PETROLOGICAL STUDY OF THE KAMUIKOTAN METAMORPHIC COMPLEX IN HOKKAIDO, JAPAN

By

Jun SUZUKI and Yoshio SUZUKI

(With 43 Text Figures and 15 Tables)

(Contributions from the Geological and Mineralogical Department, Faculty of Science, Hokkaido University, No. 764)

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I. INTRODUCTION

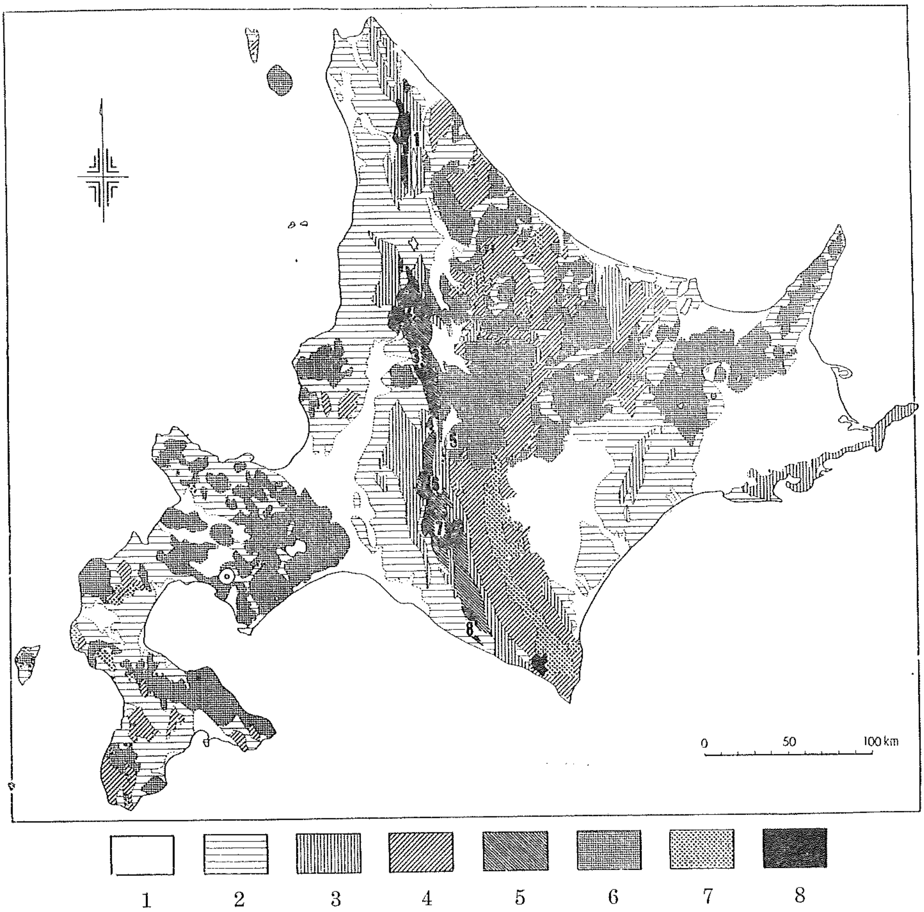
It has been well known that two prominent structural zones in central Hokkaido, called respectively the Hidaka zone and the Kamuikotan zone, run in belts roughly parallel to each other trending in north to south direction. Of these two, the Kamuikotan zone is developed about 200 km from the boundary area of Teshio and Kitami Provinces southward to Hidaka Province, along the western side of the Hidaka zone which forms the back-bone range of central Hokkaido. As there are thick Cretaceous formations and tectonic lines on a large scale, between the Kamuikotan and the Hidaka zones, the direct geological relations between these zones are yet obscure, though it is considered that they belong to a single orogenic phase and that both are chiefly made up of thick geosynclinal sediments and associated various igneous intrusives.

The Hidaka zone is mainly composed of argillo-siliceous and basic sediments and their modification; along the central axis of the zone, there develop gneisses, migmatites, amphibolites and various kinds of plutonic rock such as granodiorites, gabbros and peridotites. These plutonics are considered to have intruded in the synkinematic to post-kinematic stages during the so-called "Hidaka orogenesis". (HUNAHASHI: 1957, HUNAHASHI and HASHIMOTO: 1951)

In comparison with the Hidaka zone, the Kamuikotan zone consists mainly of various kinds of siliceous to argillo-siliceous and basic schists belonging to the so-called "Kamuikotan metamorphic complex", and schalstein formations and other members which are the property of the so-called "Sorachi series". (SASA and MINATO: 1943, SUZUKI: 1954b) And, what is more, the zone is characterized by the association of numerous large bodies of ultrabasic intrusives and by the almost entire absence of granodioritic and gabbroic rocks. (SUZUKI: 1952)

The Kamuikotan metamorphic complex associated with ultra-basic intrusives is widely distributed in the Kamuikotan zone, especially in the western parts there of good exposures of the matamorphic complex have been found chiefly in the following districts; Kamuikotan, Uryu, Yubari, in Ishikari Province, Mitsuishi, in Hidaka Province, and both sides of the boundary of Teshio and Kitami Provinces, though the distributions of the associated ultra-basic rocks are relatively large through the whole zone. (Fig. 1) The name "Kamuikotan metamorphic complex" was originally applied to the typical exposures along the Kamuikotan Valley in the middle course of the Ishikari River in the Kamuikotan district, Ishikari Province.

In general the fundamental rocks of the Kamuikotan metamorphic complex show signs of the products due to slight regional metamorphism resulting from shearing under epi-zone condition. Some of the rocks in the Kamuikotan complex, however, have suffered severe contact metasomatic action in places, after ultra-basic intrusions; there occur locally some complicated polymetamorphic rocks. By reason of the above circumstances, the complex offers many interesting facts with special reference to the petrology and mineralogy of the metamorphics. Attention was first called to some of the metamorphic rocks of the Kamuikotan metamorphic complex at the Kamuikotan Valley by B. S. LYMAN, a pioneer geologist of Hokkaido, when be travelled from Sapporo to the Sounkyo Gorge by way of the Kamuikotan Valley. He gave an interesting



1. Alluvium and Diluvium.
2. Tertiary formations.
3. Cretaceous formations.
4. Hidaka and so-called Palaeozoic formations (locally containing Jurassic).
5. Kamuikotan metamorphics and locally Jurassic formations.
6. Volcanic rocks.
7. Acid and basic plutonic rocks and migmatites.
8. Serpentinites and peridotites.

Fig. 1. Geological map of Hokkaido, indicating the distribution of the Kamuikotan metamorphic complex.

Localities

1. Teshio-Kitami boundary district.
2. Horokanai district.
3. Kamuikotan Valley.
4. Hurano district.
5. Yamabe district.
6. Kanayama-Yubari district.
7. Usappu district.
8. Mitsuishi district.

account of his early geological exploration in "A general report on the geology of Yesso (Hokkaido), 1876", though he mentioned nothing but the existence of "talcose schist, quartzose schist, blue marble, black serpentine and black quartzite" in that locality and did not touch upon either the properties or the occurrences of these rocks. (LYMAN: 1876) He employed the name "Kamuikotan group" in his report, but it was used in a broad sense including all the members of the Hidaka zone, the Kamuikotan zone, the Cretaceous formations as well as associated igneous rocks in the central part of Hokkaido; it is quite different from "the Kamuikotan zone" or "Kamuikotan metamorphic complex" as now defined by present-day geologists. (SUZUKI: 1944, HUNAHASHI: 1951)

About sixteen years after B. S. LYMAN, some descriptions on the metamorphic rocks in the central zone of Hokkaido were given by K. JINBO in his "General geological sketch of Hokkaido with special reference of the petrography, 1892", in which a considerable space is devoted to that subject. According to him, the real crystalline schists such as "amphibolite, chlorite schist, quartzite, epidote schist, etc." may be considered to belong to the Sambagawa series and whilst slightly metamorphosed members with relic minerals may be correlated to those of the Mikabu series. The rocks of both these series in the Chichibu district, Honshu, had been defined by B. KOTO[1] a short time before JINBO's publication. (JINBO: 1892)

Since the crystalline schists in the Kamuikotan Valley were noticed by K. JINBO, they have been a subject of investigation by many geologists. The glaucophane schist as boulders in the Kamuikotan Valley, was firstlly introduced by B. KOTO who gave short accounts on the rock. (KOTO: 1900) A sample of the rock was sent by B. KOTO to H. S. WASHINGTON who made a chemical analysis. The result was discussed by H. S. WASHINGTON[2] and subsequently by L. MILCH[3]

In those days, the boulders of various kinds of glaucophane schist and other crystalline schists attracted the special attention of H. YABE in the Obirashibe river heads, on the occasion of his survey of the Tertiary and Cretaceous formations of Teshio Province. These rocks were petrologically investigated and described subsequently by H. HACHIYA.

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1) KOTO, B.: On the So-called Crystalline Schists of Chichibu. Jour. Coll. Sci. Tokyo Imp. Univ. Vol. 1 (1888), pp. 77-141.

2) WASHINGTON, H. S.: A Chemical Study of the Glaucophane Schists. Am. Jour. Sci. Ser. 4, Vol. 11 (1901), pp. 35-59.

3) MILCH, L.: Ueber Glaukophan u. Glaukophangestein von Elek-Dagh (nördliches Klein-asien), etc. Neues Jahrbuch, Festband (1904), pp. 348-396.

Though these pebbles are considered to have been washed out directly from the Tertiary conglomerate layer at the upper course of the Obirashibe, it is clear that they originated from the areas of the Kamuikotan metamorphic complex. (YABE: 1900, HACHIYA: 1902)

Thereafter study on the Kamuikotan metamorphics was almost disregarded for nearly thirty years; the real properties and the mode of occurrence of the rocks were practically unknown. Since the organization of the Department of Geology and Mineralogy of Hokkaido University in 1930, the Kamuikotan metamorphics have attracted the deep interest and active study of members of the Department, whose observations have been frequently published. There are also not a few reports with respect to the same subject by the geologists of the Geological Survey of Japan and the Geological Survey of Hokkaido, of late years.

The researches on the Kamuikotan complex have thus been published by degrees and many facts bearing upon the subject have became clear but there remain to be further clarified various obscure problems with special reference to the age, stratigraphy, metamorphic mechanism of the complex. Some of the special metamorphics and associated intrusives belonging to the complex have been frequently discussed by the senior writer (J.S.) and others, but a summarizing study of all the rocks of the complex has not yet been undertaken. The specific object of this paper is to present a general account in regard to the petrographical characters of the various crystalline schists and associated igneous rocks belonging to the Kamuikotan metamorphic complex.

The writers desire to express their sincere thanks for the assistance and information of various kinds given in preparation of this paper at all times by many members in the Geological and Mineralogical Department of the Faculty of Science, Hokkaido University. A part of the expense for this study is supplied by the Department of Education as Research Fund for Natural Science.

II. GEOLOGICAL OUTLINE OF THE KAMUIKOTAN ZONE

The Kamuikotan metamorphic complex associated with ultra-basic intrusives is distributed longitudinally as an irregular thick zone between the Mesozoic and Caenozoic formations along the western side of the main axial zone in central Hokkaido. The complex is commonly composed of thick stratified formations of various kinds of slightly metamorphosed rocks which are mainly siliceous and basic, rarely calcareous.

The southern extension of the zone is hidden under the ocean and it is yet obscure to what formation in Honshu the zone may be directly correlated. It is however probable that the metamorphic zone in the Suzuya range in South Sakhalin represents, tectonically and lithologically, a part of the northerly continuation of the Kamuikotan complex. (SUZUKI, 1944, KUROSAWA 1934).

The schistosity planes of the Kamuikotan metamorphics are usually parallel to the bedding planes of the formation. The relation is clearly shown by the thin layers of quartzite, crystalline limestone and some basic schist and quartz schist which intercalate with the thick greenschists and black siliceous schist. The general strikes of the schistosity of the metamorphic rocks are N-S or NNW-SSE, being nearly parallel to the over-all trend of the complex, though the direction of dips is considerably variable because of the complicated folding of the complex.

In some places the metamorphic rock layers show anticlinorium or synclinorium and further elongated dome or basin structure where the strikes of schistosity may be nearly at a right angle to the general trend of the complex indicating that the layers show locally a double plunging anticline or more complex structure. For instance, in the Kamuikotan Valley, the Ishikari river appears to flow approximately along the schistosity of the rock crossing the general trend of the complex. The structure of the rock layers in the complex may be more complicated by recumbent folds and overthrusts as well as by the cutting of numerous faults of the later stages. As a result, it is very difficult to estimate the true thickness of each of the rock layers of the Kamuikotan metamorphics on account of such overturning, repetition and discontinuity of their formations.

In the Kamuikotan zone, there are two main types of igneous rocks, serpentinites and diabasic rocks which invaded in the Kamuikotan complex and the Sorachi series. It is a remarkable thing that there are large bodies of ultra-basic igneous rocks now mainly represented by serpentinite arranged especially along the tectonic lines in the Kamuikotan zone. With the rocks there are locally associated various kinds of differentiated hypabyssal rocks and ore deposits, especially of chromite.

It is noteworthy that there can be observed local occurrences of highly metamorphosed crystalline schists in the complex; the schists are characterized by containing soda-amphiboles, soda-pyroxenes and other special metamorphic minerals. The detailed mapping of such localities has proven that these highly metamorphosed parts have only a limited development in an area along or near a certain serpentinite mass and rarely in a xenolithic block within it, though some geological and lithological differences are found locally.

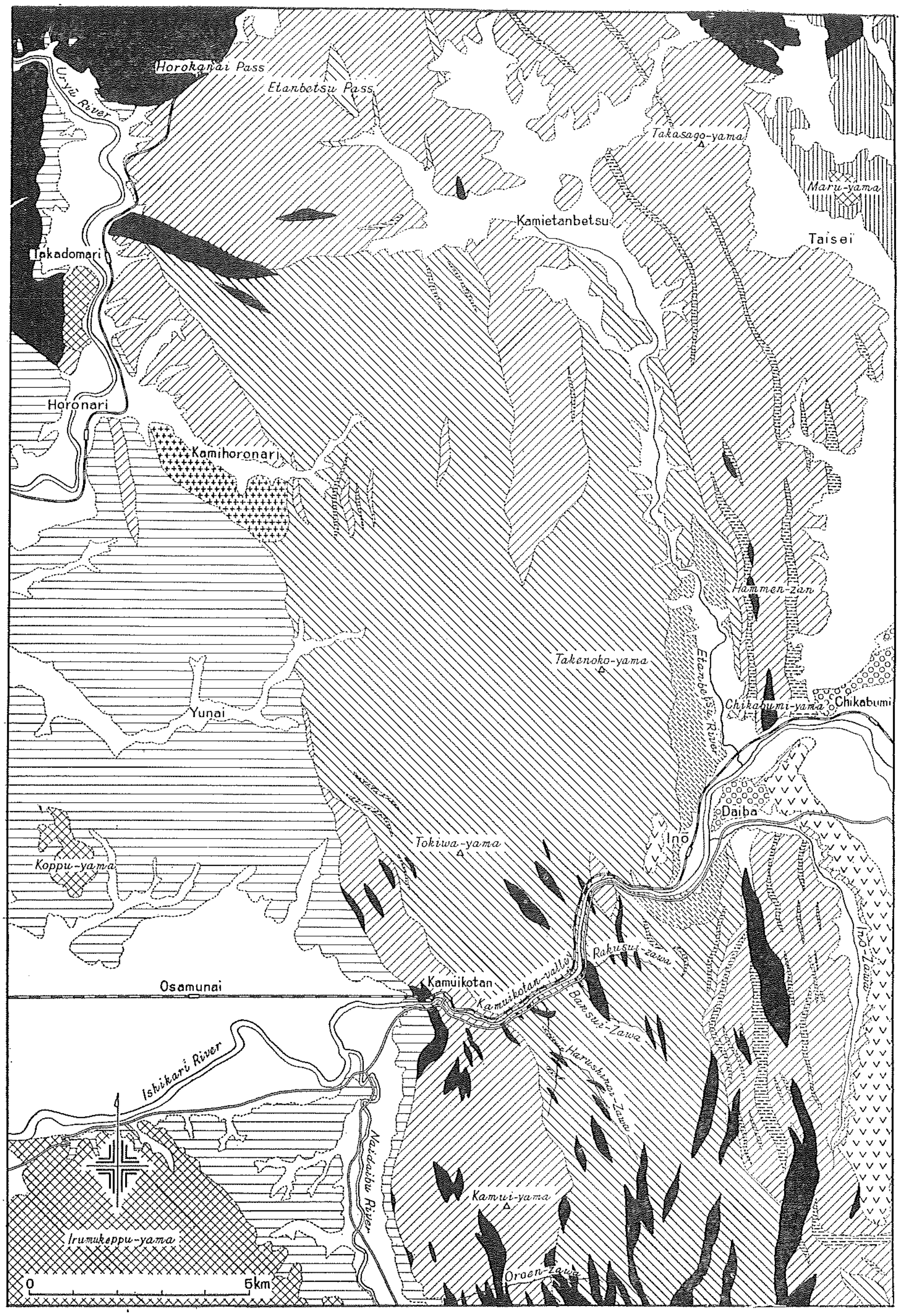
This fact may indicate that these special rocks originated from the influence of contact metamorphism due to the later intrusions of ultra-basic masses. In these cases the result of so severe contact metamorphic action does not always depend on large mass of ultra-basic, and is observable even in the vicinities effected by small intrusions.

In short, on account of the igneous cycle in the serpentinite regions, it is considered that the ultra-basic rocks were the earliest intrusives, followed closely by the differentiated dike rocks and subsequently by some hydrothermal solution which appears to be an end derivative arising from the cooling ultra-basic mass. The ultra-basic masses gave rise to contact effect with the rock not only of the Kamuikotan complex but of adjacent Sorachi series (Jurassic) and Upper Cretaceous formations (Senonian); on the other hand ultra-basic rocks are occasionally enclosed as pebbles in the conglomerate beds in the Neogene and Palaeogene Tertiary. From these available evidences it may reasonably be assumed that most of the intrusions of the ultra-basic rocks and associated hypabyssal rocks in central Hokkaido belong to an early Tertiary orogenic period. (MURATA, 1926; HARADA, 1940; SUZUKI, 1934a).

The igneous rocks known in the area in the Sorachi series are mainly serpentinites and diabase: In comparison with the igneous rocks in the Kamuikotan complex, the serpentinites in the Sorachi series occurs usually in the form of separated small bodies which are sparsely and irregularly arranged in a row, roughly parallel to each other in keeping with the trend of the series.

The ultra-basic rocks are petrographically quite similar to those in the Kamuikotan complex and it is also common that the rocks in the Sorachi series are occasionally associated with small dikes of some differentiated leucocratic rocks in the serpentinite themselves. It is an interesting thing that contact metamorphic phenomena are rarely recognized in the schalstein in the Sorachi series around the serpentinite masses. In such case some special minerals, such as glaucophane, aegirine-augite, etc. may occur in very small quantity in the slightly metamorphosed schalstein. From these several facts, it is best to consider that the serpentinites in the Sorachi series are nothing but the same as those in the zone of the Kamuikotan metamorphic complex.

Besides the serpentinites, the diabasic rocks are a conspicuous member of the igneous rocks found in the zone though they are far less than serpentinites in quantity. In general the rocks occur locally as thin


Horokanai Pass
Etanbetsu Pass
Uryū River
Takasago-yama
Maru-yama
Kamietanbetsu
Taisei
Takadomari
Horonari
Kamihoronari
Hammen-zan
Takenoko-yama
Etanbetsu River
Chikabumi-yama
Chikabumi
Yunai
Daiba
Inō
Tokiwa-yama
Koppu-yama
Rakusui-zawa
Inō-Zawa
Osamunai
Kamuikotan
Kamuikotan-valley
Bansui-Zawa
Harushinai-Zawa
Ishikari River
Naidaibu River
Kamui-yama
Irumukeppu-yama
Oroen-zawa
0
5km

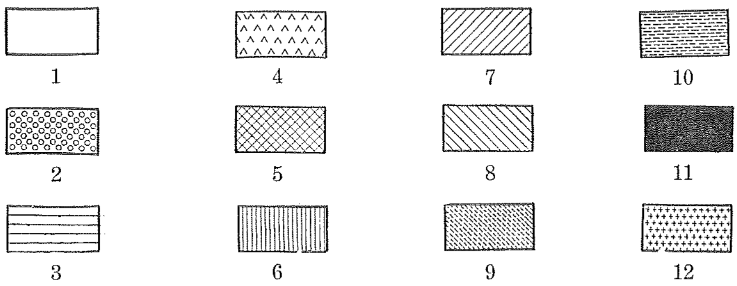


Fig. 2. Geological map of the vicinity of Kamuikotan Valley. (This map is compiled from the maps of SUZUKI (1953, 1955, 1957) and HUNAHASHI (1953)).

1. Alluvial deposits.
2. Terrace deposits
3. Neogene Tertiary formations.
4. Welded tuffs.
5. Volcanic rocks.
6. Cretaceous formations.

(7~12. Kamuikotan metamorphics and associated igneous rocks.)

7. Greenschists (include diabases).
8. Black siliceous schists.
9. Mylonite.
10. Red cherts and quartzites.
11. Serpentinites.
12. Trondhjemites.

sills, or small dikes and are distributed in the areas of both the Kamuikotan complex, and the Sorachi series. Though there can be considered that the comparatively large masses of older diabasic rocks had been intruded in the original formation of the Kamuikotan complex before or during the regional metamorphic action in large scale.

It is noticeable that the young diabasic rocks are often found as a lave with fine pillow structure in many places in the area of the Sorachi series (SUZUKI: 1954), but the similar rocks never found in the area of the Kamuikotan metamorphic complex. In general the pillow lavas are concordantly superposed on the thick schalstein layers and are covered by radiolarian cherts in the field indicating that they originated from some submarine eruption; it seems that the present situation of them may show a certain geological horizon layer in broad sense, in the Sorachi series. It is assumed there may be some diabasic rocks which were intruded in a different stage throughout the areas of the Kamuikotan complex and the Sorachi series. But there is at present no exact identity of them from the petrological and stratigraphical points of view.

In short, these injections of serpentinite and diabasic rock occurred in the final period of metamorphism and in some cases these rocks may have frequently been reduced to a partly crushed or partly recrystallized mosaic of minute granules.

Topographically the whole area of the Kamuikotan metamorphic complex with its adjacent ultra-basic masses is generally rugged and mountainous, the peaks of the major chains ranging 400 m to over 600 m in height, while the area of younger strata, Tertiary and Cretaceous, on both sides, is formed of low lands which may resist more feebly the agents of denudation, though the local features are dominated by the volcanic masses which rise above the Tertiary areas. (SUZUKI: 1953, 1955).

The Kamuikotan metamorphics exist usually in contact with the Mesozoic formation separated by faults, and there are no organic remains except the presence of incomplete radiolarian casts in some cherty rocks, as to the stratigraphical position and geological age of itself, nothing certain can be said. The Kamuikotan metamorphic complex occurs usually in close relation to the Sorachi series which is identified as Jurassic. The complex is also considered to have been periodically subjected from late Mesozoic time to orogenic movements from the east with accompanying igneous activity. The effects are noticeable along the mountain range where imbrication of strata, terrestrial displacement and deformation of rocks may be recognized.

It has been considered by the earlier writers that the Kamuikotan metamorphic complex is generally attributable to the Palaeozoic on account simply of the outward appearence of the rocks, and that these rocks were metamorphosed during the great orogeny of the Palaeozoic. On the above-mentioned grounds, some of the present geologists came to consider, however, that the complex may belong to the Mesozoic, perhaps Jurassic, and the data of metamorphism is much recent possibly even as remote as the post Jurassic. From the geological and petrographical points of view, it may reasonably be assumed that the Kamuikotan metamorphic complex, so far as the writers are aware, can be readily correlated with at least a part of the Franciscan Knoxville Formation in California.*

The crystalline schists and serpentinites of the Kamuikotan complex are occasionally found as pebbles or sand not only in the Quartanary fields but in the Neogene and Paleogene conglomerates indicating that the Tertiary layers were deposited at least after these crystalline schist and ultra-basic rocks had been originated. For example, the existence of

* TALIAFERRO, N. L. (1943): Franciscan Knoxville Problem. Am. Assoc. Petroleum Geologists Bull., Vol. 27, p. 109-219.

many pebbles of glaucophane schists and other crystalline schists in the middle course of the Obirashibe river, Teshio Province, has been well known from old times in places where these pebbles may be occasionally found with the placers of chromite and iridosmine. (HACHIYA: 1900, SUZUKI: 1942) As there is no exposure of either the Kamuikotan complex nor of serpentinite in the vicinity along the Obirashibe, the ultimate source of these materials probably lies among the conglomerates of Neogene Tertiary of the Uryu range toward the head waters of the river. For another example, there are much minute glaucophane sands and the pebbles of alkali-amphibole schists in the Alluvial and Diluvial deposits in the vicinity of the estuary of the Ishikari river which is 100 km or more distant from their points of origin at the Kamuikotan Valley or the Uryu district. It is clear that these materials were derived from the Kamuikotan complex and were carried down by the river and its tributaries. (NAKAO: 1925, SUZUKI, TAKAYANAGI: 1956).

As is above-mentioned, the Kamuikotan metamorphic complex occurs always in close association with the Sorachi series in the Kamuikotan zone. Accordingly, it may be necessary to present a short account of the Sorachi series for reference as follows before proceeding to the consideration of the Kamuikotan metamorphics themselves. Previously the so-called Kamuikotan formation was usually considered to be distributed in a wider area than that of the rock series recently defined as the Kamuikotan metamorphic complex. After detailed surveys by many geologists, stratigraphic subdivision of the formation has been considered advisable and the term "Sorachi series" has been adopted for a certain rock series in the formation.

The "Sorachi series" was names by Y. SASA and M. MINATO (1943) who have presented a summary description and defined this special rock series in the whole part of central Hokkaido, including the Onizashi formation described by Y. MORITA (1931), the Naegawa chert series by W. HASHIMOTO (1936) and the Schalstein formation by K. OTATSUME (1940). In short, the so-called Kamuikotan zone is divided stratigraphically and petrologically into two units, the Kamuikotan complex and the Sorachi series. In contrast with the latter, the rocks of the Kamuikotan complex are of interest in that they show the effects of somewhat more intense metamorphism than do the rocks of the Sorachi series.

In general, the Sorachi series is widely distributed alongside the eastern part of the areas of the Kamuikotan metamorphic complex though in some cases small patches of the complex are surrounded by the rocks of the Sorachi series. These two rock series are sharply delimited as a rule by faults; the direct geological relation between them is yet unknown. In contrast with the Sorachi series, the Kamuikotan complex is composed chiefly of schistose rocks; the Sorachi series is, however characterized by less or non-metamorphosed rocks and is composed chiefly of thick schalstein layers which are locally grouped together with thin layers of sandstone, conglomerate, slate, radiolarian chert and fossiliferous limestone. In some places the these rocks of the Sorachi series are penetrated by serpentinites and diabases.

As a rule, the schalsteins in the Sorachi series are dark greenish in color and consists mainly of minute irregular fragments of plagioclase, augite, hornblende, chlorite, devitrified glass. Sometimes it shows agglomeratic appearance because of the presence of small angular chips of diabasic rock, which form knots and lenticles varying 1-3 cm across. The typical schalstein is distinguished from diabase by its tuffaceous character being composed of pyroclastic fragments of the constituents, and from diabase schist in the Kamuikotan complex by its decidedly massive appearence without any trace of schistosity.

Remarkable things in the Sorachi series are that the radiolarian casts can be distinctly recognized in a fairly large number of the cherts, and the important fossil remains are often contained in some limestone. Excellent localities of such radiolarian cherts are known in the following districts: Onizashi, Teshio Province; Takasu and Naegawa, Ishikari Province; Iwachishi, Hidaka Province. Radiolarian casts known from the above cited localities are listed as follows:

Cenosphaera,	*Liosphaera,*	*Cenellipsis,*	*Theocampe,*
Caryosphaera,	*Ellipsidium,*	*Archicapsa,*	*Sethocapsa,*
Cryptocapsa,	*Porodiscus,*	*Dictyastrum,*	*Dicolocapsa,*
Dictyocephalus,	*Tricolocapsa,*	*Dictyomitra,*	*etc.*
Lithocampe,	*Stichocapsa,*	*Sphaerozoum,*	

Concerning the fossiliferous limestone in the Sorachi series, data regarding fossil species gathered from several localities in the central zone of Hokkaido, as follows:

HASHIMOTO, W. (1952): Tokiwa-mura, Teshio Prov. (The fossil remains were found by K. OZEKI in 1941.)

? *Milleporidium arinokiense* YABE et SUGIYAMA

HASHIMOTO, W. (1936): Ashibetsu-mura, Ishikari Prov.

Nipponophycus ramosus YABE et TOYAMA

Pynoporidium lobatum YABE et TOYAMA

YABE H. and SUGIYAMA, T. (1939, 1941) : Simekappu-mura, Iburi Prov. and Piratori-mura, Hidaka Prov.
Pycnoporidium lobatum YABE et TOYAMA
Heptastylopsis astatica YABE et SUGIYAMA
Microsolena (?) sp.
etc.

YABE, H. and SUGIYAMA, T. (1941) : Iwachishi, Hidaka Prov.
Circoporella semiclathrata HAYASAKA
Chaetetoid coral gen. et sp. indet.
etc.

These fossil evidences indicate that the greater portion of the Sorachi series may be assigned to the Upper Jurassic. (OTATSUME: 1940; YABE and SUGIYAMA: 1941; HUKADA: 1949; HASHIMOTO: 1952).

From the foregoing description, it can be readily realized that the Kamuikotan complex and the adjacent Sorachi series have something in common. Both show close occurrence in the field, forming the main units of the Kamuikotan zone, though they are bounded by faults. They are chiefly composed of similar set of rock members with each other, and are also invaded by similar intrusives, serpentinite and diabase.

Summarizing these facts and their mutual connection, there remain still some questions to resolved: whether the Kamuikotan complex is equivalent in age to the Sorachi series, or not; if it is suitable to treat them as all of a sort, the next question arises—why the Kamuikotan complex alone was regionally metamorphosed, while the Sorachi series merely remains as it is, having been ejected from a metamorphism excluding local metamorphism in some certain places, by serpentinite intrusives.

III. IGNEOUS ROCKS RELATED TO THE KAMUIKOTAN ZONE

The igneous rocks intruded in the Kamuikotan zone are roughly classified into three main types: ultra-basic rocks, hypabyssal rocks associated with ultra-basic rocks and diabasic rocks.

A. SERPENTINITES AND PERIDOTITES

Among these igneous rocks the most important member is the ultra-basic rocks, which are mostly represented by serpentinite. The ultra-basic rocks have only a limited development and occur usually in or along the area of the complex in the form of relatively large elongated masses or lenses or belts extending from north to the south in linear

Fig. 3.* Brucite serpentinite. Yamabe district. Minute flakes of brucite outline aggregations of serpentine. Diameter 1.5 mm and open nicol in all microscopic sketch figures (Figs. 3~38). in this report.

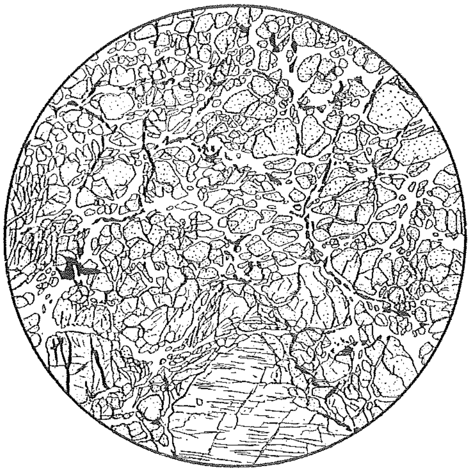


Fig. 4. Serpentinite. Yamabe district. Minute antigorite and chrysotile flakes enclose fresh grains of olivine and clino-pyroxene showing mesh structure. Granules of fine iron ore show the boundaries of the original crystals.

direction indicating that they are restricted mainly to the tectonic lines in or along the metamorphic zones of the complex.

The large ultra-basic bodies run approximately north to south in special sections between the Teshio-Kitami boundaries at the north, and Hidaka Province at the south. As a rule these bodies are sharply bounded not only by contorted crystalline schists of the Kamuikotan complex but by sedimentaries of Mesozoic and Caenozoic age though locally faults are recognizable along the boundaries between the ultra-basic rocks and others. The large bodies in the complex zone occur especially in three separate localities, viz., the Teshio-Kitami mountain range, Uryu mountain-land and Yubari-Yuhutsu-Saru district, in order from north to south. In some places, these large bodies may be connected with each other by long narrow belts of the same rock.

The most northerly body is a roughly wide belt-form mass, covering an area of about 45 km length by 7 km maximum width; it strikes nearly north and south. The outcrop in the Uryu mountain-land occurs some 40 km to the south of the above and shows an irregular form approximately 43 km in length and 10 km in width at the most southerly part,

* All microdrawings (Figs. 3~38) were made by junior author (Yoshio SUZUKI).

rising with steep sides to a height of 700 m or more above the surrounding young sediments. Finally, some 90 km, farther south three large bodies of serpentinite occur in the Yubari-Yuhutsu-Saru district. They take the form of irregular shaped masses covering an area of about 25×4 km, 18×4 km and 15×6 km respectively. Besides these main large bodies, numerous small outcrops of serpentinite are found as lenses or masses in the Kamuikotan metamorphic zone; they posses an elongated habit with their longer axes usually arranged roughly parallel to the foliation of the surrounding schists.

In general these small lenses and masses may be distinctly limited by sharp boundaries with the adjacent rocks as is the case of large bodies. The total area where serpentinite is exposed in the Kamuikotan complex may far exceed in size any other area in Japan where such phenomena are observed.

As was already mentioned, small masses of serpentinite occur in the areas of the Sorachi series intruding especially in the schalstein layers. They stand nearly in a row, separated from the main zone of the serpentinites in or along the Kamuikotan metamorphic complex. Their petrological characters are quite similar to those of the latter; the serpentinites in both zones are considered to have originated in a similar way.

The areas of serpentinite are generally covered by so thick clayey soil or occasionally fanglomerate materials, that excellent outcrops of the fresh rocks are usually rarely observable except at river cliffs, open cuts of asbestos mines and adits for chromite deposits. Alteration of the serpentinite to actinolite fels is occasionally recognizable, for example at the Horokanai pass and the Mitsuishi district. Most of the ultra-basic rocks related to the Kamuikotan metamorphic complex are now represented by serpentinite, though rarely peridotite exists in very small quantity.

The serpentinite is commonly massive and compact, partly with many irregular or regular joints and fissures. It is believed that these joints and fissures may be undoubtedly a very important factor controlling the location of some ore deposits, for instance, that of chromite or chrysotile, and that they provided the route for various kinds of ascending mineralizing solutions. (SAITO and BANBA: 1955) Small lenses or narrow belts of serpentinite have frequently a rude or fine foliation which coincides usually with that of the contiguous crystalline schist. The fissures and foliation planes of the serpentinites are often filled up by veinlets of any of such various minerals as aragonite, zeolites, pectolite, amphibole asbestos, chrysotile, picrolite, clayey materials, aquacreptite and so.

The typical serpentinite is normally composed of flakes of antigorite and very minute grains of accessory minerals of the spinel group. Sometimes it contains much flakes of brucite. (SUZUKI, Y.: 1958) Under the microscope, flakes and fibres of a serpentinious material are composed of aggregates which appear to be pseudomorphous after olivine, rarely after pyroxene. They are arranged in bundles or sheaves and are occasionally matted together. It is not seldom, that the serpentinite

TABLE I. Serpentinites.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
SiO_2	39.87	39.39	39.37	38.45	37.29	33.64	53.09
TiO_2	—	—	—	—	—	0.01	1.30
Al_2O_3	1.00	1.45	0.99	3.24	8.38	0.60	0.89
Fe_2O_3	5.24	2.94	5.17	3.26	7.23	3.91	5.42
FeO	3.82	5.60	3.77	5.16	2.23	2.19	4.46
MnO	—	—	—	—	—	0.09	0.28
MgO	36.06	37.84	35.61	36.32	28.20	42.43	20.98
CaO	0.28	0.52	0.28	0.87	0.43	0.01	10.49
Na_2O	—	—	—	0.25	—	0.01	0.53
K_2O	—	—	—	—	—	0.01	0.06
P_2O_5	—	—	—	—	—	0.01	—
$H_2O(+)$	13.73	—	13.56	—	12.37	16.08	—
$H_2O(-)$	—	—	1.19	—	3.32	0.56	—
CO_2	—	—	—	—	—	—	—
Cr_2O_3	—	—	—	—	—	0.52	—
Ign. loss	—	12.79	—	12.53	—	—	3.04
Total	100.00	100.53	99.94	100.08	99.45	100.07	100.54

(1) Serpentinite. Country rock of chrysotile veins at the Nozawa Mine, Yamabe District, Ishikari Prov. Anal. T. Inoue. (Suzuki and Inoue: 1948, p. 195)

(2) Serpentinite. Kishinosawa, Yamabe District, Ishikari Prov. Anal. H. Konishi. (Suzuki: 1941, p. 268)

(3) Serpentinite. Sakaesawa, Yamabe District, Ishikari Prov. Anal. T. Inoue. (Suzuki: 1952, p. 184)

(4) Serpentinite. Takadomari, Uryu-Gun, Ishikari Prov. Anal. A. Kannari. (Suzuki: 1939, p. 30)

(5) Serpentinite. Near Kanayama, Sorachi-Gun, Ishikari Prov. Anal. M. Sanbonsugi. (SUZUKI: 1952, p. 184)

(6) Serpentinite. Uennai-Yudachizawa, Uryu-Gun, Ishikari Prov. Anal. T. Yamada and E. Omori. (Igi et al.: 1958, p. 39)

(7) Actinolite-fels. Horokanai-Pass, Uryu-Gun, Ishikari Prov. Anal. A. Kannari. (Suzuki: 1939, p. 30)

is associated with a considerable amount of talc and bastite, which were secondarily originated from antigorite. Relict mineral is scant or almost absent. Massive serpentinite may show partial stiatitization and may be occasionally veined with chrysotile and picrolite. In some places, however the rock may contain more or less residual remains of unaltered constituents such as olivines and pyroxenes, and sometimes shows mesh structure to a certain extent, indicating that the original intrusives were peridotitic rock in nature. An individual flake or fibre has usually a very pale green color, straight extinction and low birefringence. The chemical composition of serpentinites in the Kamuikotan zone are shown in Table I.

Fresh peridotitic rock is sometimes found in the areas of the Kamuikotan metamorphic complex in small quantity. It is distributed in small areas in the serpentinite mass and occasionally occurs as small separately rounded masses enclosed in serpentinite. An example of the former is found in the vicinity of Iwanai-dake (960 m) on the east side of the Saru river in Hidaka Province, where it forms rounded area, 2 km in maximum diameter with its marginal facies gradually transitional to serpentinite.

The rock in the central part of the area consists chiefly of fresh olivine accompanied with augite as a subordinate component, and is characterised in places by its content of somewhat considerable amount of disseminated chromite-spinel grains. Examples of the rounded masses of fresh peridotite are in large number in the serpentinite mass in the open cuts of the asbestos mine at Yamabe, Ishikari Province. The rounded masses there are 0.1~1.0 m in diameter, and are sharply bounded by the surrounding serpentinite.

Most of the peridotitic rocks are composed principally of fresh olivine, showing the typical character of dunite. Olivine crystals are circular or oval in shape 0.1~0.5 mm in diameter, the margins and internal structure of which are usually replaced by antigorite giving rise to a type of mesh structure. Sometimes the olivine grains are partially or completely replaced by pseudomorphs of talc associated with minute magnetite granules.

The chemical composition of peridotitic rocks in the Kamuikotan zone are as follows. (Table II)

It is a remarkable thing that the serpentinite masses in the Kamuikotan zone are of special importance because of the associated deposits of various kinds of useful minerals, such as chromite, chrysotile asbestos, mercury, nickel, copper, platinum group minerals, etc. Some of them

TABLE II. Peridotites.

	(8)	(9)	(10)	(11)
SiO_2	43.12	42.16	39.82	39.82
TiO_2	—	—	0.86	—
Al_2O_3	4.06	3.58	2.36	2.50
Fe_2O_3	9.35	9.48	5.34	8.52
FeO	—	—	7.52	—
MnO	—	—	0.22	—
MgO	40.01	40.25	28.32	46.65
CaO	0.96	0.50	4.66	0.20
Na_2O	—	—	0.02	—
K_2O	—	—	0.01	—
P_2O_5	—	—	0.01	—
$H_2O(+)$	0.96	0.36	9.98	0.62
$H_2O(-)$	0.41	1.95	0.48	0.45
CO_2	—	—	—	—
Cr_2O_3	0.82	0.72	0.35	0.78
NiO	0.30	0.38	—	0.35
Total	99.99	99.38	99.95	99.89

(8) Pyroxene dunite (C). Iwanaidake, Saru-Gun, Hidaka Prov. Anal. S. Morita. (Suzuki: 1952, p. 183)

(9) Pyroxene dunite (B). Iwanaidake, Saru-Gun, Hidaka Prov. Anal. S. Morita. (Suzuki: 1952, p. 183)

(10) Pyroxene dunite. Inuushibetsu, 12-Sen, Uryu-Gun, Ishikari Prov. Anal. T. Yamada and E. Omori. (Igi et al.: 1958, p. 40)

(11) Pyroxene dunite (A). Iwanaidake, Saru-Gun, Hidaka Prov. Anal. S. Morita. (Suzuki: 1952, p. 183)

have been mined. As detailed description on these ore deposits has already been summerized by one of the presnt writers (SUZUKI: 1952) any further note on the subject is beyond the scope of this paper.

B. HYPABYSSAL ROCKS ASSOCIATED WITH SERPENTINITES

As was already mentioned, the serpentinite masses in the Kamuikotan metamorphic complex are in places traversed by numerous hypabyssal rocks having leucocratic and melanocratic natures which may represent later intrusions. In rare cases there can also be observed small dikes of the rocks in the areas of crystalline schists and Cretaceous formations being adjacent to serpentinite mass. These dike rocks appear mostly to be the end phase derivatives of the ultra-basic rocks and are believed to be genetically related to each other indicating that they might have been differentiated from the same magma and may belong to a single intrusive series. That is to say the most important period of the intrusions of these differentiated dike rocks was associated with the serpentinite intrusion of post-Cretaceous times.

The leucocratic rocks are classified into various groups such as: albitites, trondhjemites, microdiorite, aplites, pegmatites, labradoritites, and rodingites. On the other hand, the representatives of the melanocratic types are hornblendites, pyroxenites and diabasic rocks, though they have rarely been known in number and variety comparing with those of leucocratic types.

Of these dike rocks, albititic and aplitic types may be mostly seen in the serpentinite masses in Hidaka and Iburi Provinces, while microdioritic and trondhjemitic types mainly in those of Ishikari Province. From Teshio Province, the leucocratics have been rarely reported except small dikes of microdiorites which are traceable for only a short distance. Most of these leucocratic dikes are generally compact, projecting into the fields on account of their greater resistance to erosion, compared with the surrounding soft and loose serpentinite masses which have superficially been caused by weathering in usual. (SUZUKI: 1940, 1953c)

(a) *Albitites*

Such rock is represented by three types: albitite proper, quartz albitite and hornblende albitite, in which albite is the dominant constituent though the latter two types are respectively accompanied by plentiful quartz or hornblende.

In general the albitites proper are a very compact rock showing entirely white appearence to the naked eye. Under the microscope, they are seen to be mostly composed of equigranular or irregular grained albite, 0.5~1.0 mm across though the essential feature of some kinds may take the form of a mosaic of small grains, 0.01~0.05 mm among which somewhat larger and well shaped crystals of albite 1.0~2.0 mm occasionally tend to porphyritic development.

As to the albite, the composition approximates $Ab_{93}An_{7}$, and usually it is devoid of inclusions. Albite twin is common but the zonal structure is almost absent. The mafic minerals which are now mostly represented by chlorite, may form 5~10% of the whole constituents, but in some albitites these minerals are almost totally absent.

The quartz albitites show a similar appearance to the proper albitites but are characterized by containing a moderate amount of quartz. Some of the rocks exhibit well developed graphic texture between albite and quartz and may be rather called by the name quartz-albitophyre.

The hornblende albitites are a relatively coarse-grained rock of rather striking appearance, in which green crystals of hornblende are set in a white matrix of albite crystals. In some cases the hornblende prisms are replaced by glaucophane along their margins and cleavages.

In short, the above mentioned leucocratic rocks can be identified to the albitites which were defined by H. W. TURNER (1896) for the rocks in the serpentinite from California.

The chemical composition of albitites are cited in Table III.

TABLE III. Albitites.

	(12)	(13)	(14)	(15)	(16)
SiO_2	72.92	70.24	67.17	60.21	57.56
TiO_2	0.16	0.07	0.30	0.52	0.10
Al_2O_3	16.69	16.86	18.22	16.70	24.96
Fe_2O_3	0.25	0.14	0.46	0.28	0.24
FeO	0.50	0.86	0.65	1.40	0.36
MnO	tr	tr	0.06	0.22	—
MgO	0.43	0.73	1.08	5.27	0.72
CaO	0.42	0.92	0.92	7.23	1.82
Na_2O	7.43	6.85	9.46	6.76	3.61
K_2O	0.29	1.94	0.33	0.36	0.11
P_2O_5	—	—	—	tr	—
$H_2O(+)$	0.48	0.86	0.92	1.31	9.62
$H_2O(-)$	0.20	0.48	0.31	0.19	0.84
CO_2	—	—	—	—	0.08
Total	99.77	99.95	99.88	100.45	100.02

(12) Quartz albitite. Bankei-adit, Nukahira Mine, Saru-Gun, Hidaka Prov. Anal. S. Komatsu. (SUZUKI: 1940, p. 74)

(13) Quartz albitite. Hatta Mine, Saru-Gun, Hidaka Prov. Anal. S. Komatsu. (Suzuki: 1940, p. 74)

(14) Albitite. Shinnitto Mine, Saru-