatory extinctions and optically diverse orientation of the grains show the rock to have been subjected to great pressure. It is remarkable to observe that where quartz is plentiful, striated feldspars with the cross-hatching structure are very abundant.

Accessory components are apatite, zircon, and iron ores including magnetite, titanic iron, and pyrites.

The *apatite* occurs as enclosures, especially in biotite and hornblende, and also as an independent ingredient. In the normal mass of granite it is comparatively rare, but in the caught-up granite, as well as in those of the contact cheeks of lamprophyres, tufts of apatite-needles

1 Lossen, *Vergleichende Studien ueber die Gesteine des Spiemonts und des Bosenbergs bei St. Wendel u. verwandte Eruptivtypen aus der Zeit des Rothliegenden.* Jahrb. d. königl. preuss. geol. Landesanstalt für 1889. p. 270.

pierce through the substance of hornblende and biotite, and particularly into the grains of feldspar enclosed by the hornblende of the caught-up granite. The larger apatite-crystals are short and broad, and have the edges rounded perhaps by corrosive action; the delicate, slender needles of the same mineral are sharply bounded by plane surfaces with, however, broken terminations, and are comparatively small in size. At first sight, both modifications seem not to be of identical chemical composition ; but their respective cross-sections give the clue to their true nature, and show that both modifications belong to the same mineral. The well-defined needles may be of a later origin, and their formation may be ascribed to the effect of a contact metamorphism.

The *magnetite* is sparingly present in the normal rocks, but in the schistose variety and also in the patches caught up by biotite-granite, it is plentiful, occurring either in a drop-like form, or in well-finished octahedrons. *Iron pyrites* forms part of clumps of magnetite, and performs the function of the interstitial mass between the granitic components, just like the mesostasis of younger eruptives. The octahedrons of magnetite are specially abundant within somewhat decomposed feldspars. Also in a partly altered hornblende, the same mineral fills up the clefts of cleavage-planes, appearing just like numerous black needles, all regularly arranged parallel with the principal axis of the crystal. As a whole, the formation of the magnetite seems to stand in intimate connection with the act of metamorphism. The deposit of magnetite in the valley of Chūka makes its appearance between the diatrophic clefts of a strongly compressed gneissose or schistose hornblende-granite, and the source of the iron ore must be sought for as similar to that of the formation of magnetite in the granite, already referred to. Sometimes blood-red tablets of iron-glance are interposed in feldspars with a certain definite arrangement, appearing in black needles and in minute red scales, producing thereby the so-called aventurine lustre. The other iron ore, *titanic iron*, seems to occur in the rock, since its presence is indicated by the formation of leucoxene borders around the cores of iron. *Zircon* in grains and also in crystals of the usual habitus is chiefly enclosed in the hornblende and biotite.

Sphene is only observed in the hornblende-granite from Nakatani, near Ishikawa. *Fluorite*, so common in granites, is wanting.

The *coloured components* are represented by biotite, as well as by hornblende, and form the characteristic, dark, confusedly fibrous parts and flecks in the gneissose variety of the granites. In the striped granite the mica and hornblende have the same orientation, and the base of the biotite and the c-axis of the hornblende lie in the same plane. Consequently the maximum-extinction happens simultaneously in the two minerals, along the plane of the pressure-cleavage of the rock. Apatite, zircon, and magnetite are found as enclosures in the mica, while the hornblende contains besides them crystals of biotite, showing that the latter is of earlier generation than the former. The usual chloritic material, resulting from the decomposition of hornblende is absent in the cases hitherto observed. The amphibole is remarkably fresh. The biotite is, however, partially altered into green lamellæ by the bleaching of that mineral, these changed bands being interlaced with the fresh foliæ of the biotite; and the secondary epidote is also found in the bleached parts.

The *biotite* is by far the most common of the two minerals; the absolute quantity of it may, however, fluctuate within wide range. The pleochroic halos usually so common in it are discerned here only in a few cases. Observed from the base, it is of a dark-brown shade, and sometimes so intensely coloured as to give the appearance of an opaque body. It may at once be conjectured that the mineral is highly ferriferous, and the result of an analysis made by Mr. Hida, of the

Geological Survey, establishes its chemical nature to be that of *lepidomelane.* The following percentages are those found by him:—

SiO_2	36. 60
Al_2O_3	17. 05
FeO	21. 29
CaO	trace
MgO	10. 36
Mn_3O_4	0. 70
Na_2O	5. 39
K_2O	8. 49
	99. 88

The angle of the optic axis is so small as to give almost an uniaxial stauroscopic figure.

The hornblende-granite occurs very frequently in detached masses and in lenticular forms, enclosed within biotite-granite of a more acid composition and of a much later origin. The biotite in such a *caught-up granite* presents a peculiar feature not observed in the normal mineral. The mica is here devoid of its crystallographic outlines, and the deep brown lamellæ of this mineral with different optical orientations are heaped together around the larger one. Thus the microscopic scales of the biotite with its marginal ragged structure possess the same habitus as those found universally in contact rocks, and in many of the crystalline schists. The larger crystals are interlarded with needles of apatite.

The *hornblende* has a bluish-green colour. The extinction-direction varies within wide latitudes, and gives usually larger angles than those of common species. The most distinctive feature of the hornblende of our granite is, however, its weak pleochroism, comparatively faint polarization-colours, contrary to our expectation from its deep bottle-green colour. The degree of absorption is normal : $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$.

The habitus of the crystals of hornblende is to be slender, flat, and prismatic, with the faces $oP, \infty P\breve{\infty}$, $P, \infty P\bar{\infty}$, and ∞P; twins are rare (Fig. 2, Plate XXIII.) The analytical result obtained by Mr. Hida is as follows :—

SiO_2	45. 61
Al_2O_3	4. 47
FeO	8. 92
CaO	26. 40
MgO	11. 44
Na_2O	2. 26
K_2O	0. 79
	99. 89

The hornblende in the *caught-up* granite, like the biotite, shows some peculiar marks entirely foreign to the common species. In the massive granite the crystals of hornblende are usually idiomorphic, while in the caught-up rock they are of large dimensions and at the same time allotriomorphic, playing just the same rôle as the augite in diabases in the formation of the so-called diabasic structure. In the normal sequence, as is well known from the observation of Prof. Rosenbusch, the crystallizing-out of the ferro-magnesian bisilicates precedes that of the feldspar-group. Here we have some exceptional cases, probably arising from the uncommon circumstances under which the rock reached the solid state. A somewhat large, allotriomorphic hornblende of a dark-green colour, encloses, as it were, the interstitial mass of basaltic rock, a number of equally allotriomorphic crystals of plagioclase oriented in diverse directions (Fig. 7, Plate XXIII.). The plagioclase (? albite) in the present case presents the habitus of albite with corroded appearance, occurring usually in large quantities in the schistose amphibole rocks. The hornblende occurs in the form of an ophitic plate with uniform extinction over considerable areas, just as the augite behaves within the mass of diabasic components. This ophitic plate of hornblende is well exemplified in the rock from Kawa-na, near the railway station at Iwanuma. The hornblende, like the biotite occurring associated with the amphibole, is variously pierced through by needles of apatite.

The granite-hornblende immediately in contact with the dyke of lamprophyre presents quite an anomalous feature, one deviating from the habitus hitherto described, the changes in it having been, beyond all doubt, brought about by metamorphism in coming in contact with the intruding dyke. Here the amphibole is smaller in size than the other variety, and moreover, occurs in rather flat prisms more bluish than green in colour, while its cleavage-sutures are numerous and distinct. Its crystals show diverse intergrowth among themselves, a phenomenon rarely observed in other cases ; the outlines of larger individuals are irregular and allotriomorphic. In short, the whole appearance is an exact copy of that commonly met with in some granular crystalline schists.

Among the secondary minerals may be mentioned *epidote* in somewhat large grains with its customary intense pleochroism ; it is found usually enclosed within a more or less bleached biotite or in hornblende.

The material for the formation of epidote must have been directly derived from the enclosing minerals. Feldspars, though showing an advanced stage of decomposition, are free from it, indicating that the feldspars in the present case are poor in lime. When epidote occurs, it can only be that the material for it has flowed to that spot by capillary action through the cleavage-plane, or through some fissure admitting free passage. The epidote-grains thus originated are connected by strings of chloritic materials to the mother-mineral, which is, as is already stated, either biotite or hornblende. The end-product of decomposition of the last two minerals, the hornblende and biotite, are chloritic substances, while feldspars end in producing a pseudophitic mineral, which is regularly arranged with reference to the crystallographic outlines of the original mineral. This is rendered visible in the aggregate colours of polarization by the peculiar position of foliæ of a muscovite-looking mineral.

B. Structural varieties of Granites.

a) Amphibole-Granite.

The principal rock of the Abukuma plateau, the amphibole-granite, shows a great uniformity in its mineralogical composition, but varies locally in texture with the relative proportions of the composing minerals. It consists essentially of quartz, orthoclase, plagioclase, microcline, hornblende, and biotite, the last two ingredients being present nearly in equal quantities. As all granites contain some quantities of micas, I suggest for the present rock the name hornblende-granite. The accessories are apatite, zircon, and iron ores; titanite is rare. The general colour is rather greyish; but the weathered rock is of a rosy tint, owing to the oxidation of iron in the feldspars, and may be distinguished as the pink-granite.[1]

For the type of this amphibole-granite may be taken that from Gomi-sawa, in the Jigoku-road, $1\frac{1}{2}$ ri south-east of Ono-shin-machi. It is coarse crystalline, and its crystals of hornblende attain a length of more than 1 cm. The deep oily-brown biotite is entirely or partially enclosed by the amphibole; consequently the former precedes the latter in the act of crystallization. The pellucid needles of apatite accumulate at the margin of these coloured minerals. Plagioclase, with a rather coarse twinning-lamellation, is idiomorphic in

1 See *ante* p. 220.

comparison with orthoclase, and is usually enclosed by the latter. The twinning lamellæ extinguish light at small angles, consequently it may be fairly supposed that the mineral belongs to the oligoclase-andesine series. The broad zoning is distinct, with differentiated extinction-angles. The orthoclase is angular and allotriomorphic, its apparent regular outlines having resulted from the disposition of the adjacent crystals, especially of plagioclase. Quartz fills up the interstitial spaces left by other minerals, contains crystalloids of feldspars, and appears somewhat fibrillated, especially when viewed by polarized light between crossed Nicols. The quartz is comparatively free from liquid inclusions.

As to the structure I have to say only a few words. One of the most interesting features of our granite is the presence of the allotriomorphic feldspar, playing just the same rôle as the granite-quartz; that is to say, the interstitial masses of a non-striated feldspar between a more or less well-finished plagioclase. These masses show a homogeneous extinction over a wide area, like the vitreous base of many neovolcanic rocks; and though occurring in detached spaces, they possess surely an optical continuity. Where this kind of feldspar comes in direct contact with equally allotriomorphic quartz, the boundary is an irregular one, and the two must be supposed to be synchronous productions in the act of crystallization of the rock. To what class of feldspar it may belong is very difficult to decide. It looks like adularia and fresh, while the enclosed plagioclase exhibits more or less an advanced stage of decomposition. Notwithstanding the fresh appearance of the feldspar, it displays only weak polarization-colours, by which the other feldspars and quartz are readily distinguished. Through the want of crystallographic outlines there is no means of getting any optical proof. Lately,

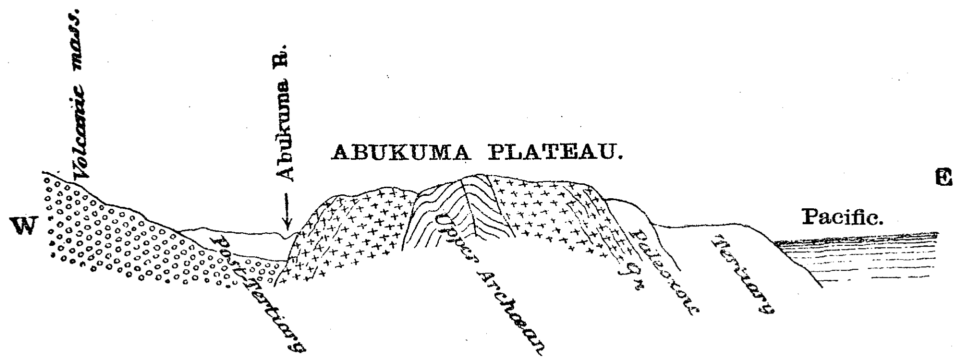
[1] Zeitschr. f. Krystallographie. 1890, XVIII, p. 192

Dr. A. Sauer and Dr. N. V. Ussing, while studying the minerals of a pegmatite dyke, have found out, that the microcline occurs in simple crystals, or in twins of the Baveno type, exactly like an orthoclase-crystal; and that characteristic, cross-hatching structure, by which alone the microcline-nature is usually recognized under the microscope, is not always fully developed. The true nature of it has been placed by both authors beyond all doubt by an exact chemical analysis, and by optical investigations on the well-oriented preparations. Therefore our feldspar, which is also not doubly twinned, may perhaps be looked upon as a variety of microcline.

The granite hitherto described forms a wild creek along the deep ravine of the Natsui-gawa, which runs at its lower course by the populous town of Taira. Recently a new road was opened toward Miharu, and the traffic thereby very much facilitated; but just a few years ago, it was one of the worst roads of this region; hence the name of the Jigoku-dōri, or the Devil's way. New road-cuttings now give good exposures of the granite.

At various localities the hornblende-granite forms a gradual transition to the so-called *granite-gneiss* or *gneiss-granite*, and we can trace them step by step from one extreme to the other, without finding any abrupt discontinuity. There are, however, other *gneisses* occurring in the same region, which look, at first sight, like schistose varieties of the preceding granite; but in truth the former has nothing in common with the latter, in regard to its genesis. The genuine gneisses, already referred to, are true members of the archæan group, perhaps the lowest and therefore the oldest rocks which we shall ever be able to find in the edifice of the Japanese islands. Confusion of the genuine gneisses with the apparent ones has thrown many of us into an intricate labyrinth, from which hitherto none could find the way of escape. The present writer endeavours to decipher, in subsequent pages, the complicated mode of arrangement of these ancient complexes, and the stratigraphical order of the schists of which the archæan is composed.

The *schistose variety*—the gneissose granite—,occurring in connection with the hornblende-granite, and forming a part of one and the same mass, is only a dynamo-metamorphic facies, but brought about under special conditions. The stowings, foldings, and faultings of the masses of rocks, so common during a mountain-building, have occurred in the Abukuma plateau only at the marginal zones; while the portion, of which the central height is formed, has remained quite intact. There has been produced a differential movement, leaving the interior as a standing block, called geologically the *Horst*, the east and west sides of the plateau being thrown down to a lower level, along the meridional dislocation-lines.



Ideal profile of the Abukuma plateau.

I had frequent occasions to observe, during my short visit, occurrences of the schistose variety (gn) along the Pacific coast, and also along the Abukuma-gawa, while the height lying between them is occupied by a normal, typically granular granite. I shall come again to the same subject, when speaking of the geotectonic condition.

It may not be out of place to speak shortly about the nomenclature. It has now become almost an imperative duty for petrologists to separate sharply the *granites* from the *gneisses*. Prof. Cohen[1] long ago pointed out that by gneiss we understand a genuine stratiform rock; and into such a rock granite is never transformed, however perfectly the latter may show the schistose structure. Such rock is properly to be designated schistose granite. As granites and gneisses are geological bodies genetically quite different, so ambiguous names like granite-gneiss and gneiss-granite, given to the metamorphosed rocks, had better be totally expelled for ever from petrographical literature. I follow the good example of Prof. Cohen, and call hereafter such dynamo-metamorphic products *schistose granites*. In order to avoid confusion, this is fundamentally necessary for a country like Japan, where these schistose rocks are so largely developed, occurring side by side with genuine gneiss, as for example, in the southern part of the Mutsu chain, in the mountains of Abukuma, Akaishi, Suzuka, Kasagi, and Katsura, as well as in the northern part of the South-Kiūshū range[2]. I now return to the granite, namely:

b) *Imperfectly Schistose Amphibole-Granite.*

As has been already pointed out, the transition to this is very gradual, and there arises consequently a number of intermediate forms, which do not allow of brief characterization. As we approach the *schistose granite* from a region of *normal rock*, it is hardly perceptible where one begins and the other ends. On large exposures such transitional rocks may be best seen by their peculiar habitus, somewhat deviating from a normal structure. On the other hand, specimens

1 *Geognost. Beschr. d. Umgegend von Heidelberg*, 1881; see also *Ueber das krystallinische Grundgebirge der Insel Bornholm.*

2 T. Harada, *Die Japanischen Inseln*, Tōkyō, 1890, p. 46.

taken from such a spot give scarcely a clue as to their true nature, especially by examining them on a fractured surface, corresponding to the plane of schistosity ; but on a face broken across that plane, the black components show a faint indication of arrangement in a definite plane. In small chips, even this structure can not be discerned.

Under the microscope with thin preparations, however, many proofs of its being affected by a mechanical deformation become evident. First of all, the uninjured *quartz-grains* already show a so-called undulatory extinction ; diverse net-works of the bands of liquid-inclusions grow numerous ; and adjoining faces of quartzes among themselves get more and more irregular, displaying vivid mosaic colours under polarized light between crossed Nicols, but not so the faces adjacent to other components. The innate but latent twinning lamellation of *feldspars* becomes visible by this time through the mass-motion of mountains. The feldspars polarize in brilliant colours, and show also undulatory extinctions akin to the connate quartz. *Biotite* in normal granite has usually a regular outline, but in this transitional rock the original form is now more or less obliterated, showing wavy bands, and its characteristic nacreous lustre between crossed Nicols. The biotite is loosened and fibrillated on the side in direct contact with the feldspars, and the latter specially kaolinize at the adjacent portion of the mica. Consequently, the cause of alteration both of feldspars and mica is *not merely atmospheric, but must be ascribed to some inner movement of the rock.* It is particularly noticeable to find frequently the secondary epidote (Fig. 4, XXIII), in conjunction with degeneration of both minerals, and the substratum necessary for the formation of epidote may probably have been contributed by biotite and feldspars, just as in the case of other *reactionary minerals.* The usual alternation of the green, bleached bands with the fresh lamellæ of biotite makes here its appearance. Fine, microscopic, trichitic needles are abundant in the quartz. *The first inducement to the schistosity of our granite is to be found in a slight shifting in the position of the ferro-magnesian silicates, and also in the commencement of granulation in the solid quartz.*

In the rock forming a cheek of the deposit of magnetite in the Chūka valley, which may conveniently be classed among the present group, I found many patches of the *micropegmatite*, filling up the interstitial spaces between the constituent minerals. Feldspars are beautifully zoned, and polysynthetically twinned; their peripheral portion is astonishingly irregular, gradually fusing together with the feldspar-substance of the micropegmatite. The feldspar forming the marginal portion, above mentioned, has the appearance being formed by the secondary enlargement, repeatedly spoken of, of late, by many American and English authors. It is a subject of considerable interest to know whether the *pegmatite in question is of primary or secondary origin.*

Prof. Judd[1] recently advocated the view that the formation of pegmatites and granophyres[2] may take place after the consolidation of rocks by the way of devitrification, concentration, and differentiation of a substance similar to glass-base, if there be any in granites, that is to say, that they are not original but secondary products. I found the true pegmatitic structure in some of our schistose granites as, for example, in the specimen from Chūka, a rock changed in its texture by pressure. This fact seems to have some important bearing on the view of Professor Judd, just stated. But I have also found the same in some normal granites, which have not been even slightly affected by dynamic changes. *Under these circumstances no decision can*

1 Q. J. G. S. Vol. LXV, 1889, p. 179.

2 Professor Lossen wishes to substitute the word *pegmatophyre* for the granophyre of Rosenbusch. *loc. cit.* p. 270.

be made as to the origin of the pegmatitic structure being primary or secondary.

c) Schistose Amphibole-Granite.

This modification may be readily recognized as such even on a cursory examination of hand-specimens, and no confounding with the normal granite is likely to occur. It is of a coarse, granulo-lamellar *(flaserig)* structure, and generally of a rather darker shade than the primary rock. The schistosity is imperfectly developed ; consequently the cleaved surface is exceedingly rough, irregular, and notched. A typical rock belonging to this class is well exposed along the steep ascent of the Kawachi tōgé (Kawachi pass), between the town of Tomioka and the village of Kawachi, and is also found near to the iron deposit of Chūka, Naraha gōri. This is really what Mr. Kochibe calls the "*Iwaki gneiss.*" All microscopically visible components are now crushed into deformed bodies ; the hitherto even-lamellar biotite is altered into flexuous and wrinkled lamellæ ; the hornblende is no longer of a prismatic form ; the quartz and hornblande are rolled out and grained, and compacted into one mass with ***a feldspar centre zoned by the grains of quartz***, well seen on a weathered surface on account of the different degrees of pellucidity of the two minerals.

Examining with the microscope, the structure becomes more apparent. Originally fresh minerals have acquired a dirty aspect and become variously fissured. In the first place the biotite is for the most part bleached, and its chloritic bands are interposed between light-brown lamellæ. No trace of its original outlines is preserved. A chloritic, fibrous substance often creeps along the adjoining faces and fissures of the compact biotite, and the fibrous mass is connected by strings from the mother-mineral, either hornblende or biotite. The hornblende has met the same fate ; its margins are irregular and frayed, surrounded by accumulations of the epidote grains; the peripheral portions are chloritized, leaving cores of the hornblende in the centre. The secondary epidote occurs fringed with chloritic fibres, and this general distribution of the green minerals causes the rocks to appear of a dark-green shade. The large well-defined crystals of magnetite are newly formed; the small crystals of it are heaped together in the spot formerly occupied by the magnesium-bisilicates out of which they have been formed. The leucoxene mineral encircles the rounded magnetite, from which it may be inferred that the iron ore is titaniferous. The quartz is darkened and clouded with an immense accumulation of liquid-inclusions, arranged in bands along the fissures and cracks.

As to the feldspar it is for the greater part kaolinized, especially in the central portion; the periphery remains comparatively in an unaltered condition; the original shell-structure and the chemical difference in the zoning thus become apparent; the peripheral portions of the crystals display weak polarization-colours. Some feldspars appear homogeneous by simple transmitted light; but after applying crossed Nicols, twinning structures are well exhibited by different colours in alternate lamellæ; and, moreover, extremely fine lines are developed just across the twins of the first type. These second twins do not extend over the whole breadth of the lamellæ, but are usually only partial, being very abundant along the twinning plane of the albite type. The feldspar, apparently of an orthoclase nature, is, therefore, really microcline, having the characteristic cross-hatching structure. Where feldspars come in direct contact with the chloritized biotite, a zone of accumulation of epidote grains occurs in the substance of the feldspar, around the altered biotite, in such abundant quantity as to make that portion appear quite dull. The feldspar itself appears at first sight simple and homogeneous, but when viewed by polarized light it shows undulatory extinctions. Moreover, the whole substance is composed of fine grains which are only made visible by the difference of the optical orientation of the several fragments. Between the epidote zone and the biotite the space is still occupied by a feldspar, but besides this, needles of epidote shoot across from the granular zones into the substance of chloritic fibres (Fig. 4, Pl. XXIII). *The formation of the secondary epidote is due evidently to the reaction of biotite and feldspar.*

As to the state of aggregation of the individual components, I have to add only a few remarks. I have already spoken about the structure of the *imperfectly schistose granite*, which is mainly due to a slight shifting of the coloured components, and this fact may be readily made out from the deformation of their crystallographic outlines. In the present case the schistose structure is more perfectly developed than the one just referred to, and is distinctly fibrous-lamellar, resembling somewhat the structure known as the "eye"-gneiss.

Under the microscope the hornblende and biotite are seen to be not only flattened and compressed, but the entire crystals were materially altered into chloritic fibres, leaving here and there only cores of hornblende and scanty remains of lamellæ of mica. Sometimes the decomposition has gone so far that a few epidote grains alone indicate the spot which both minerals once occupied, but nothing of their substance can now be seen. More than this, the allotriomorphic quartz, filling up the space left vacant by other components, is for the most part crushed, presenting a mosaic by polarized light. Simultaneously with this granulation, the quartz fragments have been shifted one over the other, penetrating into wedge-shaped interstices wherever they have been allowed to do so. The feldspar is the most obstinate of all the components, standing solidly in its original position, while other ingredients have partaken of the general decompositions and migrations. This being the case, *the feldspar has become encircled by quartz*,[1] and this, as I have already stated, may distinctly be seen in hand-specimens even with the unaided eye, although the substance of the feldspar has evidently suffered great contortion, as may be inferred from the bending of the polysynthetic lamellæ.

The untwinned, simple feldspar, a product of the second generation of the same mineral, has a habitus akin to that of the granitic quartz, having filled up the spaces between the lamellated plagioclase, hornblende, and biotite, and consequently imbedding the above-mentioned minerals. It is highly probable that the *ophitic feldspar*, if I may be allowed to use this expression by analogy with the ophitic augite in diabases, is monosymmetric; for, no polysynthetic twinnings have heretofore been observed in it. This feldspar is a far later product of crystallization of the granitic magma, but its formation took place slightly earlier or almost cotemporaneously with that of quartz, although no micropegmatitic structure has been produced. The boundary between the later feldspar and the quartz is the most irregular possible, indicating that they have consolidated not far from each other in the order of crystallization. The later feldspar has not suffered granulation, the quartz, on the contrary, has been reduced to a mosaic mixture.

d) Schistose Epidote-Granite.

In macroscopic appearance it differs from the preceding by its dark shade, owing to the general distribution through it of chloritic matters, and also to the presence of green patches of epidote. Its structure is granulo-lamellar, nearly approaching that of the plane-

1 This peculiar structure seems by no means to be of rare occurrence. Mr. Teall, while speaking of the granite from St. Davids, which has given rise to a good deal of discussion, incidentally makes the following statements: *The relation of the quartz to the feldspar in this rock is interesting. Sometimes the two minerals occur in irregular grains, at other times the feldspar plays the rôle of matrix to the quartz,...* *British Petrography*, p. 318.

schistose modification ; transverse sections of the rock have a banded appearance through alternation of feldspar-quartz zones with those impregnated with chloritic matters.

Under the microscope, the coloured components—the hornblende and biotite—are seen completely crushed and fashioned into flat spindles, and these resolved into green fibres, but some have cores unchanged. Sometimes the hornblende has disappeared entirely, being replaced by masses of epidote and magnetite. The biotite is bent, and frayed out at the margins. Heterogeneous aggregates, consisting of grains of epidote and clumps of magnetite, together with chloritic matters, form sinuating zones, contracting and widening at short distances. *The feldspar, the most enduring mineral, has escaped the general destruction and granulation, excepting its peripheral portion, where the texture is loosened and crushed, producing the cataclastic structure, and there the chloritic fibres have settled, lining the borders of the feldspar. In spite of the solidity of quartz, this was the first that yielded to pressure, and its crushing already seen in the (b) imperfectly schistose granite, is still more evident in the (c) schistose granite.*

Lastly, in the schistose epidote-granite the quartz is totally reduced to fine dust. Examined by transmitted light, the quartz appears like a homogeneous, colourless base, encircling and flowing around a somewhat porphyritic feldspar. Fine dust is distributed throughout the white mass, and the mass of quartz looks rough, as if it were, the sliced face of a mineral, like olivine. With crossed Nicols the masses resolve themselves into a truly mosaic aggregate, one grain lapping over the other, and flowing along round the deformed edges of the feldspar fragments. The usually vivid colours of polarization, are now faint-blue, and the extinction of light sweeps over from one part to the other

e) Biotite-Granite.

This is coarse and granular and of a lighter shade, being made up of a flesh-red orthoclase, quartz, and a little biotite. Under the microscope some muscovite may be seen, ***while this mineral is entirely wanting in the hornblende-granite, already described.*** The lath-shaped feldspar with twinning lamellation extinguishes at small angles symmetrically with the twinning sutures, consequently this plagioclase should be classed among the oligoclase series as in the other granites. It is idiomorphic in comparison with the orthoclase, which usually encloses it, and consequently the lamellated one must be the older. The orthoclose is more or less kaolinized, and its crystals are usually twinned on the Baveno type. The quartz has the same habitus as that in the hornblende granites, and is poor in liquid-inclusions. The biotite is common; zircon and the blood-red iron glance are found as accessories. The rock occurs in good exposures at Kawa-uchi, Naraha gōri.

The most interesting fact in connection with this granite of the Abukuma plateau is the occurrence of ***black patches of the hornblende-granite caught up and enclosed by the light-coloured biotite-granite.*** The enclosed granite is really the fragments with sharp angular edges, torn off with great force from a mass of completely consolidated rock of older date. The size of the fragments varies from 5 to 15 cm. New road-cuttings and the bottom of rivulets expose the structure in full detail. Looked at from a distance, the rock appears like a coarse conglomerate or breccia, or a mass stained with gross marks upon a white ground. It is indeed a breccia of effusive origin and primary, the older black granite, ***bearing the hornblende***, being cemented with a matrix of the younger ***biotite***-granite, the latter differing from the first only in the different development of ferro-magnesian silicate. The granite enclosing the older fragments is wide-spread in the region of the western brim of the Abukuma plateau. Commencing from Miharu, and extending northwards, the outskirts of this region may be found on the left side of the Abukuma-gawa near Nihon-matsu.

Examining this rock more closely with high powers, many interesting facts are unfolded by the microscope. The boundary between the two granites is sharp and abrupt; the enclosed rock is violently broken at its margin and terminates with keen edges, forming here and there coves and inlets within the confused mass, where the intruding or younger granite has pushed its material through any free space.

The intruding granite.—The younger granitic portion is quartzose at the junction, consequently it rarely happens that its components other than quartz come in direct contact with those of the enclosed rock (Fig. 1,[1] Pl. XXIII). The quartz is here variously fissured and broken, and the lines of fracture thus produced run approximately parallel with each other, their prevailing course being directed against the extended margin of the enclosed rock. The quartzes at the junction are dotted with swarms of liquid-inclusions which increase in number as they approach the meeting points. It is usual among contact phenomena to observe the development of air and gas inclusions, which, contrary to our expectation, is not the case in the present rock. The feldspars rarely happen to meet directly with the components of the enclosed granite. Where they do the feldspars are not homogeneous, and intact; the substance of the crystals is crowded with patches of a colourless mineral, and consequently the whole aspect simulates the appearance of either andalusite or staurolite with rich interpositions of quartz. Some of these interpositions of the feldspars may be of a negative character, made hollow by some etching solvent along the plane of chemical weakness;

1 The lower half represents the intruding, young (biotite-) granite, the upper half the intruded, older (hornblende-) granite.

others again are real enclosures of either quartz or feldspar with other optical orientation than the main mass, while the third are rather larger patches of another kind of feldspar with systems of twinning striations nearly at right angles to those of the enclosing minerals. The last have a close similarity to that of the albitized orthoclase of the Socotra granite, as described and figured by Dr. Sauer,[1] from which, however, they differ only in one particular that the changes which the mineral has undergone are not in orthoclase, but in the substance of a striated feldspar. The orthoclase is comparatively free from these patches of plagioclase, but full of irregular cracks. The quartz outweighs the striated and the non-striated feldspars, therefore this rock must be of highly acid composition. Minute crystals of apatite are abundant in quartz near the margin of biotite, being often dismembered and crooked ; the pleochroic halos are observed in biotite ; globular grains of magnetite are scattered through the general mass. Zircon is also found in fine crystals in the combination of the faces of ∞ P, and ∞ P∞, with indistinct terminations.

The enclosed granitic patches.—The plagioclase is idiomorphic with respect to that of the biotite-granite, and at the same time zonings are beautifully developed in it, which are not found in that of normal hornblende-granite. At times its central portion is more or less decomposed, and crystalloids of a bottle-green hornblende are scattered throughout that area (Fig. 7, Pl. XXIII). The feldspar is on the other hand fresh and intact in its outer, and the hornblendes within the core were probably formed by contact metamorphism. Epidote-grains of a tolerably large size occur enclosed in an apparently unchanged feldspar. The epidote seems to be wanting in the biotite-granite (intruding granite). Striated and non-striated feldspars occur in equal quantities, but their distribution in the rock-mass is not

1 Zeitschr. d. deutschen. geol. Gesellschaft, Vol. XL, p. 146.

uniform. As a general rule they are in fine crystals. The same globular interpositions, already spoken of, make their appearance in these feldspars as in those of the intruding rock, and the quartz penetrates into the substance of the feldspars, just like the pockets in the quartz of quartz-porphyries. The hornblende forms the most important of all the components not only in respect of its quantity, but of its very occurrence in the rock; while in the enclosing granite we fail to find even a trace of this mineral.

This fact affords us a clue to the two granites being of totally different origin, and by no means mere bands, such as might arise from local differentiation and partial movement of a granitic magma. Moreover, the angular and broken outlines of fragments of the rock speak for the foreign origin of the hornblende-granite; and the presence of the amphibole in this and the absence in the other give conclusive evidence as to the really fragmentary nature of the older granite caught up by the younger one.

The hornblende is dark bottle-green, and non-pleochroic, or, if at all, very weakly so. It is destitute of its own form, its apparently regular outline being due to the mutual dispositions of the neighbouring quartzes and feldspars. The mica is comparatively idiomorphic with respect to its closely associated hornblende, and grows round the hornblende in clusters. The biotite is often enclosed in the hornblende, consequently some of it must be younger than the mica. It is highly probable that the imperfectness of the shape of the hornblende is due to its simultaneous formation with the feldspars. The quartz is comparatively rare, and contains abundant liquid-inclusions. Titanite in the form of grains is also found which is wanting in the biotite-granite. Black iron-glance, reflecting somewhat bluish rays, is plentiful; some yellow pyrites is present. These iron ores have hitherto not been discerned in the biotite-granite itself.

VI. Petrography of the Takanuki Series.

A. Gneiss-Mica-Schists.

This occurs in a tabular form with the plane-parallel structure ; the surface of a cleaved slab of this rock is entirely covered with aggregates of biotite, while its transverse section is striped with black on a yellowish-white ground. This peculiar appearance arises from the interbanded zones of black mica in the quartz-feldspar layers ; the general colour is light-grey with a slight tinge of yellow, being caused by the pigment of the hydrous sesquioxide of iron that has infiltrated every fissure in the quartz and feldspar. Where biotite forms a component only in small quantities, this rock approaches both in appearance and composition to a granulite. Of course, such a granulite deviates in habitus from the typical one of the Mittelgebirge of Saxony, in having a rather coarse-granular texture, and also by the absence of the so-called microperthite. Weathered exposures of this rock look not unlike a disintegrating sandstone-mass.

