ALPINE OROGENIC MOVEMENT IN HOKKAIDO, JAPAN

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(With 3 Plates and 3 Figures)

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Introduction

The Japanese Island arc fringing the eastern border of the Asiatic continent like a festoon belt has been considered by many authors as a territory of Alpine orogenic movement. That is, the islands as a whole are interpreted exclusively as a zone belonging to a single orogenic phase. Recently, however, with the advance of geotectonic researches on this territory, long established geologic units of the islands have been re-examined as orogenic beings and are discriminated into some different orogenic belts which are separable chronologically from each other. Now it is being considered whether they may offer probable correspondences to the Caledonian or pre-Cambrian, Variscan and Alpine orogenic phases respectively. The essential point in the history of the development of the Japanese Island arc is the succession of orogenic events similar to those offered by a continent, though the scale is a very small one.

Among the islands, the orogenic units belonging to the earlier phase lie in the inner side of the arc, and the younger ones are disposed in the outer Pacific side. Each orogenic zone was originated as a sphere of thick geosynclinal sedimentation and thereafter underwent to orogenic compression producing vigorous metamorphism and pultonism at the culumination of each stage. Accordingly, continuous metamorphic zones stretching along the island arc were formed.

An Alpine orogenic zone is typically represented over the axial part of Hokkaido, the northernmost island of Japan. It spreads with N-S trend as the geological backbone of the island, and in particular, is clearly revealed along the Hidaka mountain range that lies in the southern half of the axial part. Probably, its northern continuation may prove to be connected with the axis of Sakhalin island, whilst the southern part seems to disappear under the Pacific ocean. Further southern extension should be sought among elements of the Honshu arc, but there are no correlatives to such a prominent zone of Alpine phase. "Hidaka orogenic zone" is the name given to such an Alpine orogenic zone, with its chief region of activity in the island of Hokkaido.

The island of Hokkaido has been actually colonized by Japanese since 1870; it has been explored rapidly so almost the entire area is now well known. But the axial part still remains in primeval state because of its steep mountainous ground. The first and the most extensive geological and expeditional survey of this territory was carried out in 1910-1915 by the Geological Survey of Japan with the purpose of exploring the mineral resources (YAMANE, S. 1911-a, -b, OKAMURA, Y. 1911-a, -b, -c, 1912, 1913, IKI, T. 1911-a, -b, -c, -d, KOBAYASHI, G. 1911). By these works, general geological knowledge about the axial zone attained, however, subsequent researches were made only locally and occasionally so geological information regarding the region has been left in the early state for a long time.

In 1941, the writer and Seiji HASHIMOTO commenced their geological and petrological studies under the guidance of Prof. Jun SUZUKI on the metamorphic and plutonic rocks developed in the southern extreme region of the axial zone. Since that time, students interested in this orogenic zone have increased, and they organized collectively the "Hidaka Research Group", through which they have carried on their researches with intimate collaboration. Now, taking a partial charge of the theme, the members are endeavouring their researches to expand. The present active members are as follows; Mitsuo HUNAHASHI,* Seiji HASHIMOTO*, Masayuki SAITO**, Hiroshi ASAI***, Takeo BAMBA****, Sachio IGI****, Toshiaki SAWA****,

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The first collaborative undertaking was to prepare geological maps on 1/50,000 scale to cover the region about the Hidaka mountain range. This work in the main part, has proceeded almost to completion, and the results will be published in the nearer future. With them, the general developmental history of the axial zone can be told somewhat practically.

The present view is that the axial part of the island was occupied by a vast sea of geosynclinal sedimentation till late Jurassic; then with the beginning of the Cretaceous the geosynclinal sea was transformed into a territory of orogenic folding bringing plutonism and metamorphism in its core. The movement had ceased in early Palaeogene for a while, but several disturbances have occurred successively over the whole axial zone in Neogene Tertiary.

The author deals with the whole evolution as the "Hidaka orogenic movement" and regards it as correlative to Alpine orogenic movement of the world. The following presentations describe the general course of these movements in as far as the present state of knowledge has attained.

The axial zone of Hokkaido: the Hidaka zone and the Kamuikotan zone

As significant features of the geomorphic outline of the island of Hokkaido, it should be noted that Cape Soya protrudes prominently to the north and Cape Erimo to the south. They represent the extremities of the geological axial zone extending with N-S trend in the midpart of the island. In the axial zone two prominent tectonic zones are discernible. The one is called the *"Hidaka zone"* which occupies the greater part of the axial zone. Its western border exhibits such peculiar tectonic characters that it is discriminated as a special tectonic unit which is called the *"Kamuikotan zone"* (HUNAHASHI M., HASHIMOTO, S. 1951). (cfr. Plate 1)

What is the Hidaka zone? The zone has a width of 20 km in the southern part, but it spreads in fan-shape to the north. In this zone, thick

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sedimentaries which consist chiefly of monotonous slates and fine sandstones are extensively developed, while various metamorphics with migmatitic nucleus and associated plutonics such as gabbro and granite constituting a narrow belt are contained in its central part (SUZUKI, J. 1934-c). Such metamorphic belt is exhibited along the entire Hidaka mountain range, and is named particularly the *"Hidaka metamorphic zone"*.

Along the Hidaka mountain ridge, a zone of metamorphics continues for a distance of about 140 km with 10-20 km width. Migmatite is revealed as the core-facies of the zone: it is surrounded by gneiss which grades into hornfels at its external margin. The hornfels transits gradually to non-metamorphic slate and sandstone. The metamorphic zone is covered by younger volcanics at its northern extension. Furthern northern part, the metamorphics and plutonics do not constitute a long continuous zone, but are separated into some small areas. However, it is sufficient to identify the central part of the Hidaka zone only to plot such separated scattered metamorphic aureoles. Probably, the explanation is that the metamorphic zone pitches under the non-metamorphic niveau in the northern part, and only its protruded roof exposed sporadically to the surface.

Thick sedimentary formations developed around the continued metamorphic zone are arranged exclusively in the *"Hidaka group"*. This group consists of slates and fine sandstones, and their blackish grey coloured and monotonous fine grained natures are the prominent characters. Owing to structural disturbances and deficiency of key bed the stratigraphical succession and detailed geologic structures have not yet been established.

A small limestone lens containing Jurassic *Brachiopoda* was found in the schalstein formation which is regarded as the upper member of the Hidaka group. Furthermore, Jurassic ammonites have been found from a calcareous nodule imbedded among the slate member of the group developed in the eastern environs of Shotonbetsu, northern Kitami Province.

What is the Kamuikotan zone? Bordering the entire western side of the Hidaka zone, though its width is narrower than that of the Hidaka zone proper, a prominent tectonic zone continues without interruption. It is a zone of anticlinal nature, and westward up-thrusts are discernible in some places. Low grade dynamometamorphosed rocks and mylonitic rocks are associated in some peculiar situations (SUZUKI, J. 1934-b). Accompanying with such sheared rocks many serpentinite intrusives appear to form the greatest serpentinite belt in the Japanese Island arc.

Such rocks as gabbro and granite which are prominent in the Hidaka zone are entirely lacking in the Kamuikotan zone. The main portion of the zone is constituted of a schalstein formation which is regarded as the equivalent to the upper member of the Hidaka group, and the overlying lower Cretaceous formation is also associated with it.

In such manner, the axial part of the island of Hokkaido is constructed by the N-S trending two parallel running distinctive tectonic zones, viz., the Hidaka zone and the Kamuikotan zone as above described. This is the geological backbone of the island, which is the resultant of the Hidaka orogenic movement. The younger formations of the island, too, are wholly controlled by such a framework.

The contrasting features of the metamorphic and plutonic behaviours presented within the two zones are so distinctive that their mutual relations have long been considered unsoluble. However, with the accumulation of stratigraphical and tectonical informations about the border part of the two, the relations have come to be understood as tectonical repetitions of the same formations. Detailed observations made about the region of Kanayama-Ashibetsu, eastern Ishikari Province, have promoted the formation of such view (OTATSUME, K. 1940).

It has long been noticed as a prominent feature opposed to both parallel-running zones that a narrow belt filled with Cretaceous formation lies between the two. The Cretaceous formation is disturbed in a complex manner, however, it is considered to be a zone of synclinorium structure which was folded together with the conformably underlying schalstein formation of probable Jurassic. Its western wing grades into the anticlinal structured Kamuikotan zone which is composed mainly of schalstein, and the eastern wing is connected to the thick schalstein formation of the Hidaka zone. In this manner the schalstein formations of both zones are considered to have been originally disposed in the same horizon and to have been together laid down conformably under the lower Cretaceous formation.

As the characteristic structural features of the area there are observable many tendencies of westward thrusting. Some attentions to these tectonic relations have led to the assumption that there must have been a more grand geologic structure which caused such thrusting as an exhibition of its westward pushing in a further eastern region: so the central core of such a grand structure should be found along the Hidaka mountain range. The two prominent tectonic zones of the axial part of Hokkaido are considered as being products of a single orogenic movement, which caused both characteristic metamorphisms and plutonisms according to each geological situation. These suppositions were originally put-forward by the late Dr. Kenichiro OTATSUME, to whom our petrological researches of the Hidaka mountain range are deeply indebted.

Metamorphic and Migmatitic rocks of the Hidaka zone

Most of the metamorphic rocks developed in the Hidaka zone are arranged in a narrow belt, and especially in the southern half, it forms a continuous metamorphic zone which is decidedly discriminable from the surrounding non-metamorphic rocks of the Hidaka group. Accordingly, it can be presumed that the old metamorphic basement complex was possibly pinched up between younger non-metamorphic formations. However, many instances where the hornfelses gradually transit into slates are observable in the eastern side of the metamorphic zone, also calcareous nodules prominent in the slate region are contained in hornfelses and gneisses, and even in migmatites as their metamorphic derivatives. From the geotectonic point of view, too, it is undoubted that the metamorphic zone was constructed as a result of the transformation of slates and sandstones of the Hidaka group. Most of the metamorphic rocks are of argillaceous nature similar to that of the Hidaka group. Although their original character is a monotonous one, their metamorphosed derivatives are revealed in distinctly differentiated forms.

It was the most fundamental subject of the Hidaka Research Group how to arrange an absolute "rock species" distinguishable from others, and how to represent it on the geological map by a unit colouring. In early stages of the Group's researches, determination was merely carried by sensuous impressions, however, with the gaining of experience, a clearer basis for such rock classification has been recognized as necessary. To determine a rock species merely on the basis of the features of a single hand-specimen may well confuse the geological map and make impossible the completion of it. It is rather desirable that the designation of a "rock species" carries the meaning of what position it occupies in the spatial spreading in the Hidaka mountain land and whether it constitutes a structural unit or not. The "rock species" resulting from the Hidaka Research Group's collaboratory discussions regarding such geological meanings and available for the whole Hidaka metamorphic zone are listed as follows:

A) Hornfelses
- *a*) *hornfels*
- *b*) *true hornfels*
- *c*) *schistose hornfels*

B) Schists	*a) plagioclase porphyroblast biotite schist*
C) Gneisses	*a) banded biotite gneiss*
	b) plagioclase porphyroblast biotite gneiss
	c) biotite gneiss
D) Migmatites	*a) gneissose biotite migmatite*
	b) sillimanite and cordierite bea. gneissose biotite migmatite
	c) cordierite bea. biotite migmatite
	d) biotite migmatite
	e) granitic migmatite
E) Amphibolites	*a) amphibolite*
	b) quartz amphibolite
F) Calcareous rocks	*a) metamorphosed calcareous nodules*

Inside the metamorphic zone each rock species occupies a specific situation and the species are arranged zone by zone. The following is the general arrangement which is adequate through the Hidaka mountain range enumerating from east to west.

	Zone	Constituent rock species
1)	Zone of hornfels	*hornsels*
2)	〃 true hornfels and schistose hornfels	*true hornfels, schistose hornfels*
3)	〃 banded gneiss	*biotite gneiss, banded biotite gneiss*
4)	〃 migmatite	*gneissose biotite migmatite, cordierite bea. biotite migmatite, granitic migmatite*
5)	〃 blastic gneiss	*plagioclase porphyroblast biotite gneiss*
6)	〃 blastic schist	〃 〃 *biotite schist*
7)	〃 schistose hornfels	*schistose hornfels*

Marked differences in the time relation of their formations and the transformational mechanisms or the style of tectonic movement of each rock zone are mentioned. Further, it is worthy of note that the contrasted features are acquainted between the eastern and western sides of the metamorphic zone. Accordingly, some rocks which are regarded exclusively belonging to the same rock species, present some different characters whether the specimen comes from the eastern region or the western region. The tectonic structures and the position of igneous intrusions have also intimate relationship to the spatial arrangement of these rock species (HUNAHASHI, M., HASHIMOTO, S. & others, 1956). (cfr. Plate 2)

Followings are brief notes on the petrographical features of each rock species and their mutual relations.

A) Hornfelses:—

Bordering the outer margins of the metamorphic zone there develops a zone of (a) *hornfels*. It is revealed as a well continuous belt of 2-8 km width along the eastern slope of the Hidaka mountain range. In the western side of the metamorphic zone, however, it is almost lacking except in small areas of the northern and southern terminal regions of the mountain range because huge thrust fault so cut the western side of the metamorphic zone that the gneisses directly contact with the non-metamorphic slates.

The greater part of the hornfels zone is represented by incompletely recrystallized hornfels which contains quartz and feldspar grains of the original sediments. As one approaches to the metamorphic zone from the slate region, the first sign of metamorphism is met in hardening of slate with purplish tint due to the formation of biotite. In such situation, cloudy flakes of biotite begin to spread between sand grains and matrix of slate. Hornfels of the inner zone furnishes steady flakes of biotite, and also the relict of original sediments somewhat decays and so begins to recrystallize. With such hornfels, varved stratification of sand and silt is well preserved in original state on weathered surfaces. Close to the gneiss zone is found completely recrystallized (b) *true hornfels* which has equigranular and non-foliated structure. The original sedimentary features and sand grains have wholly vanished in this rock species. The chief constituents of it are quartz, biotite and plagioclase of An_{30}. Muscovite-, cordierite-, garnet- and tourmalline-bearing types are also known, but they are characterized according to very local and specific situations, for example, such case as a type found in the contact zone of meta-diabase etc. Accessory minerals of magnetite and pyrrhotite always accompany them.

In the northern part of the Hidaka zone, far off from the Hidaka mountain range, most of the hornfelses are not associated with gneiss and migmatite. They appear as small aureoles surrounding a plutonic body. However, the hornfelses have similar petrographical features to those of the southern part. But in some part it is rather common for them to contain a large amount of cordierite which is reasonable in view of their metasomatic formation.

Closer to the gneiss zone, schistose appearances grow intensely with the hornfels. The (c) *schistose hornfels* develops in such situation. The schistose feature, at first, is brought by the growth of porphyroblastic flattened aggregates of small biotite flakes, which are arranged in parallel orientation. The orientation is represented only by the arrangement of such spotted biotite aggregates. However, its grundgewerbe remains in the non-foliated true hornfelsic nature. The foliation becomes intense to the immediate neighbourhood of the gneiss: the biotite spots spread larger on the schistose plane and the minerals of the grundgewerbe also take such parallel orientation that the rocks grade to cleavable. Sometimes it transits to biotite schist which reveals slip plane with lineation. Such strongly foliated schistose hornfels reveals the nature of banded gneiss with intercalation of thin leucocratic seams along the schistose plane.

The zone of schistose hornfels of such nature develops as a narrow belt of 100$\sim$800 m width bordering the eastern side of the gneiss zone. Another occurrence is know in the midpart of the metamorphic zone in the southern terminal region (HUNAHASHI, M., HASHIMOTO, S. & others, 1956). The tectonic situation of it indicates that it is filling the core of syncline of the deep burried gneiss and migmatite layer. Another kind of schistose hornfels is also to be mentioned as the western representative of the southern terminal region of the metamorphic zone. The mineral assemblage of this hornfels is similar to that of eastern type, but the plagioclase grows as microporphyroblast and the grundgewerbe form a somewhat parallel structure. The volumetric relation is also different, for example, quartz is about 15% less than the eastern equivalent. The northern extention of this type of hornfels is transformed into B)-(a) *plagioclase porphyroblast biotite schist,* which continues to the midpart of the Hidaka mountain range. Its grain size is larger than that of schistose hornfels, and it is furnished with distinct schistose character and lineation. The grain size of the plagioclase porphyroblast reaches to 1 mm and large biotite flakes are so undulately arranged that the rock approaches to gneissic nature.

C) Gneisses:—

A prominently developed zone of gneiss is always observed around the migmatites. The constituent minerals of the gneiss become so much coarser than those of hornfels as to be discriminable with the naked eye. The foliated arrangement of biotite flakes and plagioclase grains becomes so intense that the rock emerges from hornfelsic nature and approaches to gneissic appearances.

(a) *Banded biotite gneiss* is disposed at the transitional part that lies between the schistose hornfels and the gneiss. Banded structure is revealed by the alternation of thin layers 1-2 mm thick enriched with biotite or with plagioclase and quartz respectively. The foliation plane undulates gently and contains occasional small leucocratic patches. In some parts, banded structure is released by a coarse hornfelsic equigranular part.

The gneiss disposed in the western part of the metamorphic zone is a distinctive species compared to that of the eastern. Of the western gneiss, (b) *plagioclase porphyroblast biotite gneiss* is the most prominent type. Identical with the schistose hornfels and the biotite schist of the western zone, the plagioclase develops as a large porphyroblast. The foliated arrangement of the constituent minerals is conspicuous, in which lens-shaped porphyroblast is surrounded by the undulatory biotite flakes. Cataclastic structures are also prominent, so the plagioclase is deemed to be porphyroclast. Along the foliation plane a band of coarse grained non-foliated migmatitic part is often developed.

Instead of wide differences of structural appearance of these gneisses, the constant association of plagioclase of An_{30}, quartz and red brown biotite is the predominant feature. Often accessory minerals are observed such as interstitial orthoclase which, on some occasions, accumulates to a large quantity and also almandine garnet, particularly with the western types.

D) Migmatite:—

Constituting the central part of the metamorphic zone and bounded on both eastern and western sides by the gneiss zones, a belt of coarse-grained granite-like massive rock is developed. It extends along the ridge line of the Hidaka mountain range continuously from the northern part to the southern extremity. This rock species is *migmatite*. It appears, in general, with non-foliated massive outlook, however, ghost -like gneissose texture is presented everywhere. It is better to consider that the migmatite was produced by the replacement of gneisses and hornfels *in situ*. Where a thin seam of amphibolite is intercalated within gneiss, when the surrounding gneiss is migmatized, it is often observed that the amphibolite possesses a layered disposition as the original seam in the migmatized gneiss. Also as a sign of *in situ* transformational origin of migmatite, it should be noted that the metamorphosed calcareous nodules predominate in hornfels and gneiss are also contained in the migmatite with similar occurrence. In the border parts of the migmatite, there may be observed irregular transformation that indicate various grades of migmatitization, viz., such facies that remain in gneissose state or have been transformed to coarse grained massive state escaped from gneiss. Such a transformation shifts gradually without clear boundary line, which is suggestive that the course of development of the massive migmatite originated from the foliated fine grained gneisses. In the inner part of the migmatite zone as well, numerous fragmental gneiss blocks as "palaeosome" which are regarded as the remnants of original gneiss which somehow escaped from migmatitic replacement are scattered among massive migmatite like a xenolithic form. The boundary phase of migmatite shifting to gneiss is commonly transitional within a narrow distance. In general, at the western side of the metamorphic ozne, it attains with the growth of plagioclase of gneiss to a large porphyroblast and hence the interstitial quartz and biotite flakes to large size, with which the gneiss is transformed to migmatite. On the eastern side, coarse-grained migmatitic part is produced at first as thin seams spread along the foliation plane of banded gneiss, and with increasing of the coarser part, the rock approaches to massive migmatite. Actually, both inclinations revealed side by side with intimate association.

In our familiar migmatites the following rock species are discernible.

a) *gneissose biotite migmatite*
b) *sillimanite and cordierite bea. gneissose biotite migmatite*
c) *cordierite bea. biotite migmatite*
d) *biotite migmatite*
e) *granitic migmatite*

From the western margin of the migmatite zone (a) *gneissose biotite migmatite* is known. It has similar rock character to that of plagioclase porphyroblast biotite gneiss which lies immediate outward from it, and is discriminated from the latter by the development of plagioclase porphyroblast to a larger size of migmatitic coarseness. Although the rock presents porphyroblastic plagioclase and distinct gneissose foliation, it contains elongated spindle-like palaeosomes of plagioclase porphyroblast gneiss. Its mineral assemblage is plagioclase-biotite-quartz association with occasional accompanying large amount of almandine garnet. Another kind of gneissose migmatite is found at the mid-course of the Saruru river, on the eastern side of the southern extreme region of the migmatite zone, forming a small area of 10 km length and 2 km width. It is accepted as an absolute rock species, (b) *sillimanite and cordierite bea. gneissose biotite migmatite.* Large porphyroblasts of sillimanite and cordierite which attain, sometimes, up to 7×4 cm, occur with it. Gneissose appearance is furnished by the finely impregnated undulatory lighter coloured layers enriched with quartz and plagioclase. Further, these elements so commingle with the coarse-grained cordierite migmatitic part that the rock attains to gneissose migmatitic appearance as a whole.

(c) *Cordierite bea. biotite migmatite* occupies the main portion of the southern terminal swelling part of the migmatite zone. It contains cordierite constantly as a subordinate mineral associated with the main plagioclase-quartz-biotite assemblage. Since there are included many palaeosomes of gneiss and biotite clots which are regarded as the resorption remnants of gneiss, this type of migmatite presents a very heterogeneous appearance. It shows massive outlook without notable foliation, and in some parts furnishes a well defined joint system. In the northern continuation of the cordierite bea. biotite migmatite, it grades to a non-cordierite-bearing type of migmatite, which is called (d) *biotite migmatite*. It develops through the whole northern extension, and offers gneissose appearance in part. Sometime, hornblende bearing type which seems to be related with the gabbroic intrusives is also known from it.

(e) *Granitic migmatite* occurs at the inner part of cordierite bea. biotite migmatite or biotite migmatite zone as lens-shaped bodies which are arranged in echelon. At the part transitional to cordierite bea. biotite migmatite, it appears in thin seams alternate with cordierite bearing type, and in some parts, its irregular veins of aplitic phase impregnate through the cordierite migmatite. Generally, this type of migmatite appears with coarser grain and in more homogeneous structure than the other types, and included palaeosomes are scarce. A coarser grained and leucocratic facies is often developed as irregular patches or in dyke-like form. The mineral assemblage is similar to that of biotite migmatite, but the presence of a larger amount of orthoclase than is found in other types of migmatite is the prominent feature.

E) Amphibolites:—

These types of rock are poorly represented in comparison with the rocks of argillaceous sediment origin. The (a) *amphibolite* includes two types, the one is believed to be a metamorphosed schalstein originally intercalated in the argillaceous sediment, and the other is the metamorphosed diabasic dyke of pre-metamorphic phase. In the metamorphosed diabase the original structure is more or less preserved; it is constituted of recrystallized plagioclase and hornblende. This type of amphibolite is found chiefly in the border parts of the metamorphic zone. The schalstein derivative shows typical nematoblastic structure consisting of greenish hornblende and plagioclase of An_{50}. In the gneiss zone, it is revealed with the features of homogeneous hornblende schist, but in the migmatized area it is penetrated by many leucocratic veins enriched with basic plagioclase, or is broken up into small blocks and are dispersed in the argillaceous migmatite.

In some parts, this layered amphibolite reveals somewhat leucocratic natures being constituted of quartz-plagioclase-brown biotite-green hornblende association. This type of amphibolite is discriminated as a unit species, (b) *quartz-amphibolite.*

F) Calcareous rocks:—

(a) *Metamorphosed calcareous nodules.* These spindle-shaped nodules attain commonly to ca 20 cm. length, and are presented in every rock zone. In some cases, they can be discerned as containing in a key bed that makes a continuous zone enriched with them. They are considered as the metamorphosed derivatives of calcareous nodules which are frequently met within the fine sandstone of the Hidaka group. Various assemblages take a zoned arrangement in and around the nodules. The core, in general, is represented by the diopside-basic plagioclase-(garnet) association which is surrounded by the green hornblende-diopside-plagioclase association (SUZUKI, J. 1934-a). Even when the nodule occurs in the migmatite area, it is scarcely migmatized, and remains in the nodule form maintaining a similar nature to those of hornfels zone.

On the constituent minerals: Most of the above described metamorphic and migmatitic rocks were derived from argillaceous sediments, so the mineral assemblage of them is represented as a rule, by the quartz-plagioclase-biotite association accompanied with a small amount of orthoclase. Many rock types that contain such as cordierite, garnet, or muscovite should also be mentioned, but they occur in minor amount.

The composition of plagioclase is in average of An_{30}, and most of them lie in the extent of An_{35}-An_{25}. There are no definite differences in composition of plagioclase even if it belongs to different rock species. The chemical character of the biotites, on the other hand, seems to have some differences according to the nature of their host rock species. All have red brown tint, and have a general tendency to reveal deeper tint in hornfelses but lighter in migmatites. A chemical study shows that the biotite of the gneiss possesses an extraordinary higher content of alumina than that of other rock species (KIZAKI, K. 1953).

Pyrrhotite and magnetite are always found in company with them as accessory opaque minerals. The pyrrhotite decomposes to limonitic staining on the weathered surface, which gives rise to the characteristic appearances of the argillaceous metamorphics of the Hidaka zone. Such staining is particularly represented on gneisses and cordierite bea. biotite migmatite, and in some cases, it appears in high grade concentration as small lenses or in streaks spreading along the foliations. Upon the granitic migmatite, however, limonitic staining is entirely lacking.

The volumetric relations of the main constituent minerals are not yet well established, but it is probable that the differences will be revealed with each rock species and with each geotectonic situation. In the southern terminal region, quartz is present in larger amount with the schistose hornfels of the eastern part than with the western representatives. Also in migmatites, biotite and quartz are more abundant in cordierite migmatite than are the other types. It is expected that the biotites of these metamorphics will be found to have a chemical composition distinctive to themselves according to the differences of their host rock species. The reasons for these variations should be sought in the circumstances under which each rock was formed rather than in the difference of chemical comosition of the original rock (KIZAKI, K. 1953, HUNAHASHI, M. HASHIMOTO, S. & others 1956).

The mutual relations between the rock species: In what order the above described rock species should be arranged is a problem subject to much speculation. Concerning them the following remarks are offered in respect to the eastern region and the western region respectively.

The eastern region:

i) The circumstances that created the parallel orientated biotite clots which were born as porphyroblastic aggregates among the non-foliated hornfelsic grundgewerbe enforces the rock into schistose hornfels.

ii) The gradual transition to banded gneiss from schistose hornfels is attained by the creation of many thin seams of leucocratic part along the foliation plane of schistose hornfels.

iii) Sometimes, coarser grained and non-foliated massive parts appear among the banded gneiss, and they develop to migmatitic nature which often contains blocky gneissose parts as a resorption remnant.

iv) On occasion, vein-like pools of granitic migmatite protrude into the cordierite bea. biotite migmatite or gneissose migmatite.

Respecting the western region the following relations may be mentioned.

i) In the plagioclase porphyroblast biotite gneiss schistose hornfelsic part remains as the part of least transformation.

ii) Palaeosomes of blastic gneiss are scattered among the cordierite migmatite.

Above noted relationships of the respective rock species lead one to a possible interpretation of the metamorphic history that the transformation occurred from hornfels through schistose hornfels→banded biotite gneiss, blastic biotite gneiss,→cordierite bea. biotite migmatite, gneissose biotite migmatite→granitic migmatite step by step replacing the earlier formed rock types respectively. On the other hand, however, it is worthy of note that a petrofabric analysis carried out around the Oshirabetsu migmatite dome, a small protruded migmatite portion of the southern terminal region, suggests the contemporaneous formation of each rock species: viz. each measured quartz fabric of cordierite bea. biotite migmatite-, banded botite gneiss- and schistose hornfels-zone denotes a wholly coincident orientation and inclination in common (KIZAKI, K. 1956-a, -b). The meaning is that similar circumstances controlled the formation of the quartz of each rock species: however, the main preexisting differences of each rock species were not so much altered by such circumstances as to effect the quartz. In this respect, another petrofabric analysis carried out around the Toyoni-Daké migmatite dome, southern extreme region of the migmatite zone, reveals marked differences between the migmatite body and its surrounding schistose hornfels in the pattern of lineation, quartz fabric, etc. These discordancies point to prominent dissimilarity in the style of development of the respective rock zones, and accordingly, in the time relation of each rock transformation (KASUGAI, A. 1957). At any rate, it is better to consider that a rock species is resultant from a long-continued process.

Geochemical migration of elements: The variations of chemical composition including the migmatite to hornfels were examined, using the materials developed along the course of the Satsunai river, in the northern Hidaka mountains. According to this study, the chemical features of migmatite and hornfels are nearly the same, but the amount of alumina reaches its maximum in the gneiss zone. It seems plausible to belive that the alumina migrated from the deep to the shallower zone during the course of migmatization accumulated and became fixed in the gneiss zone. The culminated alumina seems to be fixed mainly in biotite, for it shows extraordinary high content of alumina (KIZAKI, K. 1953).

Similar phenomena are also observed in the transitional part of each rock zone as represented by the formation of special minerals which never appear on a regional scale. Andalusite, cordierite, almandine garnet, hornblende, etc., are common representatives of such minerals. Large andalusite porphyroblast is found along the boundary surface between banded biotite gneiss and cordierite bea. biotite migmatite: in other cases, basic association containing large amount of hornblende is developed in the transitional part of blastic gneiss to cordierite bea. biotite migmatite.

It is accepted that the extraordinary rock type of sillimanite and cordierite bea. gneissose migmatite may have been formed by such geochemical culmination. As already mentioned, it is a migmatized schistose hornfels which differs from the ordinary one. The geologic situation of those peculiar rock zones indicates that the schistose hornfels was originally the covering roof spread over the earlier deep-seated gneiss and migmatite, and it was afterward impregnated directly by the ascending cordierite migmatitization. Sillimanite and cordierite porphyroblast seem to be accumulations of special elements that swept up from the underlying cordierite migmatite. Many instances of such accumulation can be found in other situations (HUNAHASHI, M. 1 948). All these peculiar rock facies will be interpreted as the one of the indications of ascending wave like "migmatite front".

Mobilization of migmatite: The foliation of each palaeosome that remains in original gneissic state is scattered with random orientation among the cordierite migmatite as well as among granitic migmatite. It is common that the orientation of each palaeosome differs prominently from that of neighbouring ones. That indicates that the migmatite had a considerable mobility at some stage of its development. However, as previously stated, these migmatites possess several evidences of their replacement origin. So the mobility iteslf would have been a degree that would hardly permit the rotation of the block of palaeosome. The granitic migmatite seems to have been of more mobile nature, for it shows some evidences of concordant intrusion, besides, replacement relations are also observed.

Around the mid-course of the Pipairo river, in the northern Hidaka mountain range, some granitic rocks which present a distinct gneissose appearance are developed with north-south trend. It is discriminated as one of the absolute rock species; it is treated as *gneissose granite*. It furnishes some features which suggest a possible interpretation as an intrusive variety of mobilized granitic migmatite. Distinct linear structure is exhibited through the whole body, which points to north-south trend and pitches south at a low angle. A probable interpretation of these lineations is that the granitic migmatite ascended from the deep niveau along the basal surface of the mushroom-formed gabbroic body which spreads around the course of the Tottabetsu river that lies immediate south of the Pipairo river and thereafter changed the direction to nearly horizontal, pushing to the northward. The following evidence may be useful in support of such suggestion. In the bottom of the Tottabetsu river abundant aplitic parallel dykes cutting the gabbro are found: they are arranged as if they were filling marginal fissures which were produced

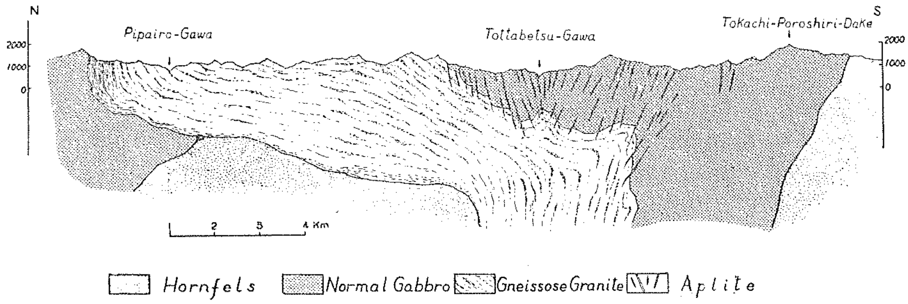

Fig. 1. North-south section extending from the Tottabetsu valley to the Pipairo valley in the eastern slope of the northern Hidaka mountains. (cfr. Plate 3)
(after S. Hashimoto)

at the curved part of the course of the intrusion of gneissose granite. (cfr. Fig. 1) Occasionally, mixed with these aplitic dykes, some micro-granitic varieties are associated. It is similar to that of aplitic facies often found in the body of true igneous granite which is arranged, locked out from the central part of the metamorphic zone, at the eastern side of the metamorphic zone. It seems plausible that there are close connections between the igneous granite and the mobilized granitic migmatite in the Hidaka metamorphic zone (HASHIMOTO, S. 1953).*

The granitic migmatite which lies in the central part of the migmatite zone has many features that tell of its replacement origin, and further, each rock forming mineral aggregates in a crystalloblastic structure. On the other hand, somewhat aplitic parts which have abundant orthoclase and idomorphic plagioclase are often meet with in the Tottabetsu aplitic dyke swarm. It is difficult, in some cases, to discriminate whether such granitic migmatite belongs to granite or migmatite when comparisions are made only with hand-specimens of such rock group.

With the progressive transformation from gneiss through cordierite bea. migmatite to granitic migmatite, metamorphic features are lost and the igneous character is enforced in the rock appearances. In this regard, it is not unreasonable to set forth the view that the natures of the highest product of the migmatitization could have attained to the magmatic

* The detailed description of the "gneissose granite" will be published by Seiji HASHIMOTO in nearer future.

state in the course of the Hidaka orogenic development. But exact evidence has not yet been found to demonstrate the actual course of the transformation of these rocks.

However, the contrasted character between migmatite and granite is also clearly perceived. Opposed to the granitic migmatite that occurs in the core of the migmatite zone, igneous granite is always found in the boundary line between hornfels and gneiss at the eastern part of the metamorphic zone. Such igneous granite is revealed with homogeneous lithological charatcer through the whole body. There are no inclusions such as palaeosomes or biotite clots, and in its petrographical texture the igneous type of hypidiomorphic granular structure is prominently exhibited. On the whole, it is not an exaggeration to say that a peculiar rock character is fixed to a definite rock zone and that the same lithic characters are never found extending over many rock zones.

Metamorphic rocks of the Kamuikotan zone

Along the Kamuikotan zone dynamometamorphosed rocks of low grade type and mylonitic rocks are often encountered. The oldest known metamorphic complex (LYMAN, B. S. 1877, JIMBO, K. 1892) of Hokkaido developed in the Kamuikotan gorge, westward of Asahigawa, central Hokkaido, is the typical representative of them. There various kinds of green schist and phyllitic schist with subordinate quartzite are arranged with N-S trend for a distance of 70 km: they constitute a structural unit which is separated by narrow serpentinite zones or thrusts from the surrounding non-metamorphic sedimentaries. Further occurrences of such metamorphosed rocks are known as the large xenolithic blocks caught by serpentinite in the northern part of Teshio Province and also in Hidaka Province of the zone. Furthermore, some mylonitic or phyllitic rocks are observed along every fault zone or strongly folded area of the zone, especially, around Mt. Yubari, eastern Ishikari Province, and the mid-course of the Mukawa river, northern Hidaka Province.

The metamorphism represented in these rocks is so low that the remnant structures of original rock such as of diabase, schalstein, slate and fine sandstone are easily discriminable. But, in some cases, wholly recrystallized coarse grained schists are associated. The assemblage of the newly formed minerals of these materials denotes that the rocks are of green schist facies. However, since mylonitic features are always observable it seems plausible that the metamorphism was carries out within a short duration of time and did not attain wholly to equibirium (SUZUKI, J. 1934-b, 1939-a).

The characteristic and most famous feature of the Kamuikotan metamorphics is that they contain various kinds of glaucophane and other soda-minerals (SUZUKI, J. 1932-a, -b, 1933, 1939-a, -b). They occur together with the green schists adjacent to serpentinite or along the sheared zone. Glaucophane, crossite, riebeckite, aegirine augite, lawsonite, albite, epidote, chlorite, stilpnomelane and quartz, etc. associate with each other forming several basic assemblages or siliceous ones (SUZUKI, J. 1953-b, HUNAHASHI, M. 1953). Among them, the siliceous part is revealed within bands or pools intercalated with the basic part. They are considered as the products of marked soda metasomatism associated with serpentinite intrusion into the green schist of the Kamuikotan metamorphics.

Followings is a list of rock species of the Kamuikotan metamorphics proper and of soda mineralized facies summarized by Prof. Jun SUZUKI (SUZUKI, J., 1939-a.)

A) *Siliceous, alumino-siliceous and calcareous rocks*

a) *quartzite*
b) *radiolarian chert*
c) *quartz schist*
d) *black quartz schist*
e) *phyllite*
f) *black phyllite*
g) *mylonite and schistose sandstone*
h) *hornblende quartz schist*
i) *glaucophane albite quartz schist*
j) *riebeckite albite quartz schist*
k) *garnet bea. riebeckite albite quartz schist*
l) *aegirine-augite bea. glaucophane quartz schist*
m) *aegirine-augite bea. riebeckite quartz schist*
n) *calcareous quartz schist*
o) *crystalline limestone*

B) *Basic rocks*

a) *diabase schist*
b) *epidote chlorite schist*
c) *chlorite amphibole schist*
d) *actinolite schist*
e) *agglomeratic green schist*
f) *albite glaucophane schist*
g) *aegirine-augite albite glaucophane schist*
h) *garnet bea. aegirine-augite lawsonite glaucophane schist*
i) *magnetite bea. garnet-fels*
j) *amphibolite*

The igneous intrusives of the Hidaka zone

Various kinds of igneous intrusives are associated intimately with the above described metamorphics and migmatites. The intrusives occupy an area almost equal to that of the metamorphics. Among them two main groups of igneous rocks, gabbroic suite and granitic suite, are discernible: both are disposed in a contrasting manner through the metamorphic zone. The gabbroic suite is arranged, for the most part, along the western side of the metamorphic zone with a continued intrusive belt, and includes various rock types, such as dioritic and ultrabasic facies. The granitic suite is confined exclusively to the eastern side of the zone, and is disposed into separated bodies adjacent to the eastern side of the swelling part of gabbroic intrusives. Its petrographical characters are rather monotonous. These igneous intrusives are continuously exposed along the Hidaka mountain range, but in the northern region, they are separated into small scattered areas.

Among them some large sewlling parts which are regarded to be the activated centres are noticed. The southern terminal region of the metamorphic zone and the Poroshiri-Daké region in the northern part of the Hidaka mountain range are typical representatives. (cfr. Plate 3) Around Okushibetsu that lies in the northern part of the Hidaka zone, aggregated minor intrusives are observed: that area is also regarded as one of the activated centres.

A continuous intrusive body of the gabbroic suite which runs along the western slope of the Hidaka mountain ridge is constituted of belts of some different rock species arranged zone by zone. As a rule the arrangement of these rock zones is as follows enumerating from west to east:

A) Zone of gabbro amphibolite
B) ,, schistose gabbro
C) ,, gneissose gabbro
D) ,, normal gabbro

A) *Gabbro amphibolites*:—A prominent thrust bordering the western side of the metamorphic zone runs for a distance of about 140 km through the whole Hidaka mountain range, by which non-metamorphic sedimentaries contact directly with the high grade gneisses. Along the hanging side of the thrust, associated with gneisses, a zone of gabbro amphibolite is continuously developed, especially extending for the mid-part from the northern Hidaka. In southern Hidaka, it takes the form of minor intermittent bodies.

Around Poroshiri-Daké, in northern Hidaka, the gabbro amphibolite is typically developed in a belt of 3.5 km width containing various kinds of rock facies, which make it most suitable field for studying the rock zone (HASHIMOTO, S. 1955). Immediate to the eastern side of the rock zone occurs a zone of gneiss with the widths varying from 500 m to a few meters, beyond which the zone of schistose gabbro is developed. The zone of gneiss which is considered as the "septa" of the intrusive chamber, is always inserted between the two gabbroic rock zones. Contrasted lithological features of gabbro on both sides of this layered gneiss zone are distinctly visible, as it gives important criteria for the zonnal subdivision of the gabbroic intrusives. The greater part of the zone of gabbro amphibolite is filled with amphibolitic rocks, but it is easy to find that the rocks are reconstructed from olivine gabbro. Saussurite gabbro, epidote amphibolite and amphibolite proper are associated with each other. The least metamorphosed part, chiefly known in the central part of the zone, has remained in the state of saussurite gabbro. In the western side of the zone, it grades to epidote amphibolite, and in the immediate neighbourhood of the thrust it is transformed by the mylonitic effect due to thrusting to chlorite-epidote-actinolite schist. In the eastern part of the rock zone, there is developed amphibolite with deep green or bluish green hornblende, from which gabbroic feature have almost vanished.

B) *Schistose gabbros*:—The zone of schistose gabbro is the most continuous among the Hidaka gabbros. It runs uninterruptedly through the entire metamorphic zone though feebly represented in the southern part. Metamorphic features are prominently exhibited, but at the same time, igneous characters are also associated with them. Although parallel arrangement of the rock-forming minerals is distinctly observable, there is no cleavable fissility: only massive appearance is predominant. All the representatives lie concordantly to the surrounding gneiss, but, some dyke-formed bodies cross the surrounding gneissosity at low angles. The chief constituents are brownish or greenish-brown hornblende and basic plagioclase which aggregate in crystalloblastic structure, though the hornblende has a tendency to arrange in parallel orientation. Typical igneous type of brown hornblende quite different from the greenish tint of neighbouring gabbro amphibolite is often revealed within the rock type. In some parts, nematoblastic hornblende similar to that of a metamorphic derivative is prominent, but the brownish tint is never lost from it. Coarse grained relict plagioclase of original gabbro is always remained in such hornblende of metamorphic nature. As a whole, they are considered as a representative of protoclastic facies of gabbroic intrusion.

C) *Gneissose gabbros*:—Gneissose gabbro is also well displayed in the northern Hidaka mountains. With Poroshiri-Daké the centre, it forms a zone of 5 km width and 40 km length, but its southern continuation is wholly interrupted through the mid-part of the Hidaka mountain range. It appears again in the southern terminal region as a large body.

In this rock species, each of the rock forming-minerals takes an elongated form breaking their idiomorphism: they are arranged in parallel orientation, so the igneous texture is entirely lacking and rather distinctive gneissose foliation is shown. In every outcrop there is exhibited a banded structure due to the layered alternation of the parts having the associations of deep brown hornblende-plagioclase and pyroxenes-plagioclase or leucocratic derivatives. Various type of norite, hyperite, gabbro and granoblastic olivine gabbro or each of these varieties containing a lot of brown hornblende are associated in this rock zone.

D) *Normal gabbros*:—Compared with the former, the intrusive body of normal gabbro forms no continued rock zone, but it occurs in separated areas. In the northern Hidaka it developes immediately on the eastern side of gneissose gabbro with an intercalating narrow septa of gneiss between them. On the other hand, such exceptional arrangement is displayed at the southern terminal region that it occurs bordering on both sides of the main part of the metamorphic zone which is constituted of migmatite core and its surrounding gneiss. The intrusive relation of normal gabbro to the surrounding is always discordant.

The normal gabbro is constituted of pyroxenes and plagioclase as its chief components, but a rock facies that contains a large amount of hornblende is prominently developed. Each rock type has the typical igneous structure that reveals idiomorphism of each rock forming minerals.

Almost of all rock species of the gabbroic suite exhibit some features which indicate exposure to metasomatic effects. An example of highly metasomatized gabbro is presented in the large intrusive body of the Horoman district, southern extreme region (ASAI, H. 1956). It is revealed by the amphibolitization and biotitization of pyroxenes, acidification of plagioclase and introduction of newly formed quartz. Consequently tonalitic association appears as one of extreme types, with which some relict features are often found. Among the strongly altered part, sometime, metamorphosed calcareous nodules quite similar to those of hornfels and gneiss are discovered. Regarding such peculiar occurrence of calcareous nodules and the wide variances of these rock facies as a whole, it seems plausible that the gabbros were transformed to tonalitic facies by the deep seated fluidal "migma" which ascended and commingled into the channels of intrusive body of gabbro and exerted strong metasomatic effects upon the surroundings. Leucocratic varieties of minor scale developed in every part of each rock zone might have been derived, in some parts, from such peculiar effects.

The intrusive position of *peridotite* is almost restricted to the zone of gabbro amphibolite. It forms long lens-shaped bodies that stretch along the foliation of amphibolite: it is furnished with so-called "fluidal structure" due to the parallel arrangement of rock-forming minerals and layered alternation of some different rock facies. In the large intrusive body of the Horoman region, the fluidal layer is arranged in a dome structure that expands to the whole body (IGI, S. 1953). It contains a small amount of pyroxenes, and the rock facies that contains plagioclase is very scarce. The greater part of it keep its unaltered fresh state with exceptional serpentinized marginal parts.

Petrological studies on the Proshiri-Daké gabbroic massif, with which the above descriptions are chiefly indebted, have long been carried by Prof. Seiji HASHIMOTO. The detailed results will be published in nearer future.

Unlike the long continued gabbroic intrusives the body of *granite* has the encircled outline and is disposed in widely separated localities. It shows clean cut contact to the surrounding hornfels, but in some places, a narrow zone of banded gneiss is developed along the contact part. The rock forming plagioclase, in general, exhibits distinct idiomorphism and zonal structure, which is quite different from those of migmatite. The amount of twinning of C-type (GORAI, M. 1950, 1951) which is less than 10% in migmatite is always over 30%, which is considered to be indicative of igneous origin. Microcline or perthite are completely lacking in these granites, and orthoclase only is represented as potash feldspar in minor amount. Biotite is the chief mafic constituent and the amount of associated hornblende is very small. It is worthy of note that pegmatite or aplite associated with the Hidaka granite are almost lacking, further, no valuable ore deposits associated with them have hitherto been found. It seems plausible to consider that the petrographical character of each intrusive body has somewhat different natures, but sufficient data for study have not yet been accumulated (HASHIMOTO, S. 1954).

Diabasic rocks are developed in some different manners in and around the metamorphic zone. They seem to have been formed in various epochs since they show several types, such as pre-metamorphic type, syntectonic type or a type coming from the latest phase of the igneous activity of the orogenic movement. Another kind of diabase which is presented as the earliest phase of gabbroic intrusion should also be mentioned. Among the diabase dykes which develop in the non-metamorphic region, there would be some differences corresponding to those of the metamorphic region, but it is hard to distinguish them practically.

In the metamorphic region, some pre-metamorphic diabases are constituted of green fibrous hornblende and turbid plagioclase with relict diabasic structure. In other cases, the diabases are converted almost to amphibolite, hence it is difficult to know whether they are derived from a diabasic dyke or from schalstein intercalated among the original sedimentaries. Post kinematic diabase forms dyke swarm which is disposed without distinction of migmatite zone or hornfels zone, or even of igneous body. This type of diabase contains titaniferous augite (SOTOZAKI, Y. 1956-b).

The order of activity of each igneous rock species cannot be demonstrated in detail, however, the following brief order may hold through the whole Hidaka zone. The first sign of igneous activity of the Hidaka zone would be represented by a small dyke of diabase which is disposed sporadically in the metamorphic area, which has suffered conspicuous alteration together with the surrounding country rocks. The schalstein effusion of the geosynclinal phase now represented in the border parts of the Hidaka and the Kamuikotan zones seems probably to be related in some respects to such earliest basic igneous activity, though no positive criteria have yet been established. With the advances of metamorphism some minor intrusions of gabbro took place occasionally. Following after the completion of the main part of the metamorphic zone, the first main gabbroic intrusion took place along the western side of the metamorphic zone. The schistose gabbro corresponds to this first gabbro. The next coming intrusion would be the gneissose gabbro. Then the succeeding normal gabbro appeared, however, controlling tectonics are quite different to those of first and second gabbro. The gabbro amphibolite is believed to be the product of the last phase of the gabbroic activity. That its intrusive position takes the continuous western-most situation and that it is always developed along the hanging wall of the great thrust is suggestive of some connection between the movement of the thrust and this gabbroic intrusion. The primary olivine gabbroic facies of it was converted into gabbro amphibolite by the tectonic movement which would be connected with the intrusion (HASHIMOTO, S. 1955). The intrusion of peridotite was clearly later than that of gabbro amphibolite; it did not suffer such tectonic effects as those which prevailed with the preceding phase. Granitic suite was formed almost at once after the completion of gabbroic activities.

Contrasting to the igneous rocks of the Hidaka zone that are furnished with variable rock species of gabbro and granite, voluminous serpentinite intrusives only characterize the igneous members of the Kamuikotan zone. The serpentinite spreads along the whole zone continuously from north to south, and forms the greatest serpentinite belt in Japan. Among the serpentinite intrusives, some probable centres of activity are also indicated. These serpentinite are disposed with variable intrusive forms controlled by the tectonic circumstances of the area. Some stretch continuously along the fault zone, and others swell to large bodies.

They are almost entirely serpentinized through the whole body, so remaining of fresh dunitic parts are only seldom obtained within a small limited extent or as a block like remnant (BAMBA, T. 1955). Although the rock is completely altered, original joint system is well preserved in the large serpentinite bodies and, in thin section, original peridotitic structure is kept without distortion. However, brecciated parts or schistose parts which caused by tectonic shearing and, further, the parts prominently altered to serpentine clay are developed everywhere.

True dunite and rhombic pyroxene bearing dunite are the original character of these serpentinites. Peculiar facies that contains a large amount of rhombic pyroxene is observed in a limited extent of the body. Any aspects of flowage which are distinctive in the peridotite of the Hidaka zone are not found in the Kamuikotan zone. Gabbroic facies is not represented in the original dunitic suite, but the later intrusive gabbroic dykes which altered themselves to amphibolite and give distinctive effect of amphibolitization to the surrounding serpentinite are often associated (HUNAHASHI, M. 1948).

Numerous leucocratic dykes and veins which are represented as albitite, quartz albitite, trondhjemite and microdiorite accompany with every serpentinite body (SUZUKI, J. 1934-d, 1940). Each leucocratic species developes in a peculiar region excluding other species.

Ore deposits

In the axial zone of Hokkaido, there are some peculiar types of ore deposits which are quite different from Tertiary epithermal deposits developed in both the eastern and western wing zones of the island. They form a distinct ore province supported with the corresponding axial zone. In the Hidaka zone, cupriferous iron sulphides deposits, nickeliferous pyrrhotite deposits and deposits of manganese and antimony etc. are associated. Deposits of chromite, platinum and asbestos associated with serpentinite of the Kamuikotan zone are also prominent features. Their formations have intimate connection to the surrounding geologic circumstances, and are considered as an expression of the development of the Hidaka orogenic movement. Accordingly, the fundamental orogenic principle will also be revealed among these ore depositions. (cfr. Fig. 2)

a) *Cupriferous iron sulphides deposits*:—Although the metamorphic zone is revealed with different manner in the northern half and the southern half, the ore deposits of this type are exhibited in similar manner throughout the entire zone. These deposits seem to be related with the basic igneous activity, for they are always found in and around the diabasic or other basic igneous bodies. In the highly metamorphosed area, migmatite and gneiss zone, no such ore deposits has yet been found. They are known from the hornfels area and the non-metamorphic slate region, and are disposed, in general, collectively around the central part which is denoted by the metamorphic zone or scattered minor pultonic bodies, and never extend to the external parts of the Hidaka zone. Though the known deposits are numerous, the greater part of them are of minor dimension: however, an exceptional large deposit is found at the Shimokawa mine, the only working mine of the zone. The characters of the deposits vary in many different ways. But, in general, lens shaped ore bodies are imbedded among a continuous mineralized zone, and often they are arranged in echelon. Most of the mineralized zone develops along the tectonically sheared zone and is characterized not only by the impregnation of sulphide minerals but by the peculiar alteration. Often, such characteristic sheared zone continues for several kilometers. Around the ore district many types of sheared zone which exhibit different natures and are of the different epochs of each formation are displayed. In Shibechari ore district, Hidaka Province, the diabase dyke accompanied with ore deposits is revealed exclusively along a special type of sheared zone, and not with other types (SAKO, S. 1956).

Prominent types of those deposits are the cupriferous pyrrhotite type and the cupriferous pyritic type: most of the known deposits can be classified either of the two. with the ore of those deposits chalcopyrite and sphalerite are always associated and, on some occasions, even magne-

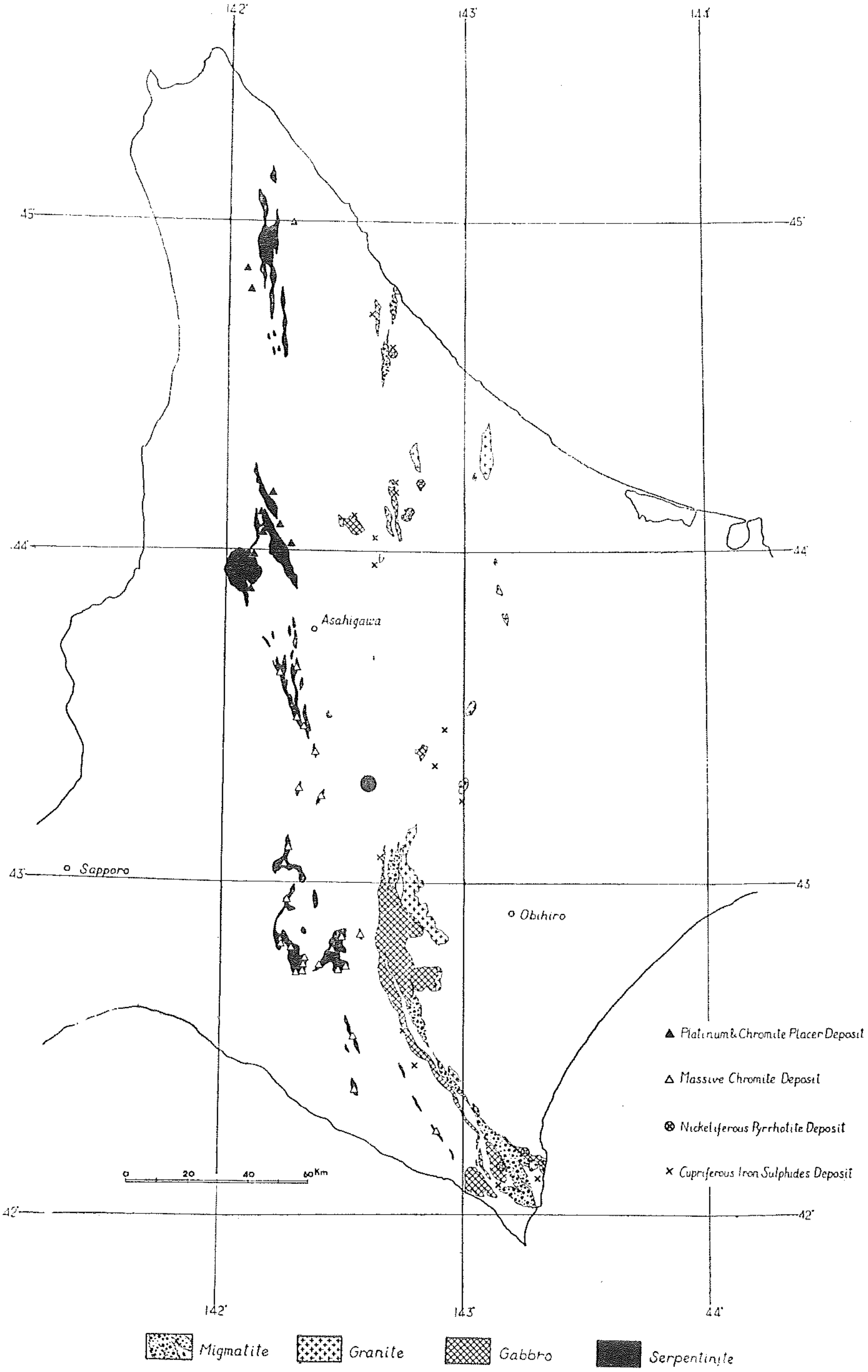

Fig. 2. Distribution of ore deposits in the axial zone of Hokkaido.

tite or galena are accompanied. Further, a few occurrences of cubanite and arsenopyrite should also be mentioned. Though their mineralogical nature show great contrast, magnetite deposit and sphalerite deposit of minor scale are observed in close association with the above mentioned type. It is plausible that they should also be considered inclusively as extreme types of the cupriferous iron sulphide deposits of the Hidaka zone.

The general course of the mineralization of these ore minerals seems to have commenced with the deposition of magnetite, following is the pyrrhotite, and it is succeeded by the deposition of pyrite. Chalcopyrite is somewhat delayed in deposition or is nearly the same as that of iron sulphides: sphalerite belongs to a still later formation. Cubanite and aresenopyrite seem to be of earlier formation: they associate with pyrrhotite and chalcopyrite. There are, however, some examples that denote a formation of pyrite distinctly earlier than that of magnetite, and other perplexing confusions of the above mentioned order (SAWA, T., 1957).

As the one of peculiar wall rock alteration of the deposit, typical Al-Mg metasomatism and amphibolitization are to be mentioned. Around the ore deposit, anthophyllite, cummingtonite, cordierite, spinel, and light-coloured biotite are arranged in several associations with the impregnation of pyrrhotite. Such type of mineralization is revealed in the hornfels area, which is associated with the type of cupriferous pyrrhotite deposit (HUNAHASHI, M., 1951). In the slate area, on the other hand, the type of cupriferous pyritic deposit is predominated. The wall rock alteration of it is represented in chlorite or chlorite-quartz association. The mineralization of these deposits would be a complex one, for various types of pyrite are developed, and cubanite which is developed in pyrrhotite depsoit is also found in a seam of chalcopyrite imbedded among the altered wall rock of chlorite-quartz association.

b) *Nickeliferous pyrrhotite deposit*:—Among the intrusive bodies of gabbro, especially associated with the normal gabbro, some nickeliferous pyrrhotite deposits have been discovered. The deposits of this type are formed in close connection to the metasomatically replaced facies of gabbro which is constituted of the dotted pyrrhotite that seems to have been crystallized simultaneously with the rock-forming minerals of the host gabbro. Chalcopyrite is the predominant accessory ore mineral, and occasionally, fairly large amounts of graphite are accompanied with them. Among the grain of pyrrhotite small particles of pentlandite are always included, and very rarely, polydymite is also known.

Although the pyrrhotite grains are always contained in the metasomatically altered gabbro, they are enriched into a localized peculiar small space to form the ore deposit. Arranged in the marginal zone of the intrusive body or in complex manners the pyrrhotite deposit is developed in sheet-like form that seems to have been controlled under the influences of some kind of shearing effect.

The concentration of pyrrhotite does not cause any alteration of host gabbro, only slight transformation of pyroxene to hornblende and biotite are noticed. Simultaneous crystallization of sulphide and silicate minerals is the prominent feature. But the high concentration of later stage pyrrhotite causes chloritization of surrounding silicates.

When the graphite associates with the pyrrhotite deposit, it always accumulates itself separately from that of pyrrhotite. With the deposition of graphite, silicification and prehnitization of the surrounding host rock are conspicuously developed. The mineralization of graphite appears to have occured in the later course of the deposition of nickeliferous pyrrhotite. It is revealed with the quartz which is accompanied as the after effect of the enrichment of pyrrhotite. Following the accumulation of this somewhat porphyroblastically developed quartz, graphite flakes attached themselves to the surface of the quartz grains and grew in size replacing the kernel quartz. With the advance of mineralization, bean-like aggregates of graphite resulted, at the same time, constituent minerals of the host gabbro are altered to prehnite and sericite. Often, silica expelled by the replacement of graphite is redeposited at the upper part of the deposit as a covering cap (HASHIMOTO, S. 1950-a).

Some considerations concerning the origin of the ore materials:— Most of the cupriferous iron sulphide deposits develop in close association with the diabasic rocks which are considered to belong exclusively with the earlier phase of the basic igneous activity of the Hidaka zone. On the other hand, the normal gabbro, the host of the nickeliferous pyrrhotite and graphite deposits, is the later phase of basic plutonics.

It seems plausible that the basic plutonic condition suitable for the deposition of nickeliferous type, but the cupriferous type prefers the hypabyssal condition or that of basic dyke rocks. However, a few exceptional cases have been noted. Small scale concentration of graphite and pyrrhotite of nickeliferous type is often met within gneissose gabbro.

Diabases developed in the slate region will be in close comagmatic relation for the gabbroic suite of the metamorphic region. It is believed that the gabbroic rocks of the metamorphic region would be the main body of the basic igneous intrusion and the branching offshoots from it would correspond to the diabasic dyke swarms of the slate region which certainly occupied a higher niveau than that of the metamrophic zone. In such manner, it may be stated that the basic igneous activities of the whole Hidaka zone have some causal dependence upon the concentration of sulphides of heavy metals.

With the gneiss and cordierite bea. biotite migmatite, pyrrhotite is always contained as an accessory opaque mineral, but the granitic migmatite which is the latest product of the Hidaka migmatitization is almost free from pyrrhotite. It will be important to seek the geochemical migration of such metal sulphides. It is often observed that small streaks of concentrated pyrrhotite develop along the foliation or sheared plane of gneisses. As an interesting phenomenon, high concentration of pyrrhotite and graphite that suggests some courses of ore deposition is noted in the assimilated gneiss that was caught by gabbro.

These phenomena call to mind the recent discussions of the "transformist" concerning the origin of ore deposits in the earth's crust. Considered practically, the writer is aware regarding for the Hidaka orogenic zone with its high possibility of such migration that the materials are derived from geosynclinal sediments by the processes of migmatitization. Further, it is worthy of note that the basic igneous activity would take a serious part in the concentration of these heavy metals. That is, it seems plausible that the material segregated from the sediments by the processes of migmatitization was involved in some way in the basic igneous activity and became concentrated to form the ore deposits.

Ore deposits of the Kamuikotan zone: — Concerning the Kamuikotan zone, deposits of chromite and platinum associated with the ultrabasic rocks are characteristic (SUZUKI, J. 1942-a, 1942-b, 1943, 1950, 1953-a). Although the petrographical features of the serpentinite of the zone indicate no differences between northern half and southern half of the belt, the type of associated ore deposit reveals somewhat contrasted features. In the northern region, chromite deposit is represented only as placer which was accumulated from the chromite grains washed out from the hinterland serpentinite; massive chromite ore deposits has not yet been found. On the other hand, in the region south of Kamuikotan gorge placer deposit is never formed, only ore deposits formed of massive aggregated chromite which take sheet or pipe-like form concordant to the joint sytsem of the serpentinite are profoundly developed (SAITO, M. 1953, SAITO M., BAMBA, T. 1953).

Platinum, too, occurs in similar fashion. Only in the northern region is it revealed as placer, and it is not found in the southern region with high concentration worthy of exploitation (SUZUKI, J. 1950-a). Such contrasted features of ore deposits in the south and the north will be connected to the geologic circumstances of the whole axial zone, but adequate interpretation of such circumstances cannot yet be given.

Stratigraphy and upheavals of the axial zone

The above described metamorphic zone is surrounded by voluminous sedimentary formations. As the tectonic centre of those sedimentary territories the metamorphic zone was constructed; the metamorphic rocks were derived from the sedimentaries equivalent to those of the surroundings. The intrusions of igneous rocks kept close pace with the tectonic movements that produced the metamorphic zone. Concerning the development of such metamorphic zone, it is of much interest to speculate on the state of the embryonic environment of the axial zone and on how it began to evolve.

The sedimentary formation developed in the axial zone are incorporated into the *"Hidaka Group"*. Blackish slate and dark greyish fine sandstone are the main constituents of the group, and both develop with various types of alternations. Some of them reveal prominent fissility caused by the tectonic shearing, consequently, they appear to belong to older rock formations.

Within the sedimentary region various kinds of tectonically sheared zones or fault zones are developed. Generally speaking, a rock formation is always limited by some such tectonic zones and lies in a corresponding structural unit. Following three unit formations are always encountered through the whole axial zone now under consideration.

a) *laminated slate formation*
b) *green sandstone formation*
c) *black slate formation*

The stratigraphical succession will be presumed in descending order from (a) to (c).

Fossil remains have scarcely been found with these monotonous sediments, so the chronological consideration has long been left in obscurity. A valuable occurrence of ammonite which furnishes Jurassic feature has been obtained from the slate formation in the east of Shōtonbetsu, northern Kitami Province. Another fossil *Brachiopoda* which is indicative of younger Jurassic has been obtained from a calcareous lens imbedded among the schalstein formation developed in the Shikagoe district, central Hokkaido. From these materials, the main portion of the Hidaka group has been assumed to be Jurassic in age. However, in the lower part of the group some older members may be included. Recent discovery of probable Tertiary conglomerate which includes limestone pebbles containing younger Palaeozoic *Fusulinidae* (ENDO, R., HASHIMOTO, W. 1955) in Kitami Province allows the supposition of the concealed existence of some Palaeozoic formations among the axial zone. But, it needs a careful consideration whether these fossils were derived from the axial zone or from the exotic border land.

In these characteristic sedimentary formations which represent the initial stage of the axial zone of Hokkaido, such as monotonous blackish sedimentation, non-fossiliferous environment, and the existence of intercalating schalstein associated with quartzite and limestone lenses, there are demonstrated the characteristics of geosynclinal deposition.

Some differences of the sedimentary facies on both sides of the metamorphic zone may be noted vaguely. Continued sandstone formation enriched with obscurely formed calcareous nodules is well represented in the eastern side of the metamorphic zone, but it is not known from the western slate region. The existence of a key bed common for both sedimentary regions has not been proven. It is not determinable that the contrast between the two sides is brought about by the correlation of the stratigraphical succession of different horizon or by differences in sedimentary facies of the same horizon.

In the southern region of the western slope of the Hidaka mountains, some ammonites and *Inoceramus* are found, which seem to be of upper or middle Cretaceous are obtained from the fine sandstone which is indiscriminable from that of Hidaka group. Probably, they are derived from the overlying Cretaceous formation that was drawn tectonically into the slates of Hidaka group (MINATO, M., SAWA, T., TAKEDA, N. 1954). The tectonic relation being in such confused condition, it is hard to establish the reliable stratigraphical succession. The researches on the non-metamorphic sedimentary region having commenced only recently, no precise data have yet been obtained. Further detailed surveys are required.

As the one of the main features of the geocynclinal sediments the schalstein formation develops occupying a characteristic situation in the axial zone. It is arranged in the marginal part of the axial zone now under consideration, and in particular, along the western part it develops continuously from south to north. It spreads overlying the Hidaka group, and from its lower part, as already mentioned fossil *Brachiopoda* are obtained. Further, from a limestone lens intercalated at the upper part of the formation *Nerinea* sp. are known (OTATSUME, K. 1940, FUKADA, A. 1953). In part, the sedimentary nature of the schalstein formation is obvious, but the main portion of it is constituted of the effusive breccias. Some pillow lavas, are also met with everywhere (SUZUKI, J. 1954-b, 1955-b). As a result of such observations, the zone of schalstein is understood as an effusive zone bordering the geosynclinal area. The schalstein formation is overlain comformably by thick lower Cretaceous shale with the transitional zone containing abundant chert and porphyrite tuff between them. It seems probable that there were no prominent tectonic disturbances at the transitional phase of Jurassic to Cretaceous, at least, in the marginal region of the geosynclinal sea (OTATSUME, K. 1940).

With the commencement of the Cretaceous period the sea was transformed in nature to something different from that of the Jurassic period. The fragments of plants, the *Orbitolina* limestone of the Urgon facies and the difference in sedimentary facies of the shale of lower Cretaceous in comparison with the slates of the Hidaka group suggest that the natures of the sea were converted to the state of continental shelf from the foregoing geosynclinal condition. With the passage to middle Cretaceous, abundant ammonite fauna that reflects a typical echological condition of the continental shelf were flourishing. Further, fundamental differences are noticed within the Cretaceous fauna that appear in the two regions which are separated by the axial zone. The chert formation of the transitional part from Jurassic to Cretaceous is thickly developed on the western side of the axial zone.

How were such vertical changes of sedimentary condition from Jurassic to Cretaceous, the geographical differences of faunal aspect and such localization of sedimentary facies brought about? As a possible interpretation for these varying circumstances the following remarks will be offered. The radical cause of them is attributable as for the transformation of the geosyncline to the orogenic upheavals from the depression with the beginning of Cretaceous period. The commencement of orogenic movements of the deep buried bottom of the geosyncline would be propagated to the surface and would agitate the conditions of the geosynclinal sea. Further, with the development of the orogenic events central part of the geosynclinal sea would be raised up as a mid-ridge, by which the sea would be divided and separated into the eastern and western remnant seas (HUNAHASHI, M., HASHIMOTO, S. 1951).

Tectonic features of the movements

The effects of tectonic forces endow the rock with foliation and other yielding features. The spatial spreading of a rock species is tectonically controlled, and the igneous intrusions also take place concordantly with the surrounding tectonic circumstances. Moreover, such effects appear in different manner according to the respective geologic situations within the zone. Present views as to the main tectonic style of these movements will be described in the following brief notes.

A) Tectonics of the Hidaka zone.

a) Throughout the extent of the Hidaka group intense tectonic disturbances are everywhere displayed. As one of the signs, sandstone is crushed and slate is converted to a phyllitic appearance with vanishing of their original stratification. A fault, in general, is substituted for a prominent sheared zone which attains, in occation, some hundreds meters width. Among them, the signs of tectonic disturbance not only mechanical crushing but also network veining of quartz and calcite, chloritization and argillization are prevailed. Compact mylonites often acquainted with those of crushed rocks. Sometimes, adinolization on regional scale is known in the slate region far off from the metamorphic area.

Various kinds of sheared zones are distinguishable depending upon the trend and nature of shearing. In a certain limited area, four sorts of sheared zones are to be seen. Each has some peculiar features, for example, characterized by strong phyllitic part or converted into clayey matter etc. It seems probable that the time of their formation was at far separated intervals.

A continuous sheared zone displayed with the same features is frequently noticed: that is helpful to structural mapping. It has been clarified that the dykes of diabase are confined only to a special sheared zone (SAKO, S. 1954, 1956). Although the sheared zones seem to be arranged with random orientations, their dispositions, in the main, are harmonious to the trend of the unit formation. That is, when the unit formations are disposed side by side, their mutual boundaries are always marked by prominent sheared zones. In such manner, it will be defined that a unit formation is disposed to the respective structural unit.

b) As the first sign of metamorphism of slate, hornfels is revealed fringing about the border part of the metamorphic zone. At the transitional part the rock generally become hardened and the structural shearing grows less noticeable. In such hornfels the original sedimentary stratification is well preserved. This means that the rock did not suffer structural deformation, at least, in the stage of hornfels building, that is to say, the metamorphic effect permeated through the slates uniquely without any cooperation of tectonic forces.

c) As already mentioned, with the formation of a flattened porphyroblastic aggregate of biotite, the hornfels is converted to cleavable schistose rock. The trend of foliation coincides with the original stratification preserved in the hornfels, but in some cases, the two intersect at a high angle. Similar circumstances are also to be seen on a regional scale. On the eastern side of the southern extreme region, the border line of hornfels area runs across the general strike of the non-metamorphic slate and sandstone series. Consequently, a key bed that is furnished with many calcareous nodules plunges into the hornfels area and extends far to the inner side of the hornfels zone.

d) Cleavable foliation is reduced in some degree with the gneiss; however, the foliation due to the banded alternation of light and dark parts is prominently represented, and crenulation of foliation plane is rather common. Generally, it continues with similar features throughout the gneiss zone. However, some coarse-grained parts which turn into massive form escaped from the adjoining parallel texture are often observed. Further, some leucocratic parts develops in vein form cutting the surrounding gneissosity. The tectonic force exerted strong effect upon the formation of gneiss forming the prominent foliation: however, such force was so reduced in the later stages that the leucocratic or coarse grained parts are almost released from such tectonic effect, and the circumstances approach to migmatitic condition.

The zone of gneiss is generally disposed as if it means a narrow rim of the migmatite zone, but was not formed as a marginal facies fringing migmatite; it takes the lead in the formation of migmatite. Remnants of gneiss contained in migmatite indicate that the greater part of the spaces now filled with migmatite had once been occupied by gneiss. The space of gneiss was far expanded at the stage prior to the formation of migmatite, and accordingly the main part of the metamorphic zone was subjected, at the time, to the effects of a huge tectonic movement.

e) With the formation of biotite migmatite and cordierite bea. biotite migmatite, the tectonic effect was reduced and massive appearance prevailed through the migmatite zone. Ghost-like remnant foliation of gneiss is preserved only occasionally. However, migmatites having gneissose foliation which seems to have been formed with the migmatitization are frequently met with in the limited areas of the western side of the migmatite zone.

Although the migmatite zone extents continuously with monoclinic trend, its tectonic structure seems to be a complicated one. In certain small eastward protruded parts of the southern extreme region, it is revealed by petrofabric analysis that the dome-structured migmatite masses ascended through migmatitization (KIZAKI, K. 1956, KASUGAI, A. 1957). Probably, the main part of the zone also may have been constructed by the assemblage of such structural units.

f) Granitic migmatite is revealed with evidences of replacement origin, however, in part intrusive nature is also evidently indicated. It takes lens-shaped form concordant to the surrounding biotite- or cordierite-migmatite, and often is arranged in echelon fixed to the mid -part of the migmatite zone. But rarely, it expands into the gneiss zone. Foliated appearance is almost lacking in this sort of migmatite; regular joint system is frequently developed.

Some considerations on the tectonic features: The foliation plan of each of the above mentioned rock zones is, as a whole, disposed with eastward dipping and is arranged parallel to the general trend of the metamorphic zone. Even in the massive granitic migmatite, some examples that take sheet-like form with eastward dipping of 30° are noticed. These foliations are revealed more strongly towards the western side of the metamorphic zone. It is possible to understand that the metamorphic zone takes an eastward dipping monocline structure as suggested by the foliation.

In some detailed mapping areas many faults which may be grouped into some peculiar types are known. As one of them, a thrust fault lying with low angle and accompanied with a chloritized zone of 3-5 m thickness is well-ascertained for the reason that it always runs along the boundary zone of different rock species. The areal mapping of such tectonic relationship suggests that the extent of a rock species is bounded within a tectonic unit limited by such thrust or fault.

The intrusive positions of igneous rocks also lie within such boundary zones. At the Horoman district, southern extreme region, most of the small dykes of schistose gabbro seen there are arranged about the boundary zone between schistose hornfels and biotite gneiss, and become rare at any distance from it. In the northern area a long-continued body of schistose gabbro separates the biotite schist from the biotite gneiss of the inner zone, and continues almost through the whole western side of the metamorphic zone. Later intruded gneissose gabbro takes its position as the boundary zone between gneiss and migmatite. Finally activated normal gabbro, at the southern terminal region, fringes on both sides of the main zone which is constituted of gneiss and migmatite. Granite is always limited to the eastern side of the zone, and its intrusive position seems to be fixed within the zone of eastern hornfels. It is suggestive that these igneous intrusions were more or less controlled under the respective tectonic movements. Surrounding the igneous bodies, especially along eastern side, prominent sheared zones that seem to have related to such tectonic movements are often observed.

The thrust which cuts the western wing of the metamorphic zone is a unique large scale one that displays a huge dislocation with an accompanying broad sheared zone. In some localities, it lies with low angle, and the slate of the foot side is sheared and silicified for the extent of 100 m, while the gabbro amphibolite of the hanging side is transformed to epidote chlorite schist.

The E-W trending Horoman-Shoya fault that bounds the southern end of the metamorphic zone also displays the same nature including a mylonite zone of some 100 m width. On the eastern side of the metamorphic zone gradual transition of hornfels to gneiss and migmatite is the rule, however, in the southern extreme part a migmatite mass comes into direct contact with hornfels as a result of a prominent fault that disturbs such arrangement. An northern extension of this fault coincides with the sheared zone that divides the schistose hornfels from the hornfels, that represents the eastern boundary of the main part of the metamorphic zone.

Above mentioned faults and sheared zones were built evidently after the formation of metamorphic rocks and of igneous bodies, however, the tendency of those tectonic movements had already been enforced in the course of the metamorphic process and of igneous intrusion. The foliations of the metamorphic rocks may correspond in some degree to the westward thrusting movements and upheavals of the metamorphic zone. Similar circumstances are also revealed within the various kinds of foliated gabbro.

Many distinctive sheared zones which reveal different features would be the representative of different movements and different times of formation. When the detailed studies concerning such tectonic development have been completed they will result in much more complicated figures than those representing present knowledges.

B) Tectonics of the Kamuikotan zone.

Moving westward from the Hidaka metamorphic zone to the Kamuikotan zone, one encounters no particular metamorphic rocks though evidences of intense tectonic disturbances are displayed. In the slate region cleavable phyllitic appearances prevail, but recrystallization of constituent minerals is represented only in limited situations such as about a sheared zone, so the greater part of the slates remain in non-metamorphic state. In the schalstein zone most of tectonic disturbances are revealed by the brecciated appearances yielding network veins of calcite, quartz and prehnite; also no areal development of green schist or the like is to be noted.

The Kamuikotan zone itself is a zone of anticlinal nature. The areal mappings carried around the Yubari-Daké have revealed its nature in detail (HASHIMOTO, W. 1952, 1953, 1955, NAGAO, S., OSANAI, H., SAKO, S. 1955). According to them, a prominent westward directed thrust runs along the western slope of the Yubari-Daké: which cuts the western wing of the anticline constituted chiefly of Jurassic shcalstein and displaces the main anticlinal part over the Cretaceous formation of the western region. Some parallel running thrusts are also developed producing a westward imbricated structure. Mylonitic rocks and semi-schists of minor scale are found within the sheared thrust zone.

The northern extension of the Yubari-Daké anticline joints to the region of the Kamuikotan metamorphics which form a unique structural unit. It is separated from the surrounding non-metamorphosed rocks by a marked thrust or a zone of serpentinite intrusion. Of course, such tectonic unit contains non-metamorphic facies, but the main part of it is furnished with metamorphic facies of areal development. The metamorphic natures of them have already been described. Among the Kamuikotan zone such the metamorphic unit occupies a structural centre of the zone: the surrounding non-metamorphic formations are arranged in the marginal part forming a large dome structure that contains the metamorphic member among its core.

The circumstances are the same for the greater part of the Kamuikotan zone.

Geohistorical development of the island of Hokkaido

In what way the style of sedimentation and the disposition of land and sea in relation to the axial zone of Hokkaido have been shifted from the initial environment to the matured present state keeping pace with the above described tectonic developments may be summarized as in the following brief discussion.

a) *Pre-Cretaceous*:—The embryonic formation of the axial zone was commenced with the development of a vast sea which prevailed by a thick monotonous sedimentation of geosynclinal nature. Concerning the basal part of this geosyncline, it is not known at all whether the condition of the sedimentation was invariably maintained ever since Palaeozoic period or whether a distinct time break occurred between the older basement complex and the younger sediments under consideration. However, it is enough to state that the upper part of the sediment, at least belongs to the Jurassic in age.

The sedimentation was so carried on in similar fashion all over the whole basin that the general stratigraphical succession of the deposits is roughly applied for the northern region as well as for the southern. Further, there are no serious differences between the eastern and western facies of the basin. Still more, it should be mentioned as a prominent event of the geosynclinal history that there arose a huge effusive activity of somewhat alkalic diabase along the border part of the sedimentary basin, which is better understood as a presentation of the boundary fractured zone between the erosion district and the sinking basin.

b) *Cretaceous*:—As already noted in the foregoing section, the Cretaceous deposits are furnished with variable sedimentary facies and other more differentiated characters compared to those of the monotonous sedimentary features of the underlying Hidaka group. These deposits were, plausibly, influenced by tectonic disturbances caused by the commencement of deep seated metamorphism and plutonism in the transitional stage from the Jurassic to the Cretaceous. In such manner, the geosynclinal Jurassic sea suffered orogenic disturbance with the entry of the Cretaceous epoch, and upheavals of the mid-part of the basin were gradually evolved. The essential character of the Cretaceous deposit of Hokkaido is that it was laid down in the sedimentary basin divided into two by a geanticlinal mid-ridge with the so-called "Flyish" type of sedimentation.

Some aspects concerning the circumstances of the Cretaceous depositions of the western side of the axial zone are of interest as summarized in the following paragraphs.

i) In the Ishikari coal field, several *Lamellibranchia* or other benthonic fossils or massive aggregates of shell fragment are often discovered at the extreme western part. On the contrary, only ammonites included in shale or fine sandstone are obtained from every eastern equivalent horizon.

ii) The middle Cretaceous formation of the Ishikari coal field is of conglomeratic nature. It is well established in every case that the conglomerate formation developes more thickly and contains more large pebbles in the western part. However, it gradually diminishes in thickness and pebble size to the east (FUKADA, A., ISHII, J., ICHIKAWA, T., SARAKI, M. 1953).

iii) In Teshio Province, the northern region of the island, some horizons are represented as sandy facies in western part, but their eastern equivalents are revealed as muddy facies.

Considered from those evidences, there is a suggestion that a land suppling clastic materials for the Cretaceous sea might have existed in the immediate western neighbourhood of those deposits. In this connection, the older formation developed in the Kabato mountainland, Ishikari Province, deserves some attention (HASHIMOTO, W. 1950). Its lithic character resembles that of the Hidaka group, and actually it has hitherto been regarded as the one of the representatives. However, such evidence that the Palaeogene deposit lies directly upon it is never found in the Hidaka group of the axial zone. Similar older formation of unknown age is disposed as the basement complex of the south-western part of the island of Hokkaido, corresponding to the western wing zone confronted to the axial zone.

There prominent pyroclastic deposits of Neogene Tertiary directly overlie the basement complex; the Cretaceous and Palaeogene deposits being completely lacking from the pilings. The older formations constituting the basement complex of the region are represented by non-fossiliferous and monotonous black slate and fine sandstone. They are disposed into some separated small massifs which constitute the structural centre of each area with attendant younger formations surrounding them. Granitic intrusive body surrounded by a large aureole of hornfels is disposed in every massif, however, gneiss and migmatitic rocks which resemble those of the Hidaka metamorphic zone are never found. To trace such separated older massifs to the southward, they are found to approach to the Palaeozoic massif of the Honshu arc, which are disposed in similar geologic situation. In view of these consideration, though precise positive evidences are lacking, it is believed that the basement older formations of western wing zone of Hokkaido should be thought of as a continuation of the Palaeozoic formation of the Honshu arc, especially that of the Kitakami mountainland, rather than to be considered equivalent to the Hidaka group. In connection with these considerations, it is an interesting problems to which of the two the older formation of the Kabato mountainland may belong.

c) *Palaeogene Tertiary*:—As a characteristic feature of the Palaeogene deposits of Hokkaido, it is worthy of note that the deposits are always appear in company with the Cretaceous formations and that they are disposed in both external sides of the axial zone; the Ishikari coal field in the west the Kushiro coal field in the east. Many coal seams and other terrestrial deposits are intercalated with them. All the deposits of the Kushiro coal field have been correlated for the upper half of the deposits of the Ishikari coal field. They are of Eocene and Oligocene in age; Pliocene deposit is wholly wanting. Though the existence of a time break is evident, the stratigraphical relation for the Cretaceous formation is always in parallel unconformity without any inclined relation.

The causal basis of those circumstances is considered to be that the successive upheavals of the axial part of the Hidaka geosyncline contracted the sphere of the remnant sea and also moved it aside to the external part during the Cretaceous to the Palaeogene (IJIRI, S. 1956). It is believed that the coal bearing formation of Hokkaido is the last buried deposit surviving from the Jurassic geosyncline. Accordingly, it might to concluded that the main active phase of the Hidaka orogenic movement possibly extended over the period from the Cretaceous to the Palaeogene in above described manner.

d) Neogene Tertiary:—With the commencement of the Miocene epoch the geohistorical environments were changed assuming a wholly different character from that of the foregoing period. The whole island was buried under the Miocene sea uniformly without distinction of axial zone or its confronting land of the preceding period. The region hitherto continued as land sustaining erosion, that is the southwestern part of Hokkaido, was transformed into a region of violent volcanic effusion and was covered with thick pyroclastic pilings (NAGAO, T. 1933, MINATO, M., YAGI, K., HUNAHASHI, M. 1956). In the axial zone, the equivalent marine sediment lies with marked disconformity on every pre-existing formation. In Kitami Province, in the eastern part of the axial zone, the equivalent deposits are formed predominantly of volcanic materials similar to those of the south-western Hokkaido. The south eastern extension is connected to a similar pyroclastic zone long stretched along the Kurile islands that constitute the basement of the Quaternary volcanic chain. A Neogene pyroclastic basin is not delimited on the island of Hokkaido, but it developes continuously along the inner side of the Japanese Island arc.

Such a situation that the island arc was divided into the inner pyroclastic zone, the so-called "green tuff region", and outer zone of older massifs was the prominent feature of the Neogene geotectonic figure. In Hokkaido, however, the continuous green tuff zone is interrupted by the axial zone, which was furnished by the Neogene tectonic quite different from that of the green tuff region.

Concerning the Neogene tectonics of the axial zone, the following remarks may be of interest. The Paleogene deposits of both western and eastern side of the axial zone have been carefully studied by the coal field geologists. In the Ishikari coal field characteristic tectonic disturbances such as thrust, nappe, or overturned folding etc., that seem to be resulted from the westward pushing up tectonic forces prominently prevailed (NAGAO, T. 1938, OTATSUME, K. 1951). On the contrary, in the Kushiro coal field, the tectonic feature of Tertiary deformation is properly applied to that of block movements. Such the contrasted style of tectonic movement of the two regions may be understood as an after effect of the Hidaka orogenic movement that is revealed in the character of the westward thrusting from the east.

The Neogene disturbances were not confined only to the coal fields but also effectively occurred in the axial zone. For example, the Neogene movement of the western thrust of the metamorphic zone is deduced to have been as follows. In western side of the southern terminal region of the metamorphic zone, small remains of lower Miocene deposit are developed. There are no metamorphic or pultonic rocks of Hidaka derivatives as the pebbles of its basal conglomerate, notwithstanding the fact that they do crop out now as a large metamorphic zone of 30 km width in the immediate eastern side with in a distance of 1000 m from the deposits. Pebbles of slate and diabase only are the chief constituents. On the other hand, upper Miocene deposits of the region include conspicious pebbles of several kinds of gneiss, migmatite and plutonics, of which the natures are almost referable to that of the now appeared metamorphic niveau. Accordingly, it is suggested that the metamorphic zone, in early Miocene epoch, may have been deeply buried under the non-metamorphic niveau, but in the succeeding epoch, it would have been upheaved along the western thrust till the migmatitic niveau cropped out on the earth surface. It is believed that the amount of this displacement might have reached to some thousands of meters. Furthermore, such lower Miocene deposits that lie along a narrowly continued zone pinched into some peculiar tectonic situations are often observed in the western slate region. This would also be a representation of late Miocene huge tectonic disturbance of the region.

The above comments are not equally applicable through the entire axial zone, but the times when each of the metamorphics and plutonics were exposed have fairly been differentiated according to every tectonic region. In northern Kitami Province, the lower Miocene deposits contain a great many pebbles of all the representative rock species of the metamorphics and pultonics that are now exposed in the region. The most peculiar rock species, glaucophane schists of the Kamuikotan metamorphics, are contained in some lower Miocene deposits as pebbles.

The tectonic disturbances found in the western side of the Hidaka mountain range are represented in particularly intense style compared to those of other regions. They propagate further to the westward and are connected with the complicated structures of the Ishikari coal field (OTATSUME, K. 1951). Some Miocene deposits of the coal field contain "Nagelfruh" like huge boulders of serpentinite derived from the Kamuikotan zone, which remember of "Molasse type of deposition" of European literatures. While in the northern half of the zone, the relation is quite different, the tectonic structure of the Tertiary formations indicates very mild disturbances. In an earlier chapter above, it is mentioned that the southern half of the axial zone is fairly different in many aspects for the northern half. That the tectonic disturbances were enforced more strongly over the southern half against the northern region and the upheavals caused by them prominently carried out in the southern half may explain the arrangement of such different aspects in the north and in the south.

References to other geotectonic units of the island arc

Some informations concerning the Mesozoic land that would have supplied the clastic materials for the geosynclinal sea of the axial zone of Hokkaido may be gathered from the sedimentary materials of the respective deposits. Actually, among the constituents of the deposits some characteristic features that have no connection with the axial zone are deduced.

A) Sedimentary materials of the axial zone.

Concerning this aspect, following briefly summarized notes may deserve to close inquiry.

a) In the Hidaka group, sand grains of perthite or microcline are included in distinct amount among the fine sandstone. Its conglomeratic seams contain pebbles of slate and fine sandstone as their chief constituents, but on occasion, microcline rich granite pebbles are found with them.

b) As the deposition of the Cretaceous formations shows in various facies, the kinds of contained pebbles included several types compared to those of underlying Hidaka group. Arkose sandstones containing many microcline and perthite grains are often intercalated in Cretaceous formations. Local differences of the assemblage of pebbles are prominently displayed in every observed part, for example, the lower Cretaceous conglomerate of Hidaka Province contains striking porphyrite pebbles, while the middle Cretaceous conglomerate in northern Teshio Province contains abundant pebbles of andesites and liparites. Besides, pebbles of various kinds of hornfels, phyllite and schist are known from several horizons and from several localities.

It is an important problem whether they were derived from the Hidaka metamorphic zone or not; the examination of the petrographical characters of them, needs careful attention. The preliminary studies based on some materials have led to the following briefly stated summary. Concerning the pebbles of hornfels, many rock types that are unlike to the Hidaka hornfels are known, for example, hornfels with scarce amount of biotite, hornfels of greenish tint biotite that differs from the reddish brown tint of the Hidaka, and hornfels having a large amount of microporphyroblastic andalusite etc. are the chief contradictions.

Concerning the pebbles of schist and phyllite, it is difficult to decide about their exact sources, but their universal occurrence in southern Hidaka as well as in northern Teshio suggests that they might probably been drived from a source of far distant regionally exposed masses rather than from the present Kamuikotan metamorphics.

c) Among the Palaeogene conglomerates the first signs of confirmable Hidaka metamorphics and plutonics are exhibited. In the Kushiro coal field, pebbles of several kinds of gabbro, probably derived from the zone of gabbro amphibolite, are obtained (ISHII, J. 1957). In the Ishikari coal field, too, pebbles of serpentinite which were probably brought from the Kamuikotan zone are obtained from the basal part of the coal bearing. Other prominent indicators such as hornfels and gneiss are also known from both coal fields.

d) In the axial zone, Neogene Tertiary deposits lie with distinct uncomformity over the older formations, accordingly, all the representatives of older rock types now exposed are included in them as pebbles. However, in the coastal region of Teshio Province, and also of Kushiro Province, far off from the axial district, the marine Neogene formations contain large boulders of granite that contain large amounts of perthite and microcline. Granite of such nature has never obtained from the Hidaka zone.

The above mentioned aspects reveal the existence of pebbles probably exotic, at least, to the axial zone. The constant appearances of microcline and perthite in sandstones or in granite pebbles of every formation extending from the Hidaka group up to Neogene Tertiary are not harmonious to the interpretation that the source is attributable to the Hidaka zone. The source of Cretaceous pebbles of porphyrites, andesites and liparites is also obscure. As a possible interpretation, it may be reasonable that they might have been derived from the effusive equivalents of the product of the deep buried Cretaceous pultonic activity of Hidaka. However, their associated pebbles of andalusite microporphyroblastic hornfels reveal a peculiar nature that is never characteristic of the Hidaka hornfels; it is rather attributable to the natures of the hornfels developed in the Kitakami mountainland of the Honshû arc. As a rule, the metamorphics of the Kitakami mountains are characterized by predominent hornfelsic rock facies, and not by gneissic or migmatitic facies. Detailed petrographical correlation of the natures of those Cretaceous pebbles with the metamorphic grounds of Kitakami is now most needful. Considering these materials, as already somewhat deduced, a land which of similar nature to that of the Kitakami mountains may have existed during the whole Mesozoic Era as the western neighbour of the axial zone occupying south-western Hokkaido and its northern extension now submerged under the Japan Sea.

The continent circumference of the Japanese Island arc was a territory of violent volcanic activities through the Jurassic and Cretaceous period; huge pilings of pyroclastics were developed everywhere. Their activated grounds would have been moved with the geohistorical development from the inner side of the Asiatic continent toward the Japanese Island arc during the time from the Jurassic to the Cretaceous. It may be rather reasonable to consider that the geosynclinal sea of Hidaka would have been supplied with their clastic materials from such a continental geotectonic province.

The distributions of the pebbles afford evidence of the probable existence of comparable sources on the eastern side of the axial zone, perhaps in the Okhotsk Sea and in the southern offing of the Kushiro and Nemuro peninsula.

The Hidaka geosyncline was existed in a narrow north-southerly stretched zone with those old lands on both sides, and its deposition was continued till the Cretaceous began; then it was transformed into a zone of orogenic movement. With the movement, the geosynclinal sea was divided in two and gradually contracted by the upheavals of the mid-ridge; the remnant sea would have been completely dried up in late Palaeogene.

B) Relations to the Honshû arc

The principal feature of the Honshû arc is focused upon the fact that the greater parts of the islands were a territory of marine sedimentation through almost the entire Palaeozoic Era (MINATO, M. 1956). Actually, the Palaeozoic formations are the largest among the sedimentary formations constituting the island arc.

The Asiatic continent also was submerged from time to time under the Palaeozoic sea, which always connected to that of Japanese Island arc. Thus, the primordial zone of the Japanese Island arc was kept under the sea as a geosynclinal deposition till the end of the Palaeozoic Era (MINATO, M. 1956).

Different to the Palaeozoic circumstances, the sea scarcely overspread the island arc in the Mesozoic Era, thinning to the inner continental side and deepenning toward Pacific basin. The area of the Mesozoic formations is so small compared with the Palaeozoic that the contrast is the most striking one in the history of the island arc. At the end of the Palaeozoic, all the sea withdraw to the Pacific basin from the continent which firmly established itself and afterward was never transgressed again by a sea riding over the Japanese Island arc through the whole Mesozoic Era. It is suggested by Prof. M. MINATO that this remarkable revolution of geological circumstances indicates the occurrence of some great disturbances which caused the geosynclinal territory of the island arc to upheave and made it an area of orogenic activity near end of the Palaeozoic Era. It is believed by many authors that the main metamorphic zones constituting the framework of the Honshû arc were the resultants of such an orogenic movement (MATSUMOTO, T. 1949, MATSUMOTO, T., KANMERA, K. 1949, KOJIMA, G. 1951, 1953, GORAI, M. 1954).

The spatial arrangement of the metamorphic zones within the Japanese Island arc is represented in Fig. 3. At the central part of the inner side of the island arc lies the gneiss complex of Hida which is considered to be of pre-Cambrian or Caledonian in age. Surrounding the Pacific side of the gneiss complex, some different metamorphic zones discriminable from each other are disposed, but they may be roughly united into a belt which is correlative to the Variscan orogenic zone of the world.

In south-western Japan, the belt is constituted of a three fold parallel running metamorphic zone. The inner most zone, the Sangun-Motoyama, is the forerunner of the remaining two which are believed to have been formed at the same time by a single orogenic movement. Of the two inner zone, the Ryoké metamorphic zone, corresponds to the "Zentralieden" which is furnished with gneiss and granite, and the outer zone of the two, the Sambagawa metamorphic zone, to the "Metamorphieden" formed of crystalline schists (KOJIMA, 1951).

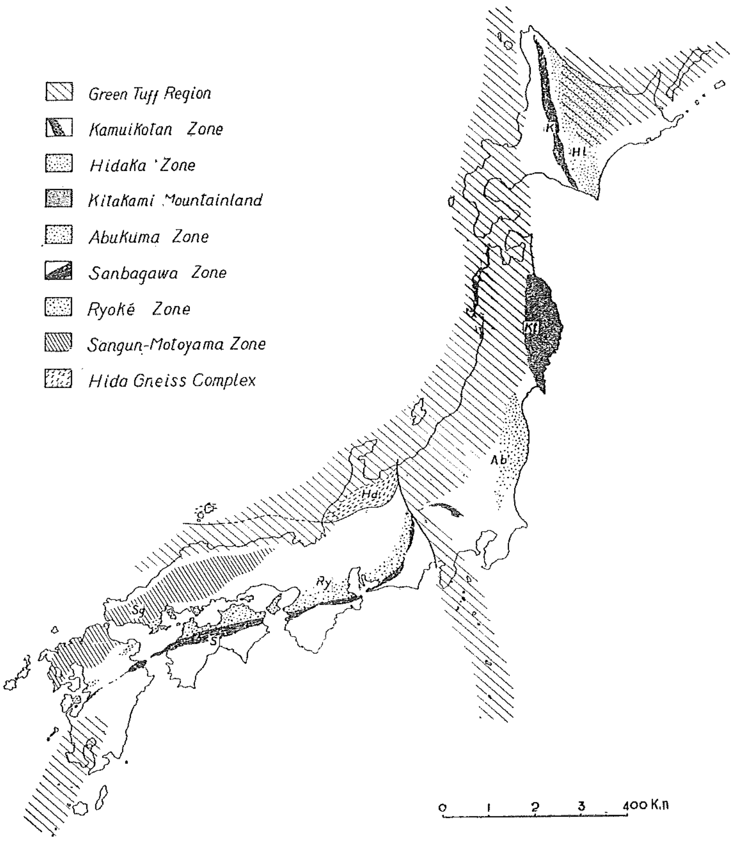

Fig. 3. Tectonic subdivision of the Japanese Island arc.

In north-eastern Japan, the arrangement is somewhat different. The older massifs, the mountainlands of Abukuma and Kitakami, are disposed in the outer zone in echelon form. The inner zone is filled with prominently developed Neogene pyroclastics, the green tuff zone. The Abukuma mountainland is a complex of gneiss and granite, while Kitakami mountainland is a less metamorphic and shallower tectonic region which is formed of chiefly of hornfelses without any prominent gneisses or schists. Palaeozoic formations are common to both mountainlands; they are tightly folded by post Palaeozoic deformation (MINATO, M. 1944, 1950, 1956).

As already mentioned, the land possibly confronted by the geosynclinal sea of Hidaka may have been of a character like that of the Kitakami mountainland. The Mesozoic deposits of the Kitakami mountainland are arranged in the eastern border part in areas of small extent. Toward the eastern, Pacific side, Triassic and Jurassic deposits develope thicker and transit to monotonous non-fossiliferous facies. Often seams of schalstein are intercalated in the eastern part.

Along the outer zone of south-western Japan, fringing the Pacific border of the Sambagawa metamorphic zone, Mesozoic deposits of unknown age, probably of Triassic to Jurassic, are very extensively developed, which recently, have been discriminated as a unit sedimentary province, the "Shimantogawa district" (YAMASHITA, N. 1957). Non-fossiliferous and monotonous slates are the chief constituents of those deposits, and it is worthy of note that they present in part similar faunal aspects comparable to those of the Hidaka group. Such circumstances are of very great interest in that the deposits of a simliar type of sedimentation as well as of the same time as that of the Hidaka group are disposed along the Pacific border zone of the Variscan belt. However, no metamorphic zone or prominent tectonic zone correlative to the axial zone of Hokkaido has yet been identified in the Shimantogawa district.

An interesting aspect is the igneous activity of the Variscan belt at the end of the Mesozoic Era. In the Variscan belt, some granite which cut the Cretaceous formations and convert them to large aureoles of hornfels are known. That is, metamorphic zones already consolidation in late Palaeozoic still offered ground for granite intrusions even at the late Mesozoic. Associated with very strong tectonic disturbances immense volcanic effusions are also identified as well granitic intrusions. Based on these Mesozoic tectonic features, the orogenic phases, Oga and Sakawa, were established, and they have been considered as the main orogenic movements that determined the framework of the Japanese Island arc (KOBAYASHI, T. 1941). However, recent studies support an opinion that the post-Palaeozoic movement has rather contributed mainly to the formation of the Japanese Island arc, and endow the late Mesozoic movement with subordinate meaning. The fundamental difference between post-Palaeozoic and late Mesozoic movements is considered to be that the former occurred continued metamorphic zone which is constituted of regionally developed gneiss and migmatite or crystalline schist, but the later is never associated with such prominent metamorphism or regional migmatitization (GORAI, M. 1954).

The movement within the Honshû arc equivalent to the Hidaka orogenic movement is represented by such above described activity for the Variscan belt, locked out from the Mesozoic sedimentary province, the Shimantogawa district. Reasonable interpretation of such duplicated disturbances has not yet been offered, but it seems plausible that they would have been effected, at least in part, by the propagated igneous activities and tectonic disturbances from the inner side of the Asiatic continent exerted toward the Pacific basin, newer disturbances on the oceanic side, during the Triassic to Cretaceous periods.

The geotectonic relation of the Japanese Island arc was converted to a wholly different state with the Neogene Tertiary. Detailed considerations concerning this aspect have been presented in the previous paper (MINATO, M. YAGI, K. HUNAHASHI, M. 1956). In Neogene Tertiary, the main part of the Variscan belt as well the Alpine belt had consolidated into united stable older massif constituting the outer zone of the island arc, and the confronted inner zone filled with immense pyroclastic pilings. Such Neogene geotectonic relation has a part in the circum-Pacific volcanic belt, the so called "green tuff region".

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References

(* indicates articles written in Japanese.)

AKAOKA, J., SUGIMOTO, I. (1941)*: On the nickeliferous pyrrhotite deposits in Hokkaido. Rep. Hokkaido Ind. Lab., Min. Surv. **1**, 1–63.

ASAI, H. (1956)*: The basic metablastic rock in the biotite-hypersthene-plagioclase gneiss of Horoman Region, Hidaka Province. Jour. Geol. Soc. Jap. **62**, 177–188.

BAMBA, T. (1953)*: Studies on spinels associated with the ultra-mafic rocks in Hokkaido. Jour. Geol. Soc. Jap. **59**, 122–128.

—— (1955)*: Iwanai-Daké peridotite body. Bull. Geol. Comm. Hokkaido. **29**, 7–14.

ENDO, R., HASHIMOTO, W. (1955): Unquestionable Palaezoic (Permian) fossils found in Hokkaido, Japan. Proc. Jap. Acad. **31**, 704–708.

FUKADA, A. (1953): A new species of *Nerinea* from central Hokkaido. Jour. Fac. Sci. Hokkaido Univ. 8, 211–216.

——, ISHII, J., ICHIKAWA, T., SARAKI, M. (1953)*: Cretaceous deposits around the Ikushunbetsu-River. Bull. Geol. Comm. Hokkaido. **22**, 1–19.

GORAI, M. (1950): Proposal of twin method for the study of the "granite problem". Jour. Geol. Soc. Jap. **56**, 149–156.

—— (1951): Petrological studies on plagioclase twins. Amer. Min. **36**, 884–901.

—— (1954): Brief note on the metamorphic zones of Japanese Islands. Sci. Rep. Yokohama nation. Univ. **3**, 67–70.

HASHIMOTO, S. (1950)-a: On the nickel-bearing pyrrhotite and graphite deposits at Oshirabetsu, Tokachi Province, Hokkaido. Jour. Fac. Sci. Hokkaido Univ. **7**, 227–236.

—— (1950)*-b: On the Poroshiri-Daké plutonic massif, northern Hidaka mountain range, Hokkaido. Earth Sci. (Chikyu kagaku) **1**, 1–6.

—— (1953)*: Explanatory text of the geological map of Japan, SATSUNAI DAKÉ. Geol. Surv. Hokkaido.

—— (1954)*: Explanatory text of the geological map of Japan, MIKAGÉ. Geol. Surv. Hokkaido.

—— (1955)*: Studies on the gabbro ampihbolite developed around the Poroshiri-Daké, northern Hidaka mountains, Hokkaido. Bull. Geol. Comm. Hokkaido. **28**, 1–10.

HASHIMOTO, W. (1950)*: Geology of the circumference Kabato mountainland. Bull. Geol. Comm. Hokkaido. **13**, 11–18, **14**, 14–28.

—— (1952)*: Jurassic stratigraphy of Hokkaido, Rep. Spec. Num. (B). Geol. Surv. Jap.

—— (1953)*: Explanatory text of the geological map of Japan. YAMABÉ. Hokkaido. Dev. Agenc.

—— (1955)*: Explanatory text of the geological map of Japan. SHIMOFURANO. Hokkaido Devel. Agenc.

HIROTA, S. (1952)*: Some considerations on the mode of formation of certain "granitoid migmatite" of Hidaka metamorphic zone, Hokkaido. Jour. Geol. Soc. Japan. **53**. 155–164.

HUNAHASHI, M. (1944)*: On some peculiar hornblende schist accompanied with the serpentinite of the Horokanai district, Ishikari Province, Hokkaido. Jour. Geol. Soc. Jap. **51**, 119–131.

—— (1948)*: Contact metasomatism associated with the pyroxene-peridotite of the Horomon region in Hidaka metamorphic zone, Hokkaido. Jour. Fac. Sci. Hokkaido. Univ. 8, 1–33.

——, HASHIMOTO, S. (1951)*: Geology of the Hidaka zone, Hokkaido. Monog. Geol. Collab. 6.

—— (1951)*: Cupriferous pyrrhotite deposit, "Saruru Mine". Earth Sci. (Chikyu kagaku) **5**, 7–14.

—— (1953)*: Explanatory text of the geological map of Japan, KAMIETANBETSU. Hokkaido Dev. Agenc.

——, IGI, S. (1956)*: Explanatory text of the geological map of Japan, HOROIZUMI. Geol. Surv. Jap.

——, HASHIMOTO, S., ASAI, H., IGI, S., KIZAKI, K., SOTOZAKI, K., HIROTA, S., KASUGAI, A. (1956)*: Gneisses and migmatites in the southern extreme region of the Hidaka metamorphic zone, Hokkaido. Jour. Geol. Soc. Jap. **62**, 401–408, 464–471, 541–549.

IGI, S. (1953)*: Petrographical studies on the peridotite in the Horoman region, southern end of the Hidaka mountain range, Hokkaido. Jour. Geol. Soc. Jap. **59**, 111–121.

—— (1956)*: Explanatory text of the geol. map of Japan, SARURU. Geol. Surv. Japan.

IJIRI, S. (1956)*: Palaeontology. Riron-sha, Tokyo 236–237.

IKI, T. (1911)*–a: Mineral resourses of the Hidaka mountains. Min. Surv. Rep. **1**, 45–59.

—— (1911)*–b: Report on the geological traverse along the Nukabira-river, Hidaka Province. Min. Surv. Rep. **4**, 25–42.

—— (1911)*–c: Report on the geology around the Monbetsu-river, Hae-river and Kerimai-river, Hidaka Province. Min. Surv. Rep. **5**, 57–81.

—— (1911)*–d: Report on the geological traverse along the Motourakawa-river, Hidaka Province. Min. Surv. Rep. **5**, 83–105.

ISHIBASHI, M. (1939)*: Petrographical studies on the soda mineral bea. rocks of Horai-San, Mitsuishi district. Bull. Geol. Comm. Hokkaido. **10**, 7–32.

ISHII, J. (1957)*: Conglomerate of the Shitakara formation in the environs of Kami-atsunai, Ohotsu-Mura, Tokachi Province. in Hokkaido. Bull. Comm. Geol. Hokkaido **35**.

JIMBO, K. (1892): General geological sketch of Hokkaido, with special reference to the petrography. Hokkaido Pref. Office.

KASUGAI, A. (1957)*: Tectonic studies on the Toyoni-Daké migmatite dome and its surroundings, southern Hidaka metamorphic zone, Hokkaido. Jour. Geol. Soc. Jap. **63**, 465–474, 527–540.

KATO, T., KOBAYASHI, H. (1944): On the origin of the nickeliferous pyrrhotite deposits of Horoman Mine, in Hokkaido. Jap. Jour. Geol. Geogr. **19**, 181–188.

KIZAKI, K. (1953)*: On the gneisses and migmatites of the central Hidaka metamorphic zone. Jour. Geol. Soc. Japan. **59**, 203–215.

—— (1956): Petrofabrics of the Oshirabetsu dome in the southern Hidaka metamorphic zone, Hokkaido, Japan. Jour. Fac. Sci. Hokkaido Univ. **9**, 289–317.

KOBAYASHI, G. (1911)*: Report on the geological traverse along the Mukawa-river, Iburi Province. Min. Surv. Rep. **5**, 1–44.

KOBAYASHI, T. (1941): The Sagawa orogenic cycle and its bearings on the Japanese Islands. Jour. Fac. Sci. Tokyo Univ. **5**, 219–578.

KOJIMA, G. (1951): Ueber des "Feld der Metamorphose" der Sambagawa kristallinen Schiefer, besonders in bezug auf Bildung des kristallinen Schiefergebietes in Zentral-Shikoku. Jour. Sci. Hiroshima Univ. **1**, 1–18.

—— (1953): Contributions to the knowledge of mutual relations between three metamorphic zones of Chugoku and Shikoku, southwest Japan. Jour. Sci. Hiroshima **1**, 16–46.

—— (1954): Geological situation of the Cretaceous Hiroshima granite. Jour. Sci. Hiroshima Univ. **4**, 1–5.

LYMAN, B. S. (1877): A general report of the geology of Yesso. Hokkaido Colon. Dept., Sapporo.

MATSUMOTO, T. (1949): The late Mesozoic geological history in Nagata Province, southwest Japan. Jap. Jour. Geol. Geogr. **21**, 1–4, 235–243.

——, KANMERA, K. (1949): Contributions to the tectonic history in the outer zone of south-west Japan. Mem. Fac. Sci. Kyushu Univ. **3**, 77–90.

—— (1952): A note on the Cretaceous history of the circum-Pacific region. Jap. Jour. Geol. Geogr. **22**, 109–116.

—— (1953): The Cretaceous system in the Japanese Islands. Jap. Soc. Promotion of Sci., Tokyo.

MINATO, M. (1944): Phasenanalyse der Gebirgsbildungen der palaeozoischen Aera im Kitakami-Gebirge, nordöstlisches Honshu, Japan. Jap. Jour. Geol. Geogr. **19**, 151–180.

—— (1950): Zur Orogenese und zum Vulkanismus im jungeren Palaeozoikum des Kitakami Gebirges, Honshu, Japan. Jour. Fac. Sci. Hokkaido Univ. **7**, 277–302.

—— (1950): Geology of the Kitakami mountainland. Monograph. Assoc. Geol. Coll. No. 5.

—— (1952): Problems on green tuff region in Japan. Shinseidai **14**, 1–10.

——, SAWA, T., TAKEDA, N. (1954)*: Inoceramus found in Hidaka Group. Bull. Geol. Comm. Hokkaido **27**, 1–3.

—— (1956): Palaeogeography of the Japanese islands and their adjacent Lands in the upper Palaeozoic Era. Earth Sci. (Chkiyo Kagaku) **28**, 1–13.

——, YAGI, K., HUNAHASHI, M. (1956): Geotectonic synthesis of the green tuff regions in Japan. Bull. Earthq. Res. Inst. **34**, 237–264.

NAGAO, S., OSANAI, H. SAKO, S. (1955)*: Explantory Text of the Geological map of Japan, OYUBARI. Hokkaido Dev. Agnec.

NAGAO, T. (1933): "Nappes" and "Klippes" in central Hokkaido Proc. Imp. Acad. **9**,

—— (1933): The Cenozoic history of western Hokkaido, with special reference to the periods of volcanism. Proc. 5th Pacif. Sci. Congr. 1933. 2461.

—— (1938): Tertiary orogeny in Hokkaido. Jour. Fac. Sci. Hokkaido Univ. **4,** 1–2.

NEMOTO, T., SANBONSUGI, M., (1937)*: Explanatory text of the geological map of Hokkaido, URAKAWA. Hokkaido Indust. Lab.

ODAIRA, Y. (1928)*: Geological and petrological studies of the Horoizumi district, Hidaka Province. Jour. Geol. Soc. Jap. **35,** 105–147, 293–326.

—— (1928)*: Geological and petrological studies of the Okushibetsu district, Teshio Province. Jour. Geol. Soc. Jap. **36,** 140–174, 205–224.

OKAMURA, Y. (1911)*–a: Report on the geological traverse along the Sarugawa-river, Hidaka Province. Min. Surv. Rep. **4,** 1–25.

—— (1911)*–b: Report on the geology of the Mitsuishi, Niikappu and Shizunai district, Hidaka Province. Min. Surv. Rep. **4,** 43–69.

—— (1911)*–c: Report on the geology of the Biro and Kasai district, Tokachi province. Min. Surv. Rep. **5,** 107–124.

—— (1912)*: Report on the geology of the northern part of the axial zone of Hokkaido. Min. Surv. Rep. **11,** 1–62.

—— (1913)*: Report on the geology of the northeastern part of Hokkaido. Min. Surv. Rep. **15,** 1–62.

OTATSUME, K. (1940)*: On the stritigraphical relations between lower ammonite bed and schalstein formation, in central Hokkaido. Bull. Geol. Comm. Hokkaido **11,** 1–48.

—— (1951)*: Geotectonic structure of the Yubari district, Ishikari coal field, with special reference to its nappe structure. Bull. Geol. Comm. Hokkaido. **18,** 1–30.

SAITO, M. (1953)*: Chromite deposits of the Saru-Gaga Mu-Kawa district. Record Min. Resour. Hokkaido. **11,** 1–33.

——, BAMBA, T. (1953)*: The chromite deposits of the Nittoh mine. Min. Geol. **3,** 30–39.

SAKO, S. (1954)*: Report of the geological survey on the cupriferous iron sulphides deposits along the Koikakushu-Shibechari-gawa, Hidaka Province. Rep. Underg. Res. Hokkaido, **12,** 25–46.

——, OSANAI, H. (1955)*: Explanatory text of the geological map of Japan, SHIMOKAWA. Hokkaido Dev. Agenc.

—— (1956)*: Report on the cupriferous iron sulphides deposits of upper course of the Tokachi river, Tokachi Province. Rep. Underg. Res. Hokkaido. **27,** 1–28.

SAWA, T. (1936)*: The cupriferous iron sulphide deposits of the Koryu mine in Hidaka Province, Hokkaido. Min. Geol. **6,** 207–222.

SOTOZAKI, Y. (1956)*–a: On granitic migmatite at Saruru river district in southern Hidaka metamorphic zone, Hokkaido. Jour. Geol. Soc. Jap. **62,** 449–463.

—— (1956)–b: On the diabase of the Meguro district, Hidaka Province, Hokkaido. Jour. Jap. Min. Pet. Eco. Geol. **40,** 70–82.

—— (1956)*–c: Notes on inclusions associated with migmatites at Saruru river district in Hidaka, Hokkaido. Jour. Jap. Min. Pet. Eco. Geol. **40,** 163–168, 196–203.

SUZUKI J. (1930): Petrographical study of the crystalline schist system of Shikoku, Japan. Jour. Fac. Sci. Hokkaido. Univ. **1,** 27–111.

—— (1932)*–a: The original source of glaucophane schists in Hokkaido. Jour. Geol. Soc. Jap. **39,** 132–137.

—— (1932)*–b: On some new facts about the glaucophane schists of Japan. Jour. Jap. Min. Pet. Eco. Geol. 8, 183–190.

SUZUKI, J. (1933): Aegirite-augite bearing riebeckite quartz schist from Kamuikotan and some other localities in Hokkido, Japan. Proc. Imp. Acad. **9,** 617–620.

—— (1934)-a: Metamorphosed calcareous concretions in the hornfels at the southern coast of Tokachi Province, Hokkaido. Jour. Fac. Sci. Hokkaido Univ. **2,** 323–338.

—— (1934)*-b: On the petrographical character of so-called "Kamuikotan system". Jap. Jour. Geol. Soc. **41,** 392–394.

—— (1934)*-c: Granite and associated metamorphic rocks in Hokkaido. Jour. Geol. Soc. Japan. **41,** 394–397.

—— (1934)*-d: On the trondjhemite of Uryu, Hokkaido. Jour. Ass. Jap. Pet. Eco. Geol. **14,** 109–116.

—— (1939)*-a: Petrographical studies on the Mikabu and Kamuikotan metamorphic complex. Jap. Soc. Promot Sci. Res. Abst. **1,** 7–36.

—— (1939)-b: A note on soda-amphiboles in crystalline schists from Hokkaido. Jour. Fac. Sci. Hokkaido Univ. **4,** 507–519.

—— (1940)*: Leucocratic rocks associated with serpentinite in Hokkaido. Jour. Jap. Assoc. Pet. Min. Eco. Geol. **23,** 65–80, 265–281.

—— (1942)*-a: On the chromite ores from Japan. Jour. Jap. Min. Pet. Eco. Geol. **27,** 115–126, 183–194.

—— (1942)*-b: On the chromite placer deposits of Hokkaido and Karafuto. Jour. Jap. Min. Pet. Eco. Geol. **27,** 205–215.

—— (1943)*: A contribution to the knowledge of the origin of chromite ore deposits. Jour. Jap. Ass. Min. Petr. Eco. Geol. **29,** 43–54.

—— (1944)*: General view on the geology of Hokkaido. Jour. Geol. Soc. Jap. **51,** 15–24.

—— (1950)*-a: Platinum placer deposits in Hokkaido. Record. Min. Res. Hokkaido. **2,** 1–41.

—— (1950)*-b: On the genetic styles of ore deposits associated with the ultrabasic rocks of Japan. Kagaku (Science) **15,** 16–24.

—— (1952): Ultra-basic rocks and associated ore deposits of Hokkaido, Japan. Jour. Fac. Sci. Hokkaido. Univ. **8,** 175–210.

—— (1953)-a: Ultra-basic rocks and associated mineral resources in Hokkaido, Japan. Proc. 7th Pacif. Sci. Cong. **2,** 245–248.

—— (1953)*-b: Explanatory text of the geological map of Japan, FUKAGAWA. Hokkaido Dev. Agenc.

—— (1954)-a: On the rodingitic rocks in the serpentinite masses of Hokkaido. Jour. Fac. Sci. Hokkaido Univ. **8,** 419–430.

—— (1954)*-b: On some pillow lavas from Hokkaido. Bull. Geol. Comm. Hokkaido. **26,** 11–20.

—— (1955)*-a: The problems of the diabases. Bull. Geol. Comm. Hokkaido. **30,** 9–23.

—— (1955)*-b: Explanatory text of the geological map of Jap., ASAHIGAWA. Hokkaido Dev. Agenc.

TAKAHASHI, T. (1936)*: Geology of the Monbetsu district, Kitami Province. Rep. Hokkaid. Ind. Lab., (Rep. Min. Res.) No. 65.

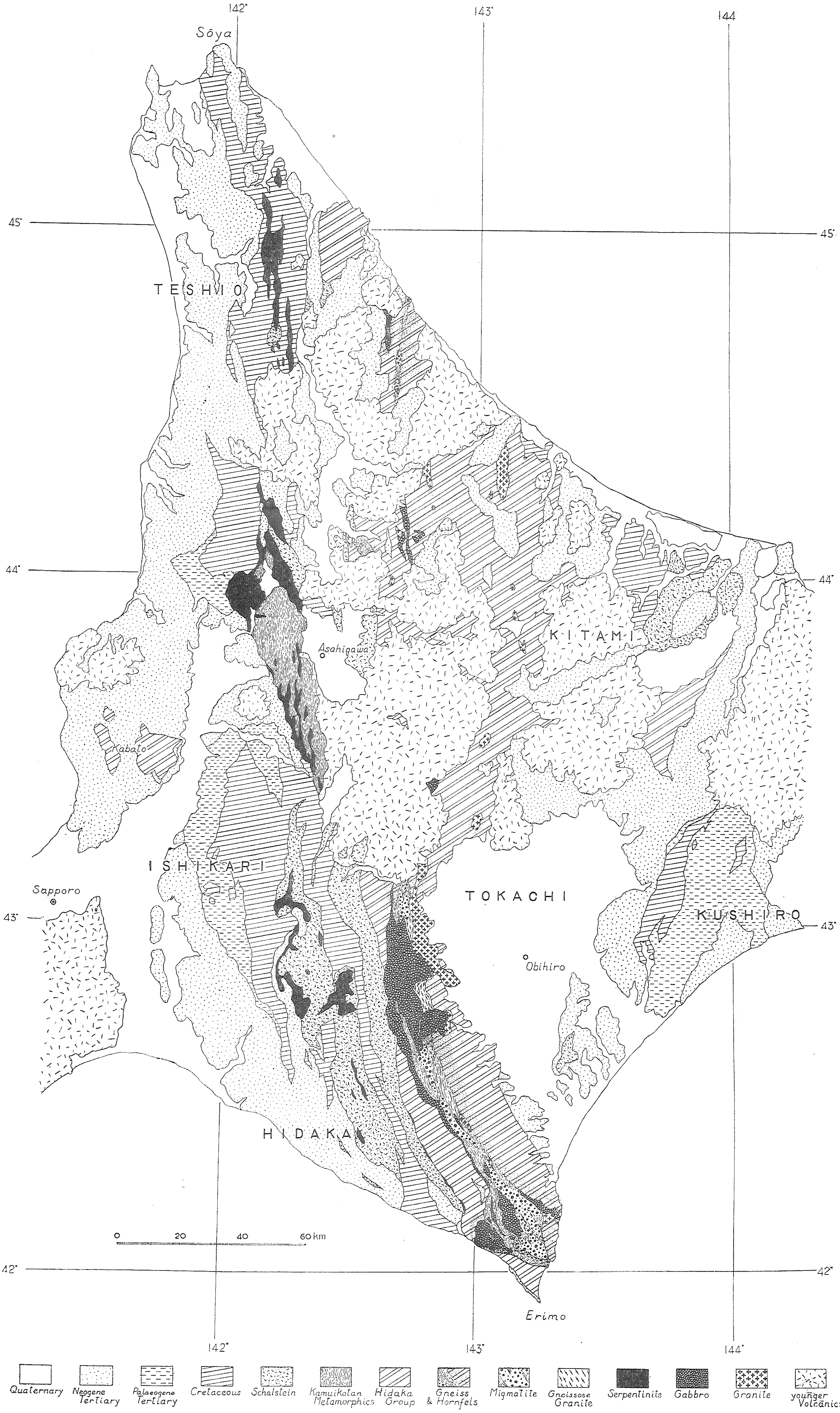
TAKEUCHI, K. (1937)*: Geology of the Horoizumi and Samani district. Rep. Hokkaido. Ind. Lab., (Rep. Min. Res.) No. 76.

——, SANBONSUGI, M. (1938)*: Explanatory text of the geological map of Hokkaido, URAKAWA. Hokkaido Indust. Lab.

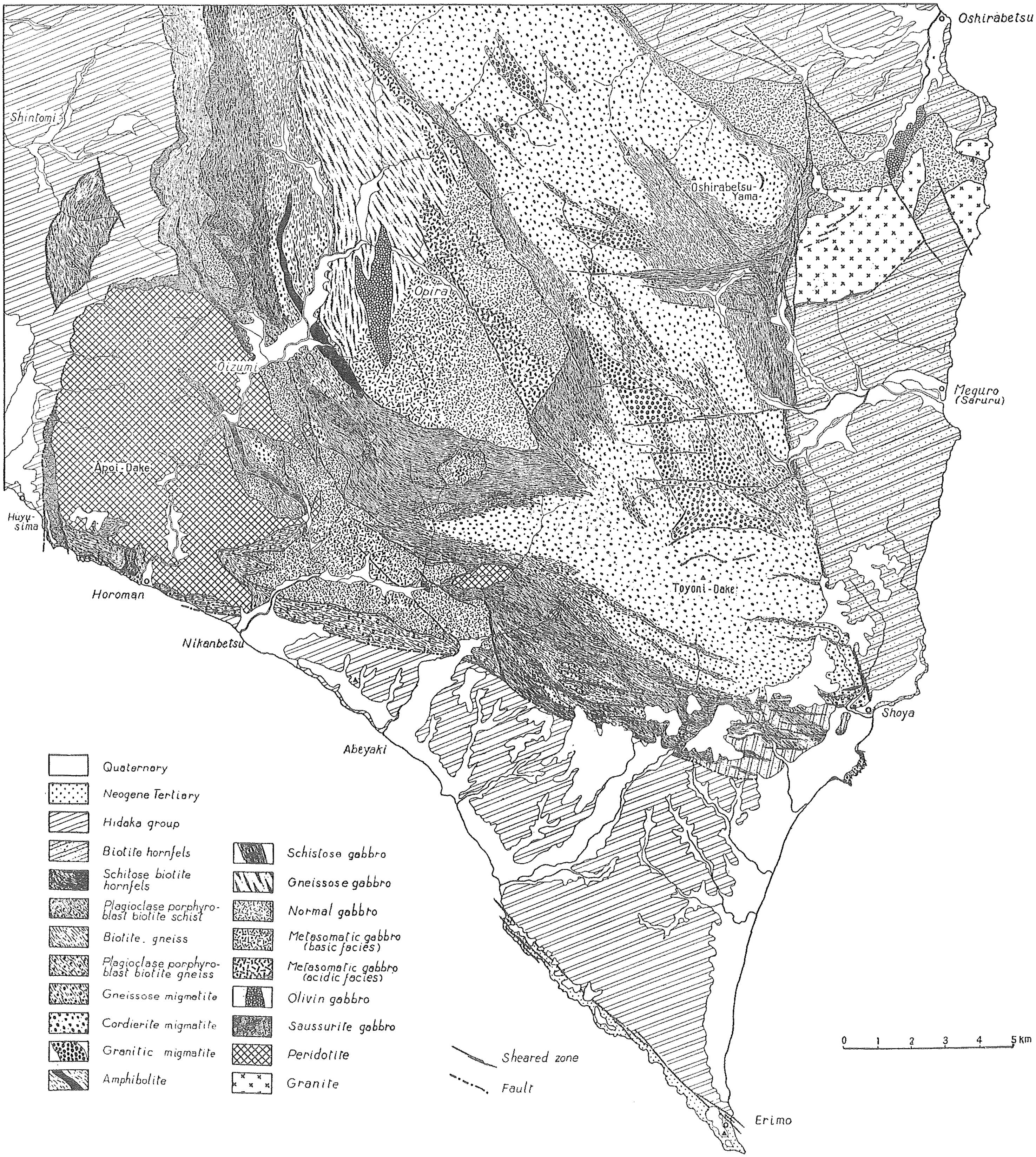
YAMANE, S. (1911)*–a: Report on the Geology of southern Hidaka Province and Biro district, Tokachi province. Min. Surv. Rep. Hokkaido. **4**, 71–105.

—— (1911)*–b: Report on the geological traverse along the upper course of Sorachi -river, Ishikari Province. Min. Surv. Rep. **5**, 125–145.

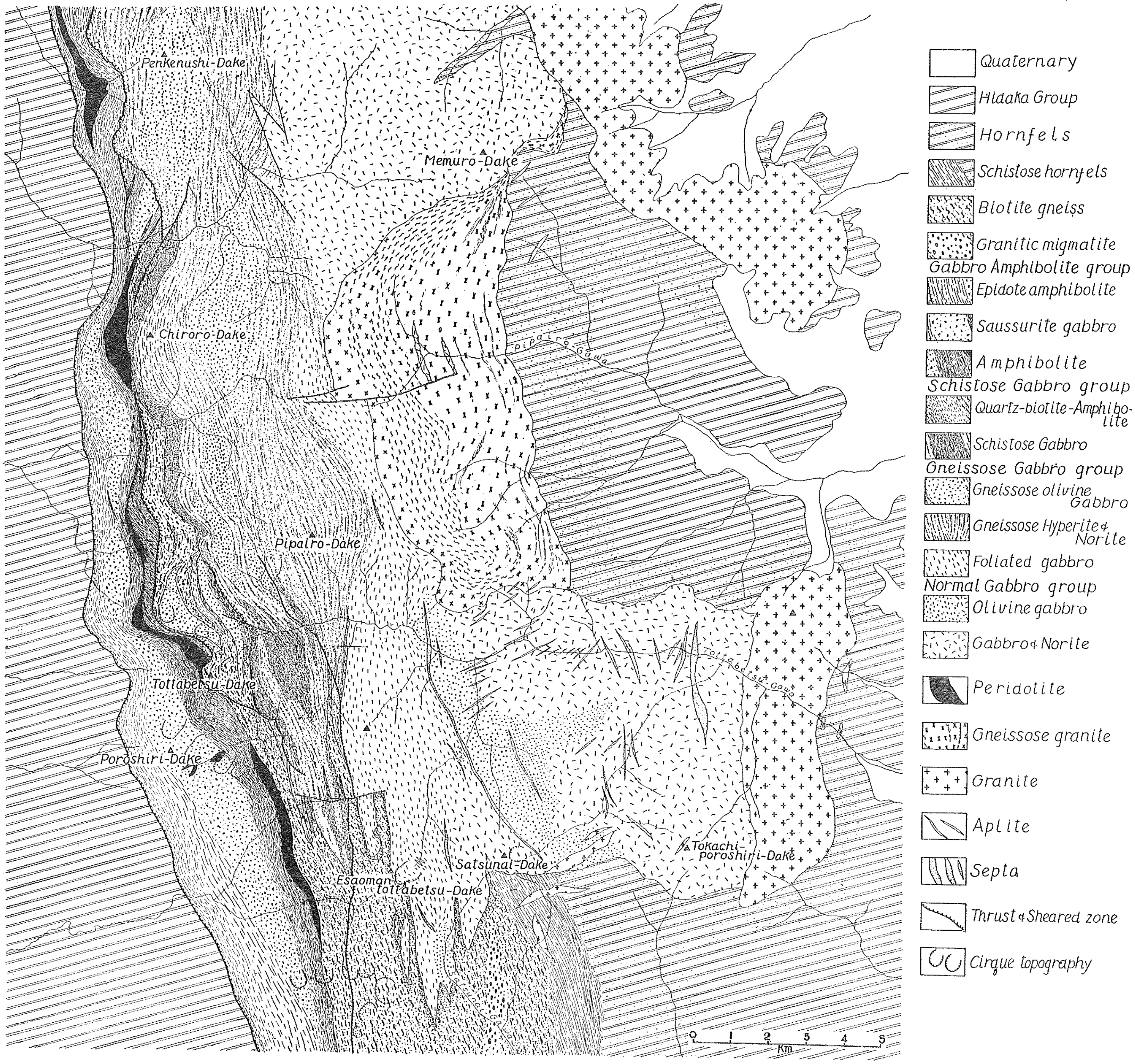
YAMASHITA, N. (1957)*: Mesozoic of Japan. Geologic Library. 10. Asso. Geol. Coll. Jap.



Generalized geological map of the axial zone of Hokkaido. (after Hidaka Research Group)



Geological map of the southern extreme region of the Hidaka metamorphic zone. (after Hidaka Research Group)



Geological map of the Poroshiri-Daké igneous massif, northern Hidaka mountain range.

(after S. Hashimoto)