The prevalent component is *quartz*, and the rock may fitly be termed a biotite-schist. The quartz abounds in liquid-inclusions with enclosed bubbles which on warming soon disappear from sight, indicating the presence of liquefied carbonic acid. These liquid-inclusions form chains, traversing different grains, irrespective of diverse crystallographic orientations, as is frequently mentioned in writings on crystalline schists. This phenomenon would be best studied in a slice, cut parallel to the plane of schistosity of a rock, brought from Shimo-Matsukawa, near the village of Takanuki. Contrary to my expectations, it was, however, not observed in a slice made at right angles to the former section, a fact indicating that the rock had yielded to pressure, in the direction parallel to the plane of schistosity, but not in that at right angles to it. In individual grains, liquid-inclusions are, however, not wanting, and swarms of them crosss the rock vertically to its bedding.

The quartz contains, besides, as enclosures, almost colourless dodecahedrons of garnet, needles of zircon, and deep, reddish-brown flakes of biotite—all making the quartz, between crossed nicols, appear like a spongy mass. There are also fine, dark or brown needles, sometimes disjointed, shooting in various directions, similar to those of the quartz in tonalite, which are so frequently described, but whose nature is so little known. The quartz is, as usual, intensely chromatic, when viewed between crossed nicols; but not all the quartzes found in this rock behave in like manner. The one which has been already granulated, displays vivid chromatic colours; while those which are still under high tension show only a weak grey tinge, and at the same time undulatory extinctions which gradually sweep over the section one after another as is rotated. The crystallization of the silica must be of a comparatively recent date, as may be seen from a great number of pre-existing minerals contained in the substance of the quartz.

Still later in its crystallization, or nearly cotemporaneous with that of quartz is the *feldspar* which, as I have already stated, makes only a small fraction of the whole rock which not infrequently passes locally into a typical mica-schist. There are, however, other cases in which the rock makes transition in another direction, by taking up a large quantity of both monoclinic and triclinic feldspars in becoming a typical gneiss. Generally speaking, the distribution of the quartzose and feldspathic components in the rock are very fluctuating. One portion may be built up only of quartz, while the other will be highly feldspathic, so that in a coarse variety found near Daibara in Shimo-matsukawa, any one may name one portion of the rock a *mica-schist*, while the other may be reasonably taken for a typical *gneiss;*

but both modifications are really one and the same rock, and should not be interpreted as alternations of two.

The substance of the *orthoclase* is for the greater part kaolinized, and has a dirty aspect ; there is therefore no difficulty in discriminating it from the quartz grains, which are otherwise not very easy to distinguish, when both are found together unchanged. The feldspar appears *isometric-polygonal* in outlines, owing to the disposition of the biotite and quartz ; and patches of it, widely separated from each other, behave optically alike, showing that they are all one mineral, just as in the case of pegmatite. Its polarization-colours are weak, and zonings are frequently observed.

There occurs also *another feldspar* which deviates in habitus from the preceding in having a granular form, polysynthetic twinning lamellation, and comparatively high polarization-colours. This plagioclase is idiomorphic in comparison with the above-mentioned orthoclase, and appears less altered than it. The plagioclase as well as orthoclase often contains round grains of quartz,[1] around which the feldspars show more or less signs of decomposition. The angle of extinction of the plagioclase is small, making nearly 2° only with the sutures of twins, thus pointing out the andesine-oligoclastic nature of the present feldspar.

The *biottte* occurs in irregular foliæ, and is of a reddish-brown colour ; *rutile* disposed as in sagenite is found in great abundance ; the pleochroic halos seen around thick but short crystals of zircon may be frequently observed. Besides large lamellæ of biotite there occur minute scales of the same mineral. They are round or sometimes rudely six-sided, non-pleochroic lamellæ of microscopic dimensions with deep-reddish-brown colour. A spindle-shaped, lamellated, highly pleochroic crystal is only a side-view of the same mica. These

1 Kalkowsky, *Die Gneissformation des Eulengebirges.* p. 30.

microscopic bodies are mostly found imbedded in quartz. The primary *muscovite*, though subordinate in quantity to that of biotite, still forms a constant component. It is usually resolved into loose foliæ, and occurs often interlaced with bleached, green, fibrous biotite.

Accessory minerals are zircon, and a cherry-red garnet, which never occurs with crystallographic outlines, but usually in rather large grains, lapped and encircled by the lamellæ of biotite. It contains in it many brown scales of magnesia mica, gas-pores in the form of dodecadedra, and also colourless grains which are usually supposed to be of a quartzose nature. The garnet was observed microscopically in nearly all the slides examined; it may, therefore, be looked upon as a characteristic accessory component, and this fact makes some of the rocks of this group approach more closely to a genuine granulite.

Among the various modifications, the following are the principal types :— *gneiss-mica schist*, *two-mica schist*, *garnet-biotite schist*, and *hornblende-biotite schist.*

A *a) Gneiss-Mica-Schist.*

Scaly, light-grey, thick tabular schist with the plane-parallel structure, being made up of quartz, orthoclase, plagioclase, and biotite. The last mineral is arranged approximately in one plane, alternating with the quartz-feldspar aggregates. The four components are all nearly of the same size (1 mm.), and the weathered rock appears not unlike a micaceous sandstone. The quartz and feldspars are present in equal quantities, the former is often *partially or wholly enclosed by orthoclase.* The liquid-inclusions with the condensed carbonic acid and bubbles are abundant in the quartz, being disposed in chains; other enclosures are round, tombac-brown biotite, clumps of the opaque iron-glance, and only a few grains and prisms of zircon.

The feldspars are of two kinds, the one orthoclastic, the other plagioclastic; the latter is minute in size, polysynthetically twinned with the angle of extinction of 3°-4° with the sutures of the fine lamellæ. The orthoclase exhibits dull-yellowish polarization-colours, and encloses often the twinned feldspar. *Both feldspars are remarkable on account of their enclosures of many quartz-grains with different optical orientations.*

The micas are also of two kinds; the tombac-brown biotite in ragged lamellæ without any crystallographic outline, with unusually dark pleochroic halos, including rutile-needles in the sagenitic form; the muscovite only in slight quantity, enclosing and often enclosed by the biotite. Accessories are zircon, apatite, and iron-glance.

The rock from Nishiyama, 1½ ri south from Takanuki, contains many stiff, disjointed needles of sillimanite (Fig. 9, Pl. XXIII); the one from the Nakayama pass, on the Nakayama road, from Tanagura to the province of Hitachi, contains a green, fibrous biotite together with white mica. *This rook is specially interesting in the possession of impressions like etched figures on the surface of the crystals of its feldspars, which are disposed one after another in series, parallel to the princpial axis of the crystal.* Moreover, large crystals of ideally pure andalusite (3 mm.) are present irregular in outline, and encircled by confused aggregates of fibres of muscovite. A few of the crystals are coloured, and then are pleochroic, and rose-red when the principal axis of the crystal is parallel with the short diagonal of the polarizer. There are some traces of prismatic cleavage, which are made more distinct by the infiltration of the hydrous sesquioxide of iron.

A *b) Two-Mica-Schist.*

A typical specimen of this variety may be found in the cliff near Sōri, not far from Ishikawa. On a cursory glance it appears just like a quartzite, being essentially made up of quartz grains together with thin layers of a brown biotite and silky mica. Under the microscope the schist is seen to be built up of quartz, biotite, feldspars in small quantity, and lastly, long, thin, lamellar, colourless crystals resolving at both ends into stiff fibres. The last-mentioned mineral is traversed by fissures at various points, and is not bent and lamellated like ordinary micas, showing thus its brittle nature. In the rock-mass this component is approximately arranged in a parallel direction; between crossed nicols it extinguishes light parallel to the longer side; its polarization-colour is vivid, coming near to that of muscovite, but it may be easily discriminated by the want of nacreous lustre, and by a peculiar wavy structure when viewed between crossed nicols. I conjecture this mineral to be *margarite.* Stauroscopic examinations show on a cleaved face a wide optic angle, so much so that the centres of concentric rings scarcely lie within the microscopic field. The dispersion of the optic axis for the red is smaller than that for the violet; i. e., $\rho < \upsilon$, while that of muscovite would be just the reverse. The biotite is of the usual brown colour, and is interlaced with the lamellæ of margarite; it is found in far less quantities than the other mica. The quartz fills up the interstices of the other components, and is consequently wedge-shaped; it shows intense polarization-colours. Occasionally grains of feldspars may be noticed.

A c) *Garnet-Biotite-Schist.*

There is no rock which varies so greatly in its outward appearance as the garnet-biotite-schist. This is in the main due to the varying quantity of biotite. The one extreme is a highly quartzose schist of a greyish colour, with its characteristic vitreous lustre, and its weathered portion usually coloured brown. Micaceous zones are indicated by dark stripes on the transversely fractured surface of the rock. The other extreme is a rather dark, imperfectly schistose, banded rock with red crystals of garnet sprinkled all through it. The microscopical components are the same in both varieties. The main mass is made up of quartz-grains with the tombac-brown biotite between them. The biotite is found in the substance of the quartz as enclosures, but the grains of quartz are comparatively free from liquid and gas inclusions. Muscovite is here wanting.

Accessories are sillimanite in fine radiating tufts (Fig. 3, Pl. XXVI), prisms of zircon, and clumps of iron glance. Garnet is a never-failing but accidental component. In the first, the quartzose, variety of the schist the garnet occurs in minute, *almost colourless* dodecahedra, while in the second, the basic, schist it is somewhat large, granular, and cherry-red. *The colour of the garnet seems to have some connection with the quantity of biotite present in the rock;* for, in the dark variety with abundance of the black mica, the garnet is *red.* This mineral is extremely rich in enclosures of quartz, and in negative crystals filled with air, so as to make it appear like some crystals of staurolite.

A *d) Hornblende-Biotite-Schist.*

This is exactly the same in its external appearance as the gneiss-mica-schist, already described, differing, however, from it by the presence of hornblende as an essential component. The rock is grey, and splits easily into an even tabular plate. The feldspars, both the monoclinic and triclinic, make up the greater part of the mass, while the amount of quartz decreases as they increase. The deep-brown biotite and the bottle-green hornblende are intimately plaited together, showing none of their crystallographic outlines. The zircon and apatite, both in the form of grains, are especially abundant in this rock. Locality: Nishida, east of Tanagura, where the rock forms a member of the complex of amphibolites and mica-schists ; otherwise its distribution is not so wide-spread as that of the other rocks.

B. Titanite-Amphibole-Schists.

They form manifold alternations with the preceding rock. They are the black, highly crystalline schists with the plane-parallel structure, whose transverse section shows interbanded, thin, light-coloured zones, recurring hundreds of times even in a small chip (Fig. 1, Pl. XXVII). If we move upward to a higher horizon, the rocks become perfectly schistose, cleaving easily into a papery slab ; and as their texture is not so compact as that of mica-schist, they easily fall into a bluish-black, ashy powder on their weathered surface.

The (*a*) *black zone*, when examined under the microscope, is seen to be made up of a bottle-green hornblende, whose pleochroism is distinct, but not so pronounced as that of the brown variety, $\mathfrak{a}$, yellowish-white, $\mathfrak{b}$, oily-brown, $\mathfrak{c}$, greenish-brown ; the absorption $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$.

Isometric *plagioclase-polygons* [1] are present, besides the hornblende, in clear crystals free from any interpositions. All the polygons, so formed from the disposition of neighboring grains, show undulatory extinctions which sweep concentrically from one zone to the other in the crystals, as the section is rotated. Only a few grains (1.3 mm.) are coarsely twinned, with the angle of extinction of 7°-10°, or 3°-4° symmetrically with respect to the twinning suture, so that here we have probably before us an andesine feldspar.

The lamellæ of biotite, with the interleaved bacillar hornblende, are oily-brown or green, but through weathering have become so entirely decolorized as to be readily mistaken for a typical musco-

1 *Vide ante*, p. 246.

vite. Examined from the base, the mica has a small optic angle, and consequently should be considered as a variety of biotite. The mica is present in fluctuating quantity, and it never takes an important part in the composition of the rock, but still it should be considered as a characteristic ingredient of the amphibole-schist, since it is entirely wanting in the series next above it. Though it occurs in meagre quantities, it may be readily recognized on the plane of schistosity by its *gold-yellow, glittering lustre.* During field work we meet with several amphibolites, all having nearly the same appearance, but belonging to quite different horizons; *the presence of the biotite should, in these perplexing cases, be taken as a criterion for the identification of the amphibolite of this series.* We name this rock in the field the *biotite-amphibolite* in order to discriminate it from other kindred varieties.

The (β) *light-green bands* in the schist, already referred to, differ in many respects from the (α) *black zones* rich in hornblende, by the presence of a *light-green augite.* Here the grains of feldspar are of minor dimensions, and for the greater part its substance has been changed into an aggregate of a colourless, fine fibrous, confused mass, which between crossed nicols displays highly chromatic, aggregate polarization-colours. The intact part of the feldspar appears, therefore, here and there in a sporadic manner within the above-mentioned micaceous mass, which seems to be identical with the so-called *pseudophite.* This white band, sometimes attaining the breath of 2 or 3 cm., is moreover very dirty, owing to an admixture of titaniferous iron and highly refractive grains of titanite (1 mm.) forming a rim of iron-ore, to which we shall have occasion to return in the sequel.

The *augite* (Fig. 12, Pl. XXIII.) already referred to, occurs in this band in great abundance, taking the place of the hornblendic element, and even of the feldspathic component. It is found always in the form of isometric grains; sometimes, however, elongated ones (1 mm.) are observed, and along their longer axis run a few suture lines which are traces of the characteristic cleavage of augite (Fig. 12, *d* and *e*). The extinction of light takes place at a very high angle, usually 30° or more, with regard to the trace of the cleavage. It is colourless or faint-green, indicating the paucity of iron in it. The colouring pigment, slight as it is, is, however, not uniformly distributed, the periphery is rather of a lighter shade than the interior. The mineral presents another very characteristic feature which is here worthy of short consideration. There are many short, black streaks, which run strictly parallel to the cleavage-direction, and are confined exclusively to the interior of the crystal (Fig. 12, *d* and *e*). Examined with high powers these interpositions are found to be nothing but negative, long, rectangular spaces, filled with air, or water with air-bubbles, and the grains consequently look not unlike the diallagic modification of augite.

Recently, Prof. Judd advanced a beautiful theory of the schillerization—a phenomenon produced through the secondary infiltration of some substance into the spaces formed by certain solvents along the so-called "solution-plane," or the plane of chemical weakness, when the rocks containing feldspar and also augite are subjected to high strains at great depth.[1] In the last number of the *Mineralogical Magazine*[2], Judd has again submitted augites to the same line of treatment which he had so earnestly advocated in his former papers. The orthopinacoid of augites, he says, is the normal solution-plane, and if once the twinning lamellation is induced to develop in crystals, then along the planes of chemical weakness just the same thing may be effected as in those of labradorite. *I can not but*

1 Mineralogical Magazine, Vol. VII. (1886).
2 Ibid, Vol. IX. p. 192.

think the present augite represents in the non-aluminous group an incipient stage of the formation of the so-called pseudo-hypersthene of an aluminous augite.

Sometimes grains with the augite-cleavage are observed (Fig. 12, *a*, *b*, and c), and these basal sections are marked with numerous spots which are nothing but the cross-cut of the cylindrical holes, well seen on the longitudinal sections (d and c) of the mineral. There seems, however, no regularity in the arrangement of these dots. The pleochroism is faintly observed only on the clinopinacoid, when the interior portion is of a darker shade than the periphery; and the absorption is the strongest when the principal axis coincides with the principal section of the lower nicol. Some grains show intense polarization-colours between crossed nicols, nearly equal to those of augite or olivine, and these, when closely examined, always extinguish light in oblique directions with reference to a few cleavage-traces. The grains with straight extinction are on the contrary very dull, ranging from grey to light-brown.

The augite is scattered through the entire mass, to the extent of nearly the half, and when it occurs associated with a rather green hornblende which is present only in small quantities, it is imbedded within the substance of the hornblende (Fig. 3, Pl. XXIII), each having different optic orientations, as shown in the figure.

From the whole habitus I consider these *light-green grains* to be the *salite* of Prof. Kalkowsky, who was the first to point out the wide distribution of this mineral in amphibole-schists. Unfortunately his original paper is not accessible to me, and a strict comparison of the salite from the Oberpfälzer Waldgebirge with the Japanese mineral is at present a matter of impossibility. Prof. Becke[1] has also given a

1 *Die Gneissformation des niederösterreichischen Waldviertels.* Tschermak's mineralog. und petrogr. Mitth. Bd. IV, p. 189.

short description of it, and its wide distribution in the amphibolites from the Waldviertel of Lower Austria.

Apatite, which is so far not found in the hornblendic zone, is present here in large quantities in the form of grains of nearly the same size as that of the salite. It is not prismatic in habitus as usually found in rocks, and in the present case, one might take it for a light-coloured salite, but its faint-blue polarization-colours, its characteristic dot-like enclosures, and its hexagonal cross-section preclude its being confounded with the augitic mineral.

Lastly, the most interesting component found in the light-green zone is the *titanite* (Figs. 5, and 6, Pl. XXIII). It is not found in well-finished crystals, but in those forms resembling rolls of butter (*weckenförmig*). Some are spindle-shaped, tapering at both ends into sharp points. Others are approximately sphenoidal, being fissured transversely at various points across the crystals ; along these fissures and also at right angles to them lie the directions of maximum extinction. We have here probably a basal view of the titanite. The other very obtuse rhombs are its clinopinacoids with oblique extinctions. There are still others which indicate no signs whatever of crystallographic forms, but present shapes like falling drops from the melted end of candle-wax.

In some of these clumps there exists a black, formless mass in the centre, which I presume to be a *titaniferous iron* (Fig. 5). At times the black cores are of a tolerably large size, and the titanite forms but a very thin coating around them. The titanite is highly refractive, and has dark margins and a chagrined surface, due to the total refraction of light that enters from the other sides. Its substance is not very clear, and has some enclosures whose nature could not be made out, owing to the high refraction of the titanite. The polarization-colours are rather weak, ranging from brown to grey ; but some drop-like grains are highly chromatic and have a striking similarity with the olivine grains which are also said to be found in some amphibole-bearing schists. Prof. Kalkowsky[1] has mentioned the occurrence of *olivine* grains which cluster round the iron-ores, and *the figures of the olivine (glinkite) given by him have a remarkable similarity with the above-mentioned grains of titanite with the enclosed titaniferous iron.*[2] I have, therefore, some doubts as to the real nature of the present titanite, and consequently have had it subjected to a chemical examination which proves the presence of titanium in it.

The titanite grains in the *basic*, hornblende zones mostly *possess black cores*, and the minerals which accompany such titanite are biotite and hornblende, both being ferriferous components, while in the *acid*, salite band the grains are usually *free from the black iron-ore*. The first modification of titanite may be fairly compared with the so-called titanomorphite, resulting from the decomposition of the titanic iron ; but in the present case I can not conceive the titanite-margin to be derived from the black core ; they are original, and should not be taken for titanomorphite.

The hornblende in the salite-band is pre-eminently green and pleochroic ; the feldspar is one of the striped varieties. There is also

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1 *Die Gneissformation des Eulengebirges*, p. 37-38. See also Dr. E. Dathes work: *Olivinfels, Amphibolit und Biotitgneiss von Habendorf in Schlesien*, in the Jahrbuch der königl. preuss. geologischen Landesanstalt für 1888, p. 322-324. The amphibolites of the gneiss formation of the Eulengebirge seem specially rich in the olivine grains, as may be judged from Kalkowsky's and Dathe's work. So far as I know, I have as yet not come across the olivine in any of the genuine amphibolite-schists of Japan. The peridotites and serpentines, however, often contain that mineral; but they occur only in the form of intrusive bosses, sheets, and dykes in the archæan members.

2 Mr. J. J. Harris Teall has given a similar figure in Plate XLVII, fig. 3, in his "*British Petrography*" with a note that it "shall represent a kernel of iron ore zoned by sphene." Unfortunately he was obliged to postpone all detailed references to this mineral to some future occasion, notwithstanding the fact that the plate had been prepared of a glaucophane-schist from Anglesea, in which the above-mentioned titanite is said to occur.

a clear, unstriped feldspar in the *hornblende zone*, which I also place in the plagioclastic group.

The above notes chiefly refer to the rock brought from Kamada, 1 ri south-west from Takanuki. Having given a general description of the amphibolites, we may now briefly consider their many modifications.

B *a) Titanite-Biotite-Amphibolite.*

This is the commonest type found all over the region included within the terrain of the present series, so that the citation of its occurrences would be quite redundant. It is thin-banded, and has a plane-parallel structure. Sometimes, however, massive modifications are not wanting; still their transversely fractured surface always shows a banding of the white, feldspathose, and black, hornblendic zones. The hornblende is brown and pleochroic, the titanite-wedges and the lamellæ of biotite are interposed between the bacillar amphiboles. The clear, polygonal feldspar is of a rather large size.

The interbanding white zone is in the main made up of the last mineral, and its grains are minute. Intermixed with these there are chains of titanite-grains with the drop-like titaniferous iron. The best exposures are found at Shimo-Yamagami near Matsukawa.

B *b) Titanite-Salite-Amphibolite.*

This rock, so far I am acquainted with it, is only found at Kamada, and its general description has been already sufficiently given in the preceding pages. It is a deep-black, somewhat granular, thick-banded schist, alternating with the light-green bands (2-3 cm.) of salite. The hornblendic zone is almost entirely made up of a bacillar amphibole; and through weathering a glittering, gold-yellow biotite comes to view on the surface of the rock.

B *c) Titanite-Feldspar-Amphibolite.*

This approaches in its outward appearance to the first variety, but it may be readily distinguished from the mica-bearing amphibolites by the absence of biotite. Also for the same reason the plane-parallel structure, which is macroscopically observable in all hand-specimens when the biotite is present, is not perfectly developed; the cross-section is, however, fine-banded, owing to repeated alternation of the white zones of feldspar with the black ones. The feldspar and hornblende are nearly of the same size, and are fine when compared with the two preceding modifications.

The hornblende is grass-green and pleochroic, bacillar in form, and is arranged approximately in parallel directions ; the feldspar is clear, and polygonal in outline. The particles of the latter are minute and granular in the white zones, and the titanite-grains, occurring with them, with their usual black cores, are chained one after another, parallel to the banding of the schist. Weathered rocks look not unlike a sandstone-mass. The specimens examined are those from Sōri near Ishikawa, and Yamagami near Matsukawa. I saw some traces of copper pyrites in them.

B *d) Biotite-Amphibole-Gneiss.*

This occurs in the titanite-biotite-amphibolite as a lenticular mass of scarcely half a metre in breadth, and can be easily distinguished from all others of the present series by a fine granular-lamellar structure. A transversely fractured block shows in the clearest manner the mode of aggregation of the components. The black, flame-shaped, patches are nothing but granular accumulations of a greenish-brown, bacillar hornblende with traces of the basal cleavage, and the white dots are porphyritic, untwinned feldspars, nearly all completely changed into a muscovite-aggregate but with some part intact on the periphery. The rest of the rock-mass is built up of quite unchanged, colourless feldspars with some grains of quartz, which on account of the parallel position of the dark-brown biotite assume a more or less wavy structure. Only a few grains of the feldspars exhibit twinning lamellation between crossed nicols; consequently it is difficult to say whether we have to do with plagioclastic or monoclinic varieties, but probably the porphyritic feldspar belongs to the latter family. A black, highly lustrous iron-glance may be observed, but not titanite. The specimen here described comes from Sōri; but this gneiss might, no doubt, be found in many other places by close examination in the field.

VII. Petrography of the Gozaisho Series.

A. *Amphibolites of the Gozaisho Road.*

We are in the habit of allowing so wide a latitude to amphibolite or hornblende-schist, that the name alone gives scarcely any clue as to the real nature of the rock a petrographer denotes by it, for the term amphibolite which includes rocks differing greatly in their external appearance and the nature of their component-minerals, as well as in their genesis, that is, whether they are metamorphic schistose diorites or really stratified schists. Therefore, it will be well here to give certain prominent features which eminently characterize our rocks, with the view of distinguishing them from the titanite-amphibolites of the Takanuki series, already sufficiently described.

Besides the great difference which exists between the horizon of the rocks I am now describing, and that of the other series, the following points are to be mentioned: 1) Perfectly fissile, evenly plane-parallel structure is to a certain extent common to the rocks of both series, but the upper part of the present rocks becomes rather compact, slaty, or thick-tabular; 2) colour more greenish or greyish; 3) absence of titanite and salite, compensated for by the presence of chlorite, epidote, magnetite, tourmaline, and sometimes rutile; 4) structure not granular, but linear or parallel and more or less compact, the last character especially giving solidity to the rocks, so that they withstand atmospheric action better; 5) macroscopically, the mineralogical components are scarcely recognizable in the green slaty rocks; 6) microscopically, the ingredients, especially the hornblende, are in parallel and linear alignment, so that a slide made parallel to the schistose plane presents the same side of the minerals, whereas in the rocks of the Takanuki series basal and longitudinal sections of the component-crystals are visible in the same slide, lying confusedly together; 7) hornblende mostly needle-shaped or prismatic in habitus, while in the other, it is polysomatic or tabular, or broad if prismatic; 8) colour of the hornblende light-green, and not intensely-green or brown.

The rocks comprehended under the present group vary greatly as well in their external appearance as in their inward structure, to such an extent that they do not allow of characterization in a few words. They differ stratigraphically as well as petrographically in mineralogical composition being accompanied by a change of structure. From a highly crystalline, somewhat granular member bearing the stamp of a genuine crystalline schist to a compact, green, slaty assemblage, they grade one into another imperceptibly without any marked break. This may be traced advantageously in coming down eastward, along the rapids of the Samegawa, from the plateau of Takanuki to the boundary of tertiary hills, at the very junction of which stands the small village of Kadōno (Profile C-D, Pl. XXV.)

I begin with the lower member, a highly crystalline amphibolite.

a) It is a schistose, imperfectly fissile, evenly plane-parallel, dark-green, slaty rock, built up of multifarious alternations of white and black bands, comprised of microscopically fine, glittering needles of a black hornblende and saccharoidal, milky-white feldspar, disposed, as I have stated, in fine zones. Such rocks differ so little from those of the *Takanuki series* in their external appearance as to lead one to suppose them to be quite identical. However, on close examination marks of distinction may be easily perceived. For besides the fineness of texture which characterizes the present rock, *the spangling gold-yellow biotite can not be seen on weathered surfaces of it as on those of the titanite-amphibolite*[1] *; these surfaces are dark-green and dull.*

Under the microscope the hornblende appears compact, and with irregular outlines, and also in ragged plates which are either short and oblong, or have the shape of slender prisms. The small prisms are arranged more or less parallel. The broader plates are less parallel, crossing each other at various angles, and giving a coarsely felted aspect to the section. In the plates very fine striations run parallel to the base. As all the crystals of the hornblende are not disposed in parallel direction, so basal sections are sometimes observed in the combination of prism and clinopinacoid. The mineral is of a dirty-green colour, and pleochroic, varying from green to oily-yellow. The general mass is made up of feldspar (and some quartz?) with crystalloids of hornblende. The feldspar is not uniform in size, and is polygonal in outline; its polarization-colour is weak, showing undulatory concentric extinctions; its substance is clear and fresh. Only a few flakes of biotite are to be seen on the cleaved plane. Microscopically the biotite may be considered as an accessory, occurring associated with the hornblende aggregates as brown, fibrous lamellæ,

1 See *ante* p. 251.

devoid of external outlines. Masses of iron glance, both deep red and opaque modifications, adhere to the crystals of the hornblende, and also form local accumulations in them. This rock crops out at the district-boundary of Kikuta and Higashi-Shirakawa, on the Gozaisho road, being cut sharply by hornblende-granite, where the latter assumes a more or less schistose structure (GHG, Profile C-D, Plate XXV).

b) Not far from the last locality, and directly overlying the preceding, we find a schist which is surely a modification of the rock just described. It is a greenish, fine banded, imperfectly fissile, feldspathose schist, with sericitic membranes and the tufts of a brownish tourmaline on its cleaved surface. Under the microscope a bluish-green, pleochroic hornblende assuming long, sheaf-like forms, is seen in more or less parallel alignment, but locally the crystals are thrown indiscriminately together so as to form a more or less intricate felt-work. The interstices between them are occupied by the fresh, clear feldspar which is *sharply bounded, polygonal, and well adjusted with the neighbouring polygons.* These polygons are peppered through with grains of black iron ore which, by reflected light, presents a bluish-black lustre and lamellar structure. It is, therefore, iron glance, but not magnetite, with which it is often confounded. The heart- and knee-shaped twins of *rutile* are scattered through the section ; *it must be expressly remarked that this mineral has hitherto not been observed in the allied rocks of the Takanuki series.* This rock occurs associated with the tourmaline-bearing mica schist, to be described in the sequel.

c) Some of the rocks higher up in the series, associated with schists such as that just described, are very similar in appearance to common chlorite schist. Indeed they are compact, bluish-green, rudely fissile, slaty rocks which, on cursory examination, might be very often taken for chlorite schists. Examined under the microscope, the predominating mineral, the hornblende, is seen to be present in the form of an intricate felt-work of fine prismatic crystals, appearing not unlike the needles of sillimanite. Only a little feldspar is found as a granular, weakly polarizing aggregate, in which actinolite is rare. The general mass is full of tea-brown, hexagonal tablets and grains of opaque iron glance.

d) The next in ascending order, and forming the basement of the temple of Gozaisho, is a schist which not only differs in its external aspect but also in its mineralogical composition from those of the preceding rocks. The appearance itself suggests at once that the rock has suffered a great physical change by dynamic metamorphism to such an extreme degree, that the zones of feldspar, now appearing dull and saussuritic, have been so torn and convulsed as to assume a puckered aspect. The rock is finely crystallo-granular, massive and slightly fissile, and imperfectly banded with milky-white, feldspar zones.

The microscope reveals that the schist is composed of a bluish-green hornblende, dirty, greenish-brown biotite, crystals and grains of magnetite, all arranged in parallel lines, and lapped over by thin flocculent chlorite. A transverse section of the rock admirably discloses the mode of arrangement in full detail. A greyish-green biotite and the dust of magnetite together make up special bands, running through the rock and flowing around the aggregates and sometimes large, well-defined crystals of magnetite. Above and below, the band is bordered with an accumulation of magnetite, whence the bluish-green, sheaf-like hornblende shoots forth in different directions into the fine aggregate of white, feldspar zones. Some feldspar occurs in the shape of large, irregular grains forming veinules within the microcrystalline mosaic of the same mineral. The feldspars are limpid, but some show traces of alteration, and are traversed by many fissures and chains of liquid-inclusions with air-bubbles, in a direction at right angles to the plane of schistosity of the rock.

I confess that I am totally unable to distinguish quartz from feldspar when their grains are thrown together in a mosaic aggregate; but judging from the massive, feldspar-hornblende rock, from which presumably the present one seems to have been derived, I naturally deny the presence of quartz. It is particularly misleading that the larger crystals of feldspar, which must have been and still must be subject to peculiar strain by pressure in such a metamorphic rock, display polarization-colours of so high order as to lead one readily to take them for quartz; but from time to time a few stripes of different colours may be noticed, which point to the latent existence of twins in the feldspar. In saying so, my notion is not strictly to preclude the presence of quartz, as this is reasonably supposed to be formed in the metasomatic changes, which any rocks, especially of eruptive origin, may suffer during an orogenetic movement of the mass. I simply mean that grains which may beyond doubt be regarded as quartz have not been observed. The bluish hornblende bears evident mark of having been produced in some secondary way in its sheaf-like form, frayed at both ends and tufted together in acicular bundles. Minute grains of epidote occur mixed with accumulation of magnetite.

e) The rock lying east of, and consequently overlying, the metamorphic schist just described, is a massive, fine-granular, green rock without any fissile structure in a hand-specimen, though a few rock-cleavages might be found in natural exposures. It appears like a rock altered under the influence of contact action of some eruptives. The surface is speckled with white dots, especially on weathered specimens, indicating the presence of much feldspar.

The granular structure of the rock may be better understood by examining a slide with the microscope. It is seen to be mainly made up of hornblende in ragged, sheaf-like or fibrous masses, frayed out at the ends into radiating tufts. The hornblende is disposed in such a confused manner that within the microscopic field all possible sections of it may be seen, and hence the granular structure of the rock. The hornblende is green at its margins, but light-brown at its centre; thus giving rise to zonings of colour of which, the peripheral, deep shade is surely due to a slight change in the substance of the amphibole. When the axis of mean elasticity $\mathfrak{b}$ coincides with the short diagonal of the lower nicol, the differences in shade are most marked, while in the position at right angles to the former, *i.e.*, $\mathfrak{c}$, the whole crystal becomes greenish in colour, and the zonings thus disappear.

The interstices between the hornblende are occupied by feldspar crystals which appear quite homogeneous by simple light, while between crossed nicols they are resolved into dot-like, minute grains imbued with the feldspar substance, and the arms of the interference-cross sweep round as the section is rotated, after the manner of a spherulitic mass of chalcedony. It may be fairly inferred from the optical deportment of the rock that after its granulation and crushing, *its temperature was raised by orogenetic movement so far as to partially melt the feldspar into a more or less plastic mass, or else that a molecular rearrangement took place in it at a comparatively low temperature.* The substance of the feldspar is made dusty by accumulation of microscopic grains of epidote and crystalloids of hornblende. Formless masses of an opaque iron ore are plentiful, surrounded by a dull, white, granular accumulation, probably of leucoxene.

f) The one occurring to the east of the last-mentioned, and near the last house, the westernmost of Ōdaira, locally called Saragai, is a medium-granular, massive rock of a dark-bluish colour, showing no signs of fissility. This I considered in the field to be a fine structured variety of a gabbro and under the microscope I find it differs in no essential point from this. The habits of the hornblende, magnetite, and interstitial feldspar are exactly the same. The needles of secondary hornblende, detached from the larger crystals are, however, plentiful in the apparently homogeneous feldspar.

g) Finally, we come to the uppermost of the rock-series, now under consideration, which is found along the banks of the Samegawa, at the village of Odaira lying close by Negishi, not far from the boundary of the tertiary terrain under which the rock gradually dips to be seen no more in this region. This rock represents the extreme phase of development of the thick series of Gozaisho, the corresponding other extreme is, as has been already stated, the one found near the west end of the Gozaisho Narrows, just at the district-boundary of Kikuta and Higashi-Shirakawa, and which I have already proposed to call the *feldspathose hornblende-schist.* The present rock appears at first sight as if it were made up of silt, ashes, and the paste of volcanic mud, consolidated and pressed subsequently to its present form. It is a rather *greyish*, rudely fissile, slaty rock, simulating very much the appearance of the *clasto-amphibole slate of the Mikabu series*[1] which forms the basement of the palæozoic group of Japan. The present rock is glossy in appearance on a cleaved face, and the greyish shade seems to be caused by the light colour and acicular habitus of *actinolite*, as well as by the presence of minute grains of epidote, which make up no small portion of the bulk of the rock.

Under the microscope almost the entire rock is seen to be built up of needles and fibrous shred-like masses with a decided tendency to parallel arrangement. Exceptional cases are not rare, as there are often-times found confused aggregates of fibrous matter, concealed by chloritic membranes, having an appearance very much like the antigorite-variety of serpentines, especially when viewed between crossed nicols. The actinolite is of a light-greenish colour and weakly

1 B. Kotō; "*On the so-called Crystalline Schists of Chichibu,*" in which the minute structure of the amphibole slate has been considered in full detail. This Journal, Vol. II, p. 112.

pleochroic. The interstitial, half-granulated feldspar, probably albite, is visible through the flocculent chlorite; and the whole rock is peppered through with almost colourless grains and slightly yellowish crystalloids of epidote.

B. *Mica-Schist.*

The mica-schist, interbanding with the amphibolites, may at once be discriminated from those of the complexes of mica-schists and granulitic gneisses of the Takanuki series, by its coarse-lamellar texture and glossy iron-black lustre. Common mica-schists are, as a rule, highly quartzose, and the biotite that enters into their composition is usually scaly; this rock, however, is highly micaceous, being for the greater part made up of lamellæ, but not the hexagonal scales, of biotite. The rocks classed here as mica-schist exhibit within narrow limits a considerable diversity, as well in their outward appearance as in their microscopic aspect. Therefore, they may be conveniently divided into two varieties.

a) A coarse-lamellar, somewhat wavy structured variety is basic and rich in feldspars; the tombac-brown lamellæ of mica lap one over the other, forming a thick, continuous membrane, and constitute undulating zones with the quartz-feldspar aggregate. A cleaved surface is not even, but lumpy or nodular, due to the local swellings of quartz in the schist, into spindle-shaped assemblages well seen on the transverse fracture, and these give a gnarled or knotted appearance to it. In its outward aspect this rock resembles the so-called "*Garbenschiefer*," or the graphite-sericite-schist of the Sambagawan series of the author,[1] differing, however, from the last-mentioned in the presence of true biotite instead of a green, fibrillated, sericitic mica. The feldspar occurs in polysomatic forms; simple twins are often made visible by

1 *On the so-called Crystalline Schists of Chichibu*; This journal, vol. II, p. 97.

the behaviour of different polarization-colours in the two-halves, as well as by unequal angles of extinction on the right and left. Its polysynthetic lamellar structure is rarely to be observed, and then only partially, being chiefly confined to the margins of crystals, and coming to an end abruptly near their middle. Maximum-extinction takes place usually at very small angles with the twinning-sutures, a fact which compels me to place this feldspar in the andesine series. The great majority of feldspars occur, however, in simple crystals, and should therefore be considered as orthoclase. Some of the orthoclastic feldspar have acquired an "eye"-like habitus, being of somewhat larger size than the neighbouring grains, and encircled by the foliæ of biotite. The feldspar-"eye" has been transformed into scales like muscovite, and encloses a mass of iron-glance disposed in such a manner as to assume a fluidal structure. Opaque *iron-glance* (not magnetite) enters into the composition of the schist in such large quantity as would allow one to speak of the rock as being literally charged with iron ore, and is found especially in those parts where the foliæ of biotite have been brought together into a thick heap. Taking into account the considerable amount of feldspar present in the rock, I propose to call it the *feldspar-biotite-schist.* The rocks examined were brought from Shimo-ichino-kaya (Sono-ana), Iwa-mae gōri; and Kamesaku, 1½ ri east of Ōta in Hitachi.

β) Another modification, a true biotite-schist, is rather fine-granular, black or greenish-black, and a perfectly fissile, evenly plane-parallel schist, being made up of alternations of thin bands of biotite and quartz. A typical specimen of this rock is found at Gongendō (Kami-Yoshima), not far from the town of Taira. *Feldspars* seem not to be present, and if present are rare. *Tourmaline* is the most characteristic accessory component, and through its presence, I think, I may discriminate this schist from allied micaceous rocks. The *tourmaline is of greyish-brown*, or *sometimes of greenish-blue colour*.

(1) Of these the greyish-brown kind occurs in the form of prisms with imperfect terminations, which enclose a large quantity of the dust of iron glance. The mica occurring associated with this variety of tourmaline is a *brown* biotite in irregular lamellæ, frayed out at the margin into a felt-work of fibrous mass ; while the general matrix in which it is imbedded is a mosaic of round grains of quartz. There are other patches of much larger, angular interlocked quartz forming irregular, sinuous bands in which biotite is proportionally rare, while in the micaceous portion both muscovite and the brown biotite are plentiful. The quartz is ideally pure, and in this point the rock differs from those of the lower horizon. Round-edged crystals of apatite are sporadically present.

(2) The schist with a dirty *brownish-green* biotite, of the same habitus as the preceding, appears somewhat like a chlorite schist and contains the prismatic, *greenish-blue tourmaline* which clusters at some places into a confused aggregate, a peculiar habitus not observed in the other mica-schist. Angular grains of feldspar are found intermixed with quartz, which through weathering may be readily distinguished from each other. The yellowish-brown needles of rutile occur in the foliæ of the biotite in divergent-radial arrangement. Garnet, the commonest accessory, is, however, not present in all the schists of this group. *Iron glance is always more or less present, taking the place of magnetite in the other rocks*, lying above and below this one.

C. *Garnet-Chloritoid-Quartz-Schist.*

Intercalated between the chloritic amphibole-schists of the upper

Gozaisho complex, we find a quartzose rock of an uninviting, dirty-greyish appearance with a characteristic vitreous lustre on its fractured surface. Looked at from the side it seen to be formed of fine banded, slightly rosy, garnetiferous stratulæ alternating with other greyish ones. Under the microscope it is seen to be mainly made up of quartz, garnet, and chloritoid, severally traversed by veinules of quartz. The garnet dodecahedra are plentiful, the rosy zone being especially so mottled by aggregates of this mineral as to make the section appear dull. The colour of the garnet is faintly red; small crystals of it are, however, colourless.

The chloritoid occurs in lamellar masses with irregular outlines and also in rounded forms. The latter are of plum-green shade, non-pleochroic, and indifferent to the action of polarized light; sections of the former exhibit a few cleavage lines from which the direction of extinction deviates at an angle of about 15.° The pleochroism is distinctly pronounced, the rays vibrating in the direction of the principal axis are plum-green, those at right angles to it, olive-yellow. The thick, brittle, lamellar mass of this mineral has a tendency to aggregate at certain spots, and the crystals of garnet are here particularly abundant. The characters of our chloritoid agree well in essential points (Photogramme 1, Pl. XXVI) with those of the Austrian occurrence whose description has been given by v. Foullon[1]. This rock is found at Naka-Misaka, near a water-mill, Iwamae gōri. Another rock belonging to the same category was taken from near the temple of Gozaisho.

D. *Amphibole-Picrite.*

The olivine rocks seem to be of a wide distribution within the

1 *Ueber die petrographische Beschaffenheit der krystallinischen Schiefer,* etc. Jahrbuch d. geol. Reichsanstalt, 1883, p. 220.

confines of the Abukuma plateau, as may be judged from a number of specimens which have been brought home from different localities by my colleagues; but their modes of occurrence are unfortunately very little known to me. T. Kochibe[1] was the first who acquainted us with the occurrence in the Abukuma district of a dunite which was then considered as an archæan schistose member. S. Ōtsuka, however, found it occurring in intrusive dykes within pyroxenites of the palæozoic age. "It is a compact or fine-granular, dark-green or light-brown rock, essentially built up of *olivine*, *chromite* and a little *hypersthene*. A fresh dunite is only known from Ishigami and Akasaka-Higashino, near Ishikawa in Iwaki; and Saimaru, Taga-gōri, in Hitachi.[1]"

I myself collected some specimens from other localities entirely new to Dr. Harada. One was found as an intrusive boss through a salite-amphibole-tourmaline schist, at Naka-Misaka, and another at Yama-gami, near Takanuki, the latter forming a dyke through a complex of gneiss-mica schist and titanite-amphibolite. The peridotite seems to me from its modes of occurrence to be of a decidedly irruptive origin, injected through various rock-groups of different ages. (Profile 4, Pl. XXIV). But whether there are any near relatives of the peridotite, which might substantially be connected at their root with the olivine rock, or whether it is pressed up alone as dykes through several fissures, quite independent of magmas of other rocks, I am as yet not able to assert definitely.

It has been known for a long time that basic rocks at their points of contact with others are particularly rich in olivine. Extended researches made by Dr. E. Stecher[2] have well shown, how the proximity of the intruded rocks could exercise an influence upon the

1 T. Harada; *Die japanischen Inseln*, p. 75.

2 *Contacterscheinungen an schottischen Olivindiabasen*, T. M. M. IX, 1887, p. 146 et seq.

intruding basic magma in the formation of olivine in the latter. In several of the papers by Professors Judd and Bonney it is clearly pointed out, how fluctuating are the relative quantities of the component minerals of basic rocks. It is frequently observed that, by a slight textural modification, dolerite (diabase) gradually passes into gabbro, by the disappearance of feldspar, into picrolite, by the disappearance of augite, into troctolite, and, by the disappearance of olivine, into eucrite; while by the excessive development of accessory constituents like enstatite and picotite fresh varieties such as lherzolite may arise.

The prevalent rock, and at the same time the foundation stone of the Abukuma, is of intermediate chemical composition, to, *i. e. the syenitic granite*, which is specially liable to form transitions to *tonalite*, *diorite*, *monzonite*, and eventually to *gabbro*; and it seems to me highly probable that the olivine rock in question represents the extreme basic member of the syenitic magma, which has sent out various offshoots in the form of apophyses from the main mass in the bosom of the earth. Being influenced by cooling surfaces which must have been comparatively large and many in such narrow fissures, a selective crystallization has been induced in the magma, whereby olivine has been formed at the expense of the other minerals; and thus we have several dykes filled up with rocks of a peridotic composition.

The olivine rock which came under my notice in the field should be grouped together with *amphibole-picrite*. It is always very massive in appearance, rarely exhibiting banded structure. Its irregular, rounded blocks are often covered with a thin coating of a deep-red colour due to decomposition, beneath which, however, the rock is surprisingly fresh and of a dark greyish-black. Under the microscope it seems to consist of a sheaf-like, colourless *hornblende* (tremolite) piercing through the granular aggregates of olivine. The latter is encircled by fibres of chrysotile which separate individual grains from each other; and as several grains behave optically in exactly similar manner, they must have been formerly parts of a larger individual which by serpentinization has now become detached and isolated grains. The olivine-core is filled with the dust of chromite, and also with round or rectangular grains of the *spinel* group. The spinels are isotropic, and highly refractive, and have therefore dark margins. Some of the opaque aggregates which might easily be confounded with chromite are surely octahedra of spinels. Examined with high powers the minerals are found coloured either dark-brown or green; the former may be *picotite*, the latter *pleonaste* or *hercynite*.

The colourless tremolite is bacillar in form, some rods attaining 2 mm. in length; their terminations are never perfect, being always resolved into tufts of fibres which, in turn, eventually pass into a filamentous aggregate of serpentine. The substance of the tremolite is not compact, and seems to be extremely thin; it is also traversed through its whole stretch by fine divisional lines parallel to the principal axis, in consequence of which the mineral displays only aggregate polarization-colours. That the tremolite is the primary component and not a secondary one is proved by the fact that it penetrates the remnant of the olivine, and also cuts sharply the edges of the dismembered grains of the same mineral.

The final product of degeneration of both the tremolite and olivine is the well-known serpentinous mass; the one originated from tremolite appears in the form of splinters of wood, which are thrown together in such a manner as to form an imperfect "bladed" structure (*Balkenstructur*) of *antigorite;* while that resulting from olivine is the fibrous *chrysotile* which produces a characteristic mesh-work, with aggregates of chromite along the original fissures of the olivine.

A rock from Saimaru in the collection of the Geological Survey is a pure, fresh *dunite*, entirely made up of olivine grains with only a little serpentinous matter; that of Akasaka-Higashino belongs to the same species with exactly identical mineralogic composition and habitus, but differs from the former in the particular that it abounds with interposed *picotite*.

VIII. Dyke-Rocks.

A. *Pegmatophyritic Dykes.*

Along the water-worn banks of rivers and road-cuttings, there are found innumerable flesh-red dykes, severally interpenetrating both the younger and older granites, and even the complexes of Takanuki and Gozaisho, and it is very remarkable to observe that wherever a granite occurs it is usually accompanied by this dyke rock.

No solid rock could withstand exposure to such powerful external agencies as the alternate frost of winter and heat of summer, which are excessive in, and very characteristic of, the climate of some parts of Japan as may be witnessed in the costumes of the people in the half-yearly exchange from a cold-temperate to a tropic fashion. All the rocks of the Abukuma plateau, especially the granites of coarse texture, are, therefore, soon reduced to an incoherent mass after new excavations even within the short interval of a few years. This necessitates incessant repair of roads, in order to keep them in tolerably good condition. Among such crumbling debris, the red pegmatophyritic dykes, in virtue of their solidity, escape the general disintegration, and stand up in bold relief in various directions crossing rivers and slopes of hills, and giving thereby a peculiar character to the scenery, when seen from a distance.

Guided by prudence, the people of the district use only this dyke-rock for macadamizing durable roads to which it affords a firm skeleton and solidity. It would be superfluous to cite every occurrence of the dykes, since they are met with all the way through and in any part of this region, like Jacks at every street corner. A large series of exposures of the dykes under their least equivocal and most characteristic conditions of occurrence may be studied on the ascent from Nogami (Tamano-yu cold bath) to Chikenjō, Naraha gōri, for a distance of 8 km. This profile is very instructive, as there are found in it the often-mentioned two types of granite, one penetrating the other, and both passing imperceptibly into gneissose modifications, to which the name "*Iwaki gneiss*" has been already given. Through these granites, the *aplitic*, *pegmatophyritic*[1] *dykes*, the granophyre of Rosenbusch, make their way usually at low angles, and strike with the main axis (N 10 E) of the mountain.

These in turn are cut at very steep angles by a number of *diorite-porphyrite* dykes[2]. Since the filling up of the red dykes (Peg.), the country-rocks have undergone considerable tectonic disturbances to which is due the formation of parallel fissures (Fig. 2, Pl. XXIV). Different parts have then been shifted one after another, causing a continuous band of the dykes to appear like a set of stairs, and some of these clefts have been subsequently filled up with the igneous magma, which we now find in the shape of the black *diorite-porphyrite dykes*, as may be clearly understood from Figs. 2 and 3, Pl. XXIV. From what has been said, there is not the slightest doubt as to the younger age of the diorite-porphyrite, and its formation may perhaps have been at the time, when the crust in this quarter had suffered the last orogenetic movement, in which state it has re-

1 K. A. Lossen, *Vergleichende Studien über die Gesteine des Spiemonts und des Bosenbergs bei St. Wendel und verwandte benachbarte Eruptivtypen aus der Zeit des Rothliegenden*, Jahrb. d. Königl. preuss. geol. Landesanstalt für 1889, p. 270.

2 I wish to substitute the word *diorite-porphyrite* for lamprophyre in Figs. 2 and 3, Pl. XXIV.

mained since without any marked terrestrial disturbance. The black dykes are surely of post-archæan age.

Deferring details about the diorite-porphyrite to subsequent pages, I shall first speak of the material of the *pegmatophyritic dykes*. It is flesh-red and compact, breaking into polygonal blocks with sharp edges. Under the microscope it is very simple, as in its macroscopic aspect, but it shows a very instructive structure. The main mass is made up of nothing but quartz and orthoclase, regularly intergrown and showing a hieroglyphic or *à la grec* form. The only other ingredient, that is visible under the microscope, is a skeleton-like magnetite which is transformed at the margins into brown sesquioxide to which is largely due the reddish tint of the rock. The quartz and feldspar are in about equal quantities ; consequently it is difficult to decide which of them should be considered as the main mass. The latter is for the greater part kaolinized and dirty, while the fresh quartz is charged with swarms of liquid-inclusions.

The pegmatophyritic dykes occur, as has been already stated, in regular bands of uniform but moderate breadth, traceable for considerable distances. Apophyses have so far not been observed. Such being the condition in which the pegmatophyre occurs, I felt considerable diffidence in deciding as to its origin, whether, that is, it is a primary secretion after the manner of a miarolitic mass, or a filling up of cefts by lateral secretion, or lastly, an injected magma from the earth's interior, solidified in the present form. The last supposition seems to be the most probable, as the rock traverses indifferently all the varieties of granite, and even those of amphibolite.

The macroscopic development of the preceding is, to speak morphologically, nothing but pegmatite dykes, of which we have opportunities to meet with in *as large a number as the pegmatophyre dykes.* Pegmatites are usually considered as an accidental, mineral aggregate, deposited from solution, by lateral secretion. If we view our pegmatite from this stand-point, its formation must be ascribed to an origin entirely different from that of the pegmatophyre dykes, in spite of close resemblance in their mode of occurrence, structure, and mineralogical composition.

My trip to the Abukuma district had for its scope to establish, if possible, the stratigraphical sequence of archæan rocks, the study of which has been long neglected by us, and which no one had attempted to follow in detail. Keeping always in my mind this important question, I had no time to avail myself of opportunities to make observations on dykes in general, and I am at present not able to say anything definite about the *relation of the pegmatite and pegmatophyre dykes*. At the time I simply considered them to be all of one and the same origin, which in reality cannot be the case!

The true *pegmatite* may be best studied at Ishikawa-yama, 2 km. north of Ishikawa, where Kochibe had found a crystal of beryl in the newly exposed dyke on the road-side. Large orthoclase, twinned on the Baveno type, and equally large and well-shaped, grey quartz, pegmatically intergrown with the former, together with biotite and muscovite, form the materials of the coarse dykes. Beautiful dykes of graphic granite with biotite may also be observed at Gomisawa, 12 km. east of Ono-niimachi. Microcline seems to form an important part among their components. These and many other dykes, of which there are ample variety, require more extended researches than I had time to institute.

B. *Dykes of Augite-dioritic Lamprophyres.*

A dyke of about 2 m., cutting through hornblende-granite, is found in Nishiyama (Ogura), on the way to Tanagura. It is a compact, dark-greyish rock in which are porphyritically imbedded crystals of hornblende and augite (3 mm.). No other components are visible to the naked eye. Under the microscope it proves to be pilotaxitic, consisting of lath-shaped plagioclase, needles of hornblende, and magnetite, with scanty remains of some colourless basis, which fill up the interstices of the crystalline ingredients.

The phenocrysts are plagioclase, hornblende, augite, and a zeolitic mineral; the first is long rectangular or square, occurs in simple crystals, or in simple twins, all extinguishing in oblique directions at more than 30.° In spite of the simplicity of the crystals and the scarcity of twins, the feldspar may be looked upon as a basic plagioclase. Zonings of the plagioclase are well developed, the central part being often hollow, and partially filled up with a chloritic aggregate; the peripheral zone is fresh and glassy. The hornblende is greenish-brown; its forms are never perfect, but eaten away by magmatic corrosive action, and the crystals are in consequence encircled by an aggregate of opacite and needles of augite. These marginal masses are prolonged into long "tails," just as hornblende is in some porphyrites. Its pleochroism is quite pronounced. Twins of common type are discernible *only in that shape which has been formerly considered as anomalous twins whose plane of contact was said to be the prism* $\infty \mathrm{P} 2$ *(120).*[1] The augite is rare, its habitus is andesitic, consequently its basal section is approximately hexagonal, being bounded by the predominating faces of pinacoids, truncated at the four corners by prismatic faces, and its colour is light-yellow and non-pleochroic. Biotite and olivine are not to be seen in the specimens hitherto examined. This dyke-rock seems to have a close resemblance to the *comptonitic modification of the dioritic lamprophyre.*

1 Becke; Tschermak's Mineralog. und petrogr. Mitth. Bd. IV, p. 365.

Near Harimichi, south-east of Fukushima, Kochibe has found many dykes of a dark-green, fine-granular diabase in granite, containing grains of olivine.[1] This may probably belong to the same class of rocks as the present one.

A similar dyke may be seen in a vertical cleft of about 2 m. within a nodular hornblende-granite at the boundary of Nakagura and Nakatani (L P in Profile F-F, Pl. XXV).

C. *Dykes of Diorite-Porphyrites.*

There are many peculiar dyke-rocks whose mutual relation to each other, and to the country rocks are but imperfectly known. I can give here only a preliminary notice of them, deferring their microscopic detail to another occasion. Their mineralogical composition and structural form seem to deviate so greatly from normal *dyke rocks, that I feel considerable diffidence* in placing them in any of the known class of lamprophyres. The dyke materials show great variations within narrow limits. From a compact, grey hornstone-porphyry to a light-coloured, coarse crystalline diorite-porphyrite, they vary through a number of intermediate forms. Some of them appear dark and fine granular, others are aphanitic ; while a third modification is medium-granular with black hornblende-crystals porphyritically imbedded within the greyish general mass. In short, they seem to have nothing in common to them, but in reality they are offsprings from a common stock under deceptive appearances.

1) *The compact variety* possesses the aspect of a *hornstone-porphyry*, with sporadic crystals of feldspar as a porphyritic component ; the general mass is grey, and is splintery with a conchoidal

1 Harada, *Die japanischen Inseln*, p. 76.

fracture. Under the microscope nearly the half of the whole bulk is seen occupied by granophyric bundles which consist of fibrous feldspar and quartz arranged in a divergent-radial manner around a feldspar-crystal, so as to form a spherulite. Between crossed nicols the spherulite is divided into imperfect sectors which sweep along one after another as the section is rotated on the stage. A few plates of hornblende and lamellæ of muscovite are irregularly intermixed with the granophyric mass, from which it may be inferred that the spherulitic bundles came into existence after the crystallization of the bi-silicates. The formation of these bundles is probably the effect of an unequal cooling, or they may have been formed secondarily in a manner somewhat similar to that of devitrification by molecular rearrangement and differentiation of an unindividualized mass.[1] The remainder of the rock consists of a cryptocrystalline aggregate of quartz and feldspar, muscovite and green hornblende; most of the colourless components becoming visible only on applying crossed nicols. Copper pyrite is present.

2) *The dark and fine-granular dyke rock* has a few feldspar-crystals as a porphyritic element. No other minerals are discernible by the naked eye. Under the microscope the porphyritic feldspar is found beautifully zoned with different optical orientations in the centre and the periphery, having an extinction-angle of more than 20° with the twinning sutures; the decomposition begins in some from the core, whereas in others just the reverse happens. The minerals of the second generation are the bluish-green, fibrous hornblende, and zonally structured, long-rectangular or square-shaped feldspar; while the general mass is made up of needles of hornblende and lamellæ of tea-green biotite, lath-shaped feldspar, and grains of quartz. The structure is holocrystalline-porphyritic. Accessories are apatite, octa-

1 *Vide ante* p. 235.

hedra of magnetite, and a little epidote.

Through the preponderance of feldspar of the second generation, the rock becomes dioritic in appearance with somewhat large crystals of fibrous hornblende as porphyritic crystals often arranged in stellar aggregates. Some of the fibrous amphibole contains cores of *augite*, from which it may be inferred that the hornblende of uralitic habitus has been derived from the augite.

3) *The third modification* is black and fine-granular, and a dark magnesian bisilicate glitters through it by reflected light. Examined with high powers, it is a panidiomorphic-crystalline aggregate of lath-shaped feldspar, and prismatic hornblende, together with biotite and epidote. The feldspar is simple-twinned, rarely polysynthetic, and more or less kaolinized and dirty, being full of muscovite, with the secondary epidote at the centre; zonings are rarely developed. The hornblende is prismatic in habitus with the clinopinacoid present, so far as may be judged from the outlines of imperfect basal sections. It is pleochroic; $\mathfrak{c}$=dark-brown with a slight tinge of violet, $\mathfrak{b}$=brown, $\mathfrak{a}$=light-yellow; absorption, $\mathfrak{c}=\mathfrak{b}>\mathfrak{a}$. Forms of the hornblende are never perfect, but ragged and tattered, as if it were, the resorption-residue of larger individuals. This supposition is, moreover, strengthened by a beautiful emerald-green colouring of the peripheral portion which is materially connected with the brown core; the former has surely resulted from alteration of the original amphibole. At first sight, the hornblende appears like augite, for which it may be easily taken. It seems to me that the present amphibole is likely to be one of the sodium-bearing varieties, as otherwise the formation of the bluish-green margins can not be explained.

A dirty green biotite is irregularly scattered through the whole mass, and the dark colour of the rock is due mainly to the presence of this component. Titaniferous iron is sparingly present with highly refracting margins of titanite. Zircon with well-finished forms is also observed. The structure is more or less porphyritic. The part in direct contact with the cheek of granite is typically porphyritic, with feldspar, hornblende, and biotite as large components; while the rest is a crypto-crystalline aggregate of grains of feldspar and quartz, and also foliæ of biotite, making the ground mass of a beautiful fluid-like structure, seen in the bending of streams, and bands of mica around the larger feldspar-crystals.

4) *The coarse porphyritic modification.*—This differs entirely from all the preceding rocks in its external appearance, so that any confounding of this with the other varieties is impossible. It is a typically porphyritic rock with large, rectangular or broad-tabular feldspar (3 mm.) imbedded within the greyish ground-mass. The feldspar is zonally structured with differentiated optical orientations in each zone. Some crystals are simple; a few are coarsely polysynthetic with oblique extinctions of about 14° with the suture-line, while about 23° with P/M on the brachypinacoid. Therefore, it corresponds to the mixture of $ab_1\ an_2$ of the labradorite series.

Minerals of the second generation are also discernible by the naked eye, if carefully examined. They are long-rectangular, polysynthetic plagioclase, devoid of zonal shells, and a greenish prismatic hornblende with combination of the pyramid, prism, and brachypinacoid. The hornblende is greenish-brown or bluish-green, and pleochroic. A dirty-green biotite is found with sagenitic rutiles in apparently fresh lamellæ.

The general mass in which the components of the earlier generations are found, consists of a crypto-crystalline aggregate of grains of feldspar and quartz, and also shreds of a green biotite. Accessories are rounded apatite, and titaniferous iron with the margins of leucoxene.

IX. Summary.

The general results I have arrived at by my study of the archæan formation of the Abukuma plateau may be summarized as follows :—

This archæan plateau constitutes a portion of the ecto-peripheral zone of the North Japan *garland*,[1] and is separated from the backbone of the island by the longitudinal valleys of the Abukuma-gawa and Kuji-gawa, while on the east it is bordered by the Pacific sea-board. The south end of this archæan zone has been the subject of one[2] of my former papers. The present one is the result of study made in the northern prolongation of the same belt, *i. e.*, the Abukuma plateau.

The archæan rocks of this region are primarily separable into a lower division, the Laurentian, and an upper division which again may be subdivided into two well-recognizable, leading groups, the Gozaisho and the Takanuki series.

The *Laurentian* is mainly composed of rocks of the granitic, syenitic, and dioritic types of mineralogical composition, and panidiomorphic-hypidiomorphic granular structure. These granitic-granular rocks show in places different degrees of schistosity, depending upon the circumstances under which they have been formed. Accordingly we have a number of foliated granites which may be conveniently brought together under the following heads, viz., 1) imperfectly schistose amphibole-granite, 2) schistose amphibole-granite, and, lastly, 3) schistose epidote-granite. The young biotite-granite, though less extensively developed than the other, has also equivalent modifications.

1 The late Melchior Neumayr, when speaking of volcanic islands, said: *Vom Feuerland an zieht sich eine Riesenkette gewaltiger Vulkane nach Norden, bis Alaska, wo dann jene eigentümliche Bildung geschwungener Vulkanreihen, meist auf Inseln gelegen, beginnt, welche (Festoninseln) man mit herabhängenden Blumengewinden verglichen hat. Erdgeschichte*, I Band.

2 See p. 198.

These pathological varieties, so to speak, which go by the current name of gneiss-granite or granite-gneiss, though very improperly, are, no doubt, mainly dynamo-metamorphic products. Microscopic analyses give at any time sufficient proofs of their having been affected in the way indicated. My own detailed study of them shows that the first inducement to the schistosity of granites is to be found in the slight shifting in position of the ferro-magnesian silicates, and in the commencement of granulation in the solid quartz. In a more advanced stage of schistosity as in 2), ordinary schistose granite, all essential components have been compressed into deformed bodies; the once evenly lamellar biotite altered into flexuous and wrinkled lamellæ with bird's-eye-maple shimmer; the hornblende no longer of a prismatic form; and the quartz and hornblende rolled out and grained and compacted into one mass with a feldspar centre zoned by the grains of quartz, thus simulating the so-called centric structure by migration of the granular quartzes. In the last phase of transformation as in 3), the schistose epidote-granite, the hornblende has disappeared entirely, being replaced by a mass of epidote and magnetite. The biotite is bent and frayed out at the margins. Heterogeneous aggregates, consisting of epidote, magnetite, and chloritic matters, form wandering zones. The feldspar, the most enduring mineral, escapes the general disintegration and granulation, excepting in its peripheral portion, where the crystal is crushed, producing the cataclastic structure. In spite of the solidity of quartz, this has always been the first to yield to pressure.

The cause of the schistosity is undoubtedly dynamo-metamorphic. Extensive rendings and foldings have taken place in the Abukuma plateau only at the marginal zones, while the central height has remained quite intact. By the orogenetic, differential movement thus produced, the east and west side of the plateau have been thrown down to a lower level, along the meridional line of dislocation. Consequently the granulated and compressed varieties—the schistose granites—are confined to the above-mentioned tectonic lines, one alnog the Pacific sea-board, and the other along the Abukuma valley, as may be clearly understood from the diagram, page 232.

I have repeatedly spoken of the young and old granites which are by no means easily distinguishable from one another. They occur in such a confused manner as to try the patience of even careful observers; and many have entirely ignored the heterogeneous origin of the two kinds of massive rocks. The best exposure, illustrative of the mode of occurrence of the younger biotite and older hornblende granite may be found between Ishikawa-yama and Shimo-Kawabe, where the two appear successively between the line of fault after the manner of ruin-marbles (Fig. 5, Pl. XXIV), and moreover assume at times a schistose structure. In this exprosure, it is clear that one is the dyke-rock to the other, but the granites being developed in almost equal masses it is not easy to say which is the country-rock and which the intruding one. Another very illustrative profile is shown in Fig. I, Pl. XXIV, in which such complicated modes of occurrence of the granites are to be seen that their mutual relations can not be easily determined.

Judging from the wide distribution of the hornblende-granite, it seems to form the general foundation of the Abukuma plateau, upon which are built up all the later formations. If this be the case, then the hornblende-granite in the first section must be the country-rock through which the biotite-granite made its irruptions at several points, the older one being itself already in the solid state. In the second section the same cannot be said; for the two granites intermingle with one another in such a manner as to lead one almost to suppose that the hornblende-bearing variety must have been in a more or less plastic condition at the same time as the other. It is thus a matter of considerable difficulty to decide which is the earlier granite.

When speaking of the line of section at Shimo-Kawabe (p. 271), it has been already shown that the brownish, granulitic gneiss of the Lower Takanuki series, accompanied by a micaceous schist with plenty of garnet, has been so disturbed in various ways and at numerous points by the intrusion of biotite-granite, as to make one believe that the gneiss-complex has been broken up and cemented subsequently together by the matrix of that plutonic rock. Generally speaking, the biotite-granite occurs only in the form of apophyses or of bosses within other complexes. On the other hand, the hornblendic variety seems to be present in extensive masses, disturbing all the complexes formed prior to the period of the Gozaisho series, in such a manner as if the whole Takanuki rocks had been swimming on that magma. The last-mentioned series, in all observed cases, is geologically separated from the Gozaisho rocks by the intervention of masses of hornblende-granite.

The biotite-granite, as I have already said, intersects the Takanuki series at numerous points, forming sporadic masses and irregularly ramifying dykes; the relation of the hornblendic variety to the same complex is, however, somewhat different. Near the contact the Laurentian granite holds as enclosures sharply angular, sub-angular, or somewhat rounded blocks of mica-schists and amphibolites of the Takanuki series. This is well seen on the Hanatate pass (A-B, Pl. XXV). The schistose modification of the same has likewise foreign enclosures of the Takanuki rocks, as more or less attenuated bands drawn out parallel to the foliation of the hornblende-granite and confused with it (Fig. 5, Pl. XXIV).

These facts, taken in connection with the prevailing shattered character of the Gozaisho, and of the Takanuki strata in particular, at their contact with the Laurentian rocks, leave no room for doubt but that these inclusions are detached portions of the overlying formations, which, in a firm and brittle condition, have become immersed in the underlying viscid magma, which subsequently crystallized out as the Laurentian gneiss and granite. This mode of foliation of the granites *(plastic deformation)* seems to have been produced by differential pressures upon the thickly viscid magma, inducing a flow in the mass, similar to that endogenous growth of a volcano by *Nachschub*, experimentally observed by Reyer. To this flow is ascribable both the schistosity of certain foliated granites, and the parallel arrangement of enclosures of foreign rocks imbedded in it, as in the Rainy Lake region.[1] It must be expressly remarked that there is another process which leads to the formation of foliation, quite distinct from that just mentioned, which may be termed that of *solid deformation*, since the schistosity is in this case brought about by internal granulation of the component-minerals. Foliated granites, which occupy extensive area in the plateau, owe their structure to the latter action.

The upper archæan is represented by bedded formations, in which can be recognized at least two leading groups.

One of them is the *Takanuki series* which is again divisible into the lower acid, and the upper basic member. *a*) The former rests directly upon the Laurentian, and its petrographical elements are gneiss-mica schist, two-mica schist, garnet-biotite schist, and hornblende-biotite schist, which together make up the considerable thickness of 5,000 metres. All these rock-varieties have in common a tabular form with the plane-parallel structure, and their transverse sections show the interbanding of black-mica zones with light-greyish quartz-feldspar layers (photograph, figure 2, Pl. XXVII).

1 Andrew C. Lawson, *On the Geology of the Rainy Lake Region*, p. 131. *et seq.*

Where biotite occurs in only small quantities, they approach both in appearance and composition to a granulite. Feldspars, both monoclinic and triclinic, usually make only a small fraction of the whole rock which, in consequence not infrequently passes locally into a typical mica-schist. This complex seems to correspond with Harada's *Rioké schiefer*,[1] so named from the locality of Rioké, Sūchi gōri, in the province of Tōtōmi, where the rocks were collected for the first time. Harada seems to have given them that name simply with the petrographic object of covering with it various schists of his gneiss system, found near the village of Rioké, without assigning to them any special horizon in his stratigraphic scheme.

β) The Upper Takanuki complex embraces multifarious alternations of 1) the titanite-amphibole schists and 2), the gneiss-mica schists. The first are black, highly crystalline schists with the plane-parallel structure, whose transverse section shows interbanded, thin, light-coloured zones, recurring hundreds of times even in a small chip. They are perfectly schistose, cleaving easily into papery slabs ; and as their texture is not so compact as that of the underlying mica schists, they readily fall into a bluish-black ashy powder on their weathered surface. These black, fissile schists are peculiarly characterized by the presence of titanite which is found in those forms which resemble rolls of butter *(weckenförmig)*, and with sometimes a black, formless mass in their centre, which is probably of a titaniferous iron. Another very interesting component is the salite which almost exclusively makes up the stuff of the light-green zones. Biotite is present, but it never takes an important part in the composition of the rock; still it should be considered as a characteristic ingredient, since it is entirely wanting in the series text above it. It may be readily recognized on the plane of schistosity by its gold-yellow, glittering lustre. We name these

1 *Loc. cit.* p. 43.

titanite-bearing rocks in the field the biotite-amphibolites in order to discriminate them from other kindred varieties. The biotite-amphibole gneiss occurs usually in lenticular masses. Those of the other category (gneiss-mica schists) show the following modifications, namely, gneiss-mica schist, two-mica schist, garnet-biotite schist, and also hornblende-biotite schist. The whole complex, consisting of the above-mentioned rocks, attains a considerable thickness, as seen in the exposure between the hilly stretches from Nakagura to Sōri (E-F, Pl. XXV), where this Upper Takanuki was found to have the thickness of 5,500 metres.

The voluminous green mass of the *Gozaisho series* is well exposed along the banks of the Samé-gawa whose river course runs nearly at right angles to the strike of the whole complex. Its basal member lies in a somewhat elevated portion of the plateau on the west, while in the eastern half of the section, towards the tertiary hills of Kadōno, the younger series occurs, with a thickness which I venture to estimate as probably not less than 10,000 metres.

The uppermost rock of this series is a greenish, rather massive schist, cropping out along the banks in a vertical position but with a slight inclination towards the east. It has the aspect of a clastic rock, and is like a hardened deposit of volcanic ashes. This is followed to the west by alternate bands of green schists and quartz rocks, intruded into at times by a hornblende-granite. A black mica-schist accompanies these green schists. They gradually disappear, to give place at last to a black, crystalline, hornblende schist which occupies the basal portion. When we compare the extreme members of these schists, side by side, they seem at first sight to have nothing in common with each other, but on close examination in the field they are seen to form a lithological continuity and a harmonious whole. These green, fissile rocks have much the same appearance as the clasto-pyroxenites of my Mikabu series, which form the basement of the palæozoic group of Japan.

Sometimes they bear a striking resemblance to the chlorite schists of my Sambagawan series,[1] which lies directly below the Mikabu complex. The question concerning the age of the Sambagawan series involves serious difficulties. When the results of my studies on the schists of Chichibu[1] were made public in 1888, I expressly remarked that it is by no means safe to give the Sambagawan series a final resting place in the archæan group, without extended researches. In spite of my warning against such a hasty conclusion, Dr. Harada[2] assigned its place to the Upper archæan, as had been done before him by Dr. E. Naumann. I do not as yet find any positive argument that supports its archæan position, as no additional light has since been thrown on the stratigraphical situation of the Sambagawan series. The relation of the Gozaisho series to that of the Sambagawan is unfortunately not very clear, and we must wait for some time to come to see the final solution of the problem, whether the two are geological equivalents, or whether they succeed each other in point of time.

I take here the opportunity of expressing my thanks to Professor Edward Divers and Director Dairoku Kikuchi for their kindness in assisting me in various ways in the revision of the proof sheets of this paper.

1 This Journal, vol. II.
2 *Loc. cit.* p. 49.

CONTENTS.

PLATE XXII.

Plate XXII.

Topographical map, recently published by the Geological Survey of Japan, representing a portion of the extensive plateau of Abukuma between Tanagura and Taira. It covers a portion of the province of Hitachi, and also that of Iwaki. The red lines indicate the positions of the line of section, given separately in Plates XXIV and XXV, with corresponding letters.

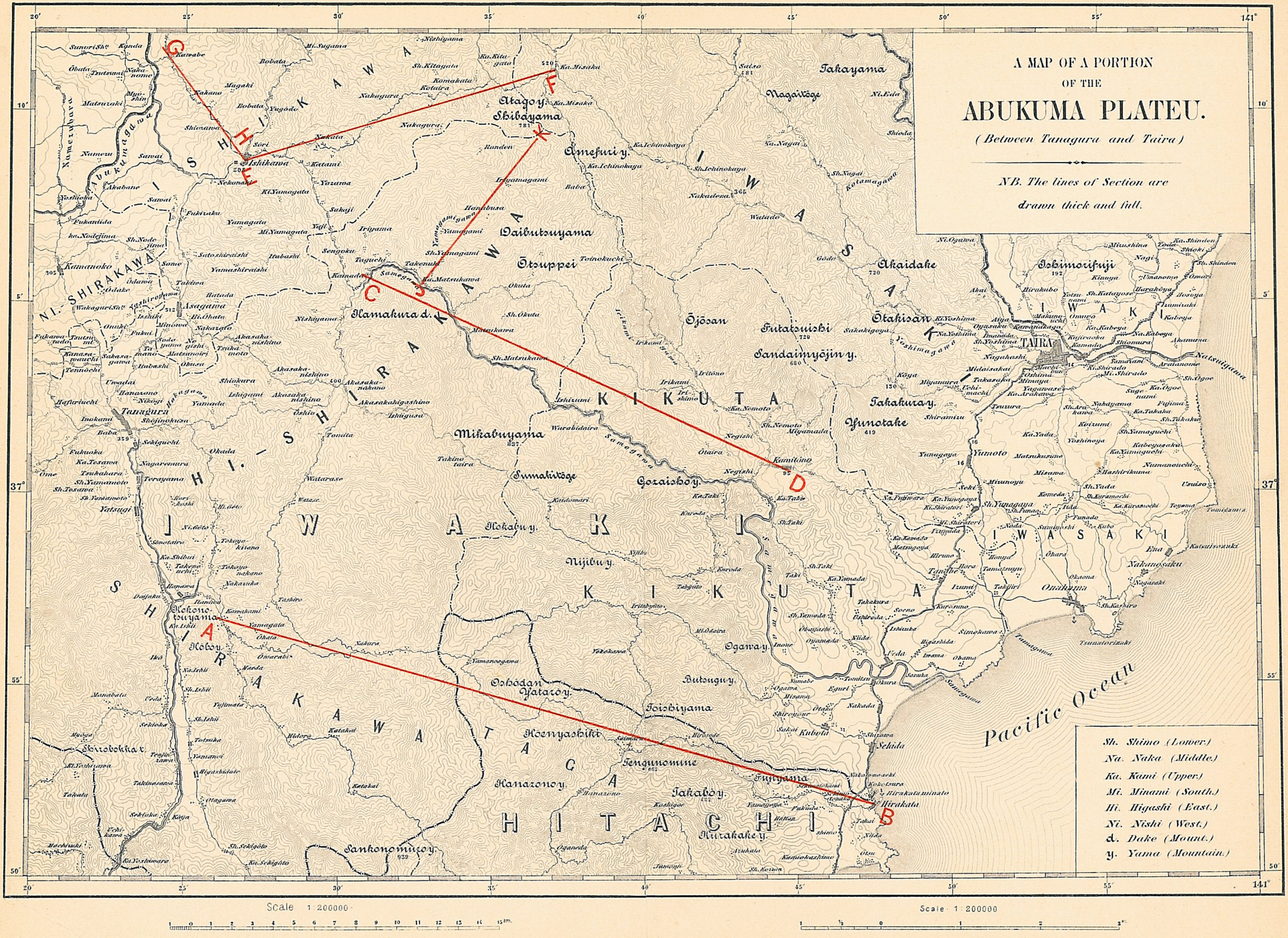

A MAP OF A PORTION OF THE
ABUKUMA PLATEU.
(Between Tanagura and Taira)
NB. The lines of Section are drawn thick and full.
Sh. Shimo (Lower.)
Na. Naka (Middle.)
Ka. Kami (Upper.)
Mi. Minami (South.)
Hi. Higashi (East.)
Ni. Nishi (West.)
d. Dake (Mount.)
y. Yama (Mountain.)
Pacific Ocean
IWASAKI
SHIRAKAWA
KIKUTA
HITACHI
TAIRA
Tanagura
Scale 1:200000

PLATE XXIII.

Plate XXIII.

Fig. 1,—illustrates the point of contact of two granites, the lower half representing the intruding, young (biotite-) granite, the upper half, the intruded, older (hornblende-) granite. Feldspar and quartz at their contact are variously fissured, and the lines of fracture thus produced run approximately parallel with each other. (See p. 242.)

Fig. 2.—A bluish-green hornblende, forming an essential ingredient of granite. (See p. 227.)

Fig. 3,—shows a green hornblende with the imbedded grains of salite, each having different optical orientations. (See p. 255.)

Fig. 4.—Reactionary rim consisting of the grains and needles of epidote around a decomposed biotite at the contact with feldspar. (See ps. 234 and 238.)

Figs. 5 and 6,—represent peculiar forms of titanite, resembling rolls of butter, with opaque, formless masses of titaniferous iron. (See p. 256.)

Fig. 7.—A somewhat large, allotriomorphic hornblende, enclosing a number of equally allotriomorphic crystals of plagioclase, oriented in diverse directions. (See p. 227.)

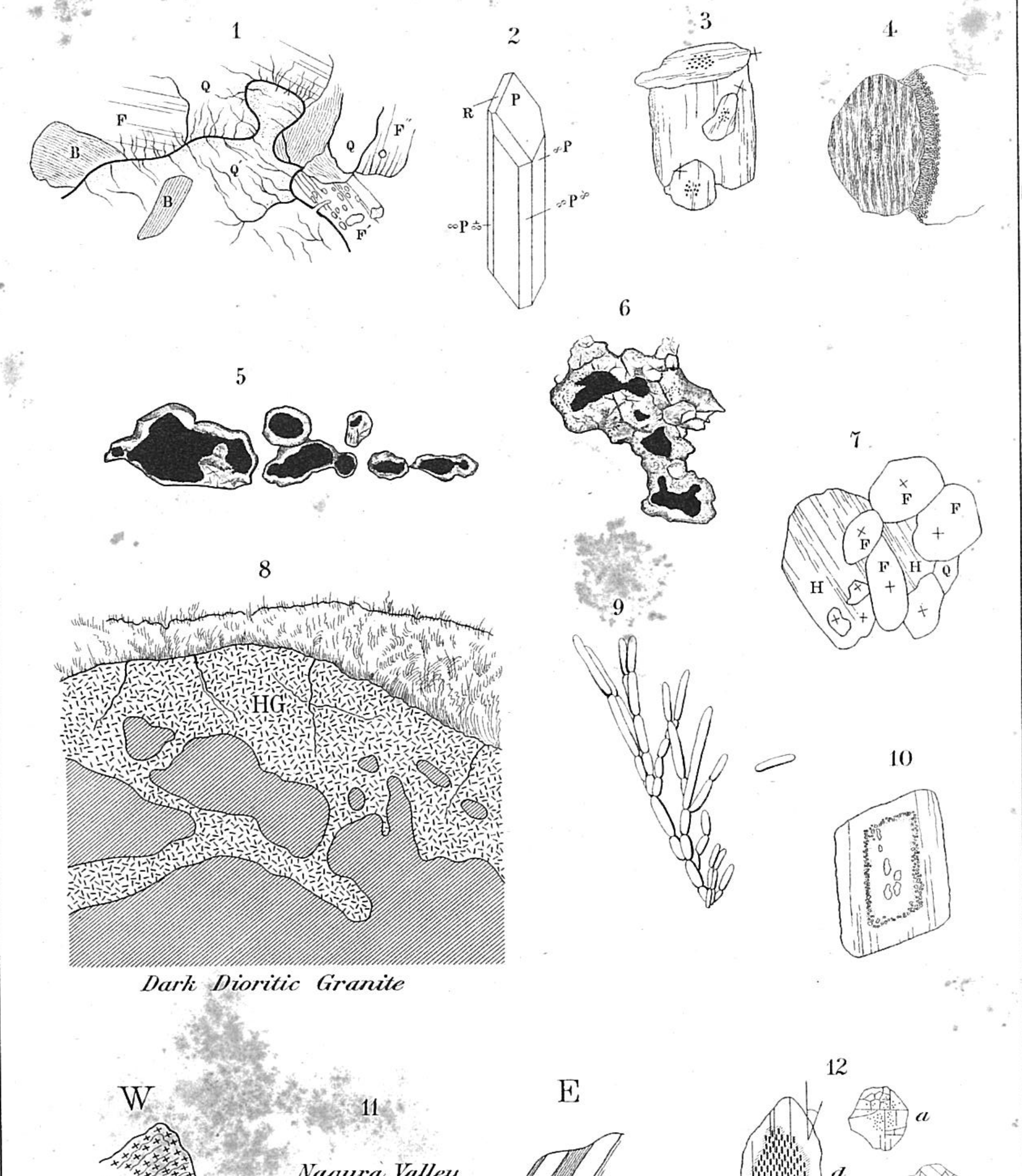
Fig. 8.—Black dioritic patches of various sizes enclosed in hornblende-granite, as if a dioritic scum had floated on a granitic paste, and then been torn asunder by some movement in a semi-fluid magma. These patches are only a portion of the same granitic magma, slightly different in chemical composition. (See p. 217.)

Fig. 9,—shows many stiff, disjointed needles of ? sillimanite. (See p. 220.)

Fig. 10.—Crystalloids and grains of hornblende, enclosed by a feldspar. (243.)

Fig. 11.—Section of the Nakagura valley, showing the heterogeneous nature of schistose granite and the Upper Takanuki complex. (See p. 215.)

Fig. 12.—Salite, a characteristic component of titanite-amphibolites, with black streaks regularly arranged parallel with the c-axis. (See p. 254.)



N. Sasaki del. Lith. & Imp. Seishibunsha.

PLATE XXIV.

Plate XXIV.

FIG. 1.—Section from Serigasawa to Miharu, the latter being the well-known town in the Abukuma plateau. It exhibits the complicated mode of arrangement of granites. (See p. 219.)

gnBG,—schistose biotite-granite;	gnG,—schistose hornblende-granite.
BG,—biotite-granite;	

FIG. 2 and 3.—Cuttings along the newly opened road west of Tamano-yu, Naraha gōri, Iwaki, showing the relations of granites and dyke-rocks. (See p. 276.)

HG,—hornblende-granite;	Peg,—pegmatophyre-dykes;
BG,—biotite-granite;	Lamprophyre,—diorite-porphyrite.

FIG. 4.—Section J-K, from Kami-Matsukawa in north-easterly direction to the district-boundary of Ishikawa and Shirakawa, illustrating very clearly the relations of the Takanuki series, granites, and serpentine.

gnG,—schistose hornblende-granite;	UT,—Upper Takanuki;
HG,—hornblende-granite;	LT,—Lower Takanuki;
BG,—biotite-granite;	S,—serpentine.

FIG. 5.—Section near Shimo-Kawabe, showing the relation of schistose hornblende-granite and fleams of the Takanuki gneiss. The whole is traversed by a pegmatitic dyke. (See p. 218.)

FIG. 6.—Cutting between Tonda and Higashino, exhibiting black, attenuated patches of the dioritic composition within hornblende-granite, which arise from chemical differentiation of its granitic magma. (See p. 216.)

FIG. 7.—Section near Ōtsuka, as exposed on road side, bringing to view a gradua-transition of hornblende-granite to its schistose variety within the amphil bolite series of the Upper Takanuki. (See p. 214.)

A,—gneiss-mica-schist;	B,—titanite-amphibolite;
gnG,—schistose-granite;	HG,—normal hornblende-granite.

FIG. 8.—Small belt of the Gozaisho rocks pinched in between granites. (See p. 212.)

BG,—biotite-granite;	a,—epidote-amphibole slate;
b,—salite-hornblende-schist;	c,—chloritoid-quartz-schist;
d,—amphibole-picrite;	HG,—hornblende-granite;
gn,—schistose hornblende-granite.	

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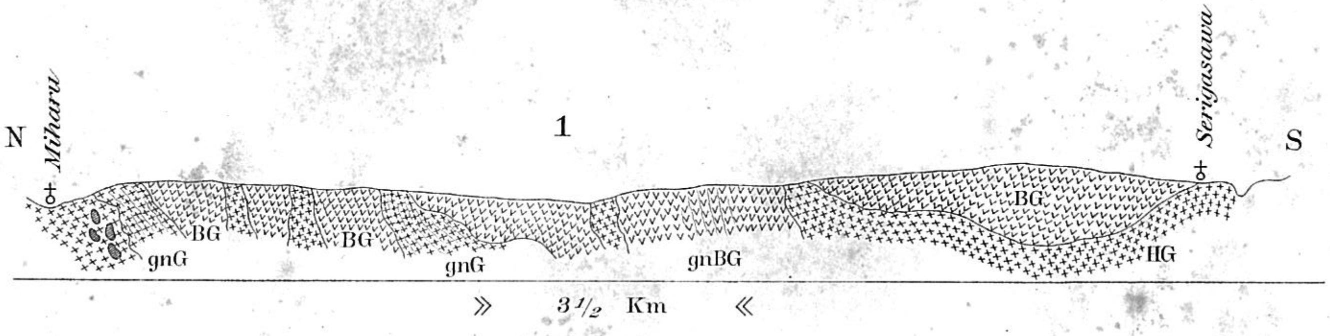

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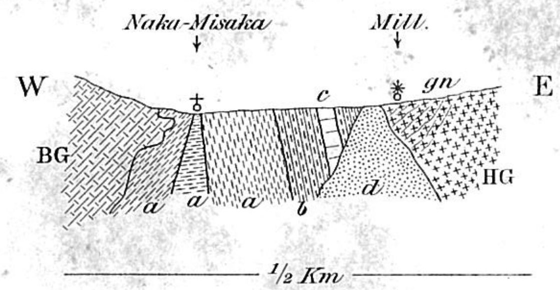

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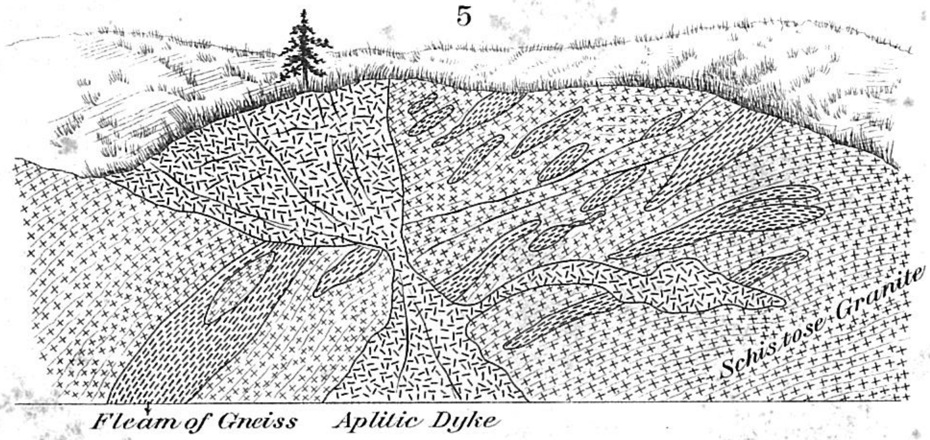

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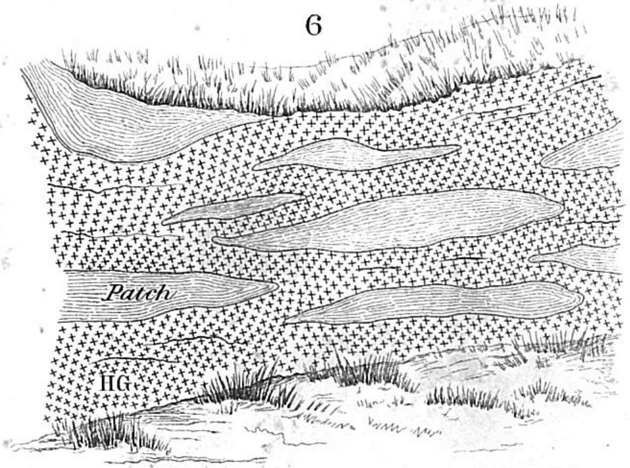
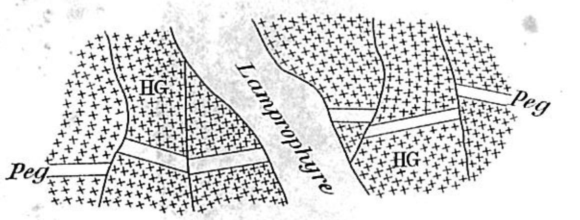


Exposure between Tonda and Higashino, Higashi-Shirakawa Gōri.

2



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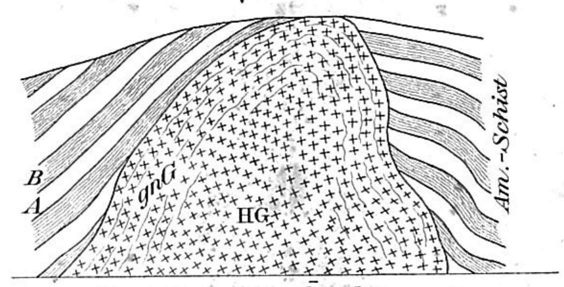
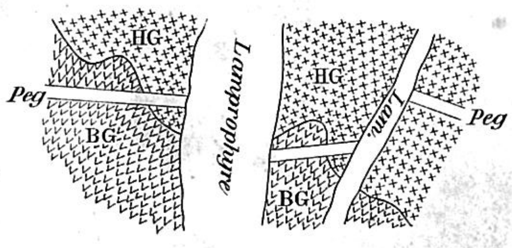


Exposure at Ōtsuka

3



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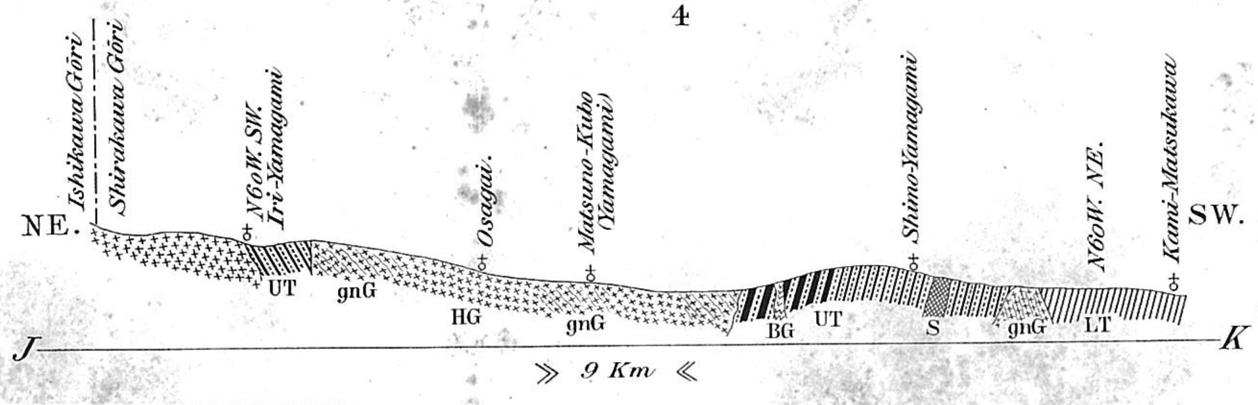

PLATE XXV.

Plate XXV.

In this Plate, an attempt is made to illustrate by means of four sections the general geological succession of the Laurentian, Takanuki, and Gozaisho divisions of the Abukuma Archæan, together with the dykes of lamprophyre and pegmatophyre. The positions of the line of section are indicated by thick lines, with corresponding letters on the map, in Plate XXII.

Section A-B, from Hirakata on the Pacific sea-board through Nakayama to Kawakami in the Kuji valley. (See p. 202 *et seq.*)

Section C-D, is drawn westwards from Kadōno, 12 km. west of the city of Taira, across the ridge of Gozaisho, to the west of Takanuki. This is the best profile of the whole region. MG=BG, *i. e.*, biotite-granite. (See p. 204.)

Section G-H, from Ishikawa to Shimo-Kawabe on the right bank of the Abukuma. (See p. 216.)

Section E-F, from the small hamlet of Kami-Misaka (where a patch of the Gozaisho may be seen) to Ishikawa on the west. (See p. 212.)

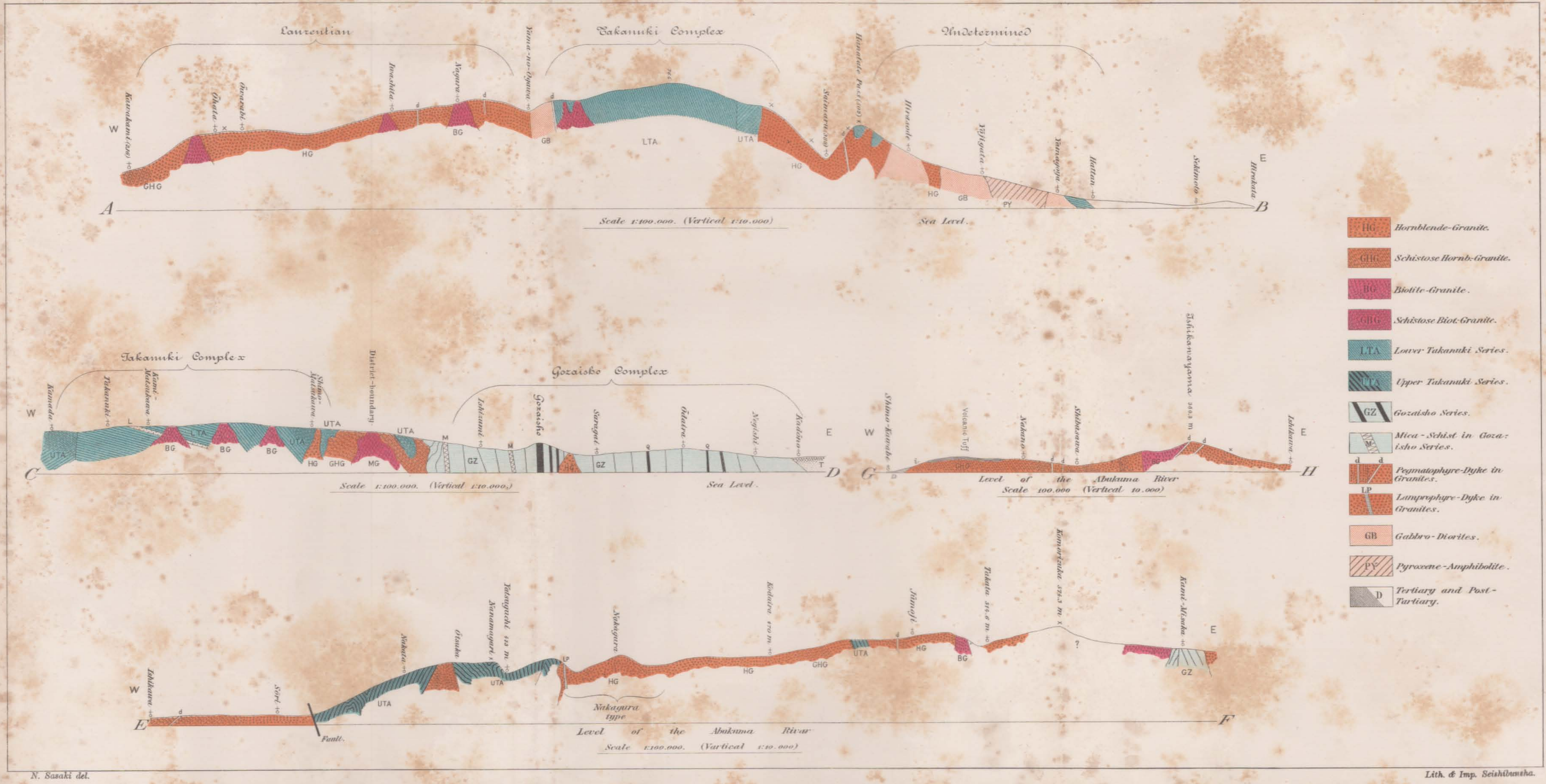
Laurentian
Takanuki Complex
Undetermined
W
E
A
B
Scale 1:100.000. (Vertical 1:10.000)
Sea Level.
Takanuki Complex
Gozaisho Complex
C
D
Scale 1:100.000. (Vertical 1:10.000.)
Sea Level.
G
H
Level of the Abukuma River
Scale 100.000 (Vertical 10.000)
E
F
Fault.
Nakagura type
Level of the Abukuma River
Scale 1:100.000. (Vertical 1:10.000)
HG Hornblende-Granite.
GHG Schistose Hornb.-Granite.
BG Biotite-Granite.
GBG Schistose Biot.-Granite.
LTA Lower Takanuki Series.
UTA Upper Takanuki Series.
GZ Gozaisho Series.
M Mica-Schist in Gozaisho Series.
d Pegmatophyre-Dyke in Granites.
LP Lamprophyre-Dyke in Granites.
GB Gabbro-Diorites.
PY Pyroxene-Amphibolite.
D Tertiary and Post-Tertiary.

PLATE XXVI.

Plate XXVI.

In this Collotype Plate, an attempt is made to represent the general features of the most characteristic rock-sections, as they appear under the microscope. All give the magnification of 140 diameters.

FIG. 1,—represents the rock-section of garnet-chloritoid-quarz-schist, one of the members of the Gozaisho series. Colourless granules in the photograph is the aggregate of garnet, while the irregularly outlined, black patches are the plum-green lamellæ of chloritoid. The white ground consists of quartz. (See p. 270.)

FIG. 2,—shows a portion of the light-green band in titanite-salite-amphibolite. The crystalloids with a few cleavage-lines are the crystal-grains of salite, while at the lower margin of the figure we find a basal section of the same with its characteristic augite-cleavage. The white ground in the figure represents the aggregates of feldspar which is changed into a colourless, fine fibrous, confused mass, displaying highly chromatic, aggregate polarization-colours. The intact part of the feldspar appears in a sporadic manner within the micaceous mass which seems to be identical with pseudophite or saussurite. (See p. 253.)

FIG. 3,—shows sillimanite in confused aggregate, occurring in garnet-biotite-schist of the Takanuki series. (See p. 251.)

FIG. 4,—is the section of a typical titanite-biotite-amphibolite, in which are seen the bacillar amphibole, and round titanite, resembling rolls of butter, sometimes with clumps of titaniferous iron in the centre. Locality: Kamada near Takanuki. (See p. 252.)

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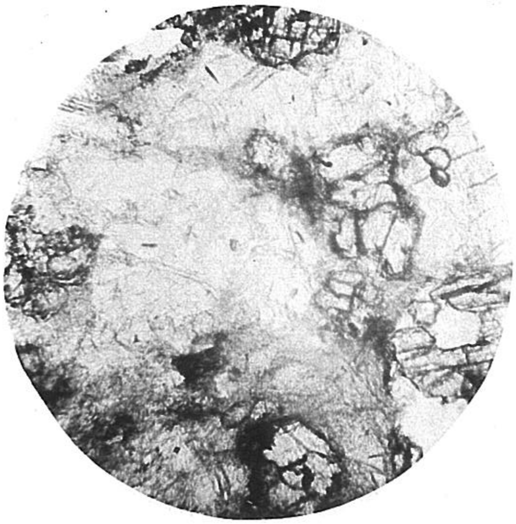
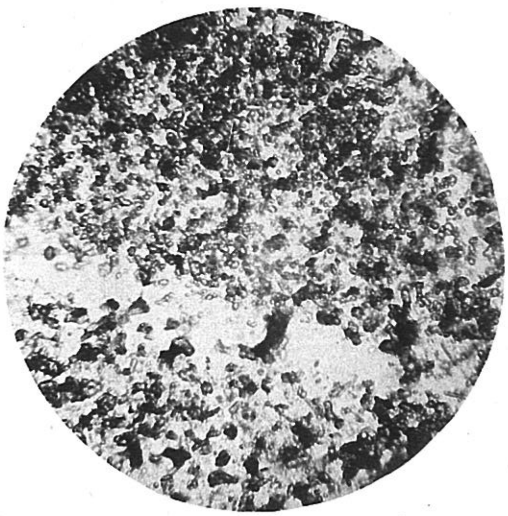


4



Collotype by K. OGAWA.

PLATE XXVII.

Plate XXVII.

This Plate represents the appearances of the polished surfaces of the Takanuki and Laurentian rocks, at right angles to the plane of schistosity, excepting Fig. 4.

Fig. 1,—is the transvers esection of titanite-salite-amphibolite. The dark bands are mainly composed of a bacillar amphibole, alternating with the white bands of salite whose magnified section is represented in Fig. 2, Pl. XXVI. (See p. 258.)

Fig. 2,—shows the transverse section of a granulitic gneiss-mica-schist of the Takanuki series. Locality: Kamada near Takanuki. (See p. 248.)

Fig. 3,—shows also the transverse view of a schistose granite, from the Kawachi pass, Naraha gōri, Iwaki. (See p. 236.)

Fig. 4,—shows a view parallel to the schistose plane of a granite of a dioritic type of mineralogical composition, brought from Shimo-Matsukawa, on the banks of the Samé-gawa.

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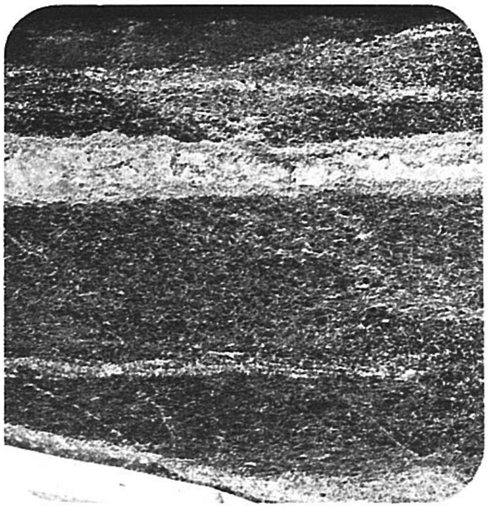

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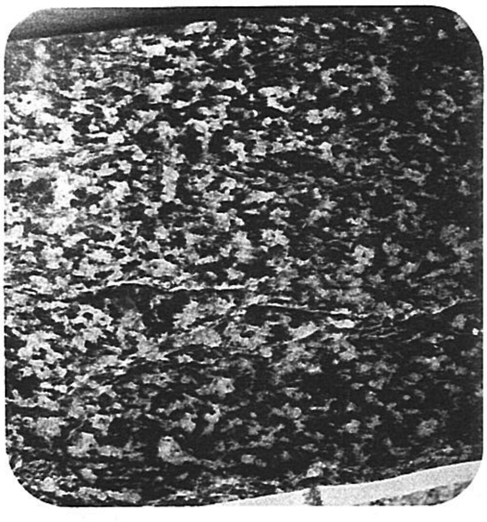

Collotype by K. Ogawa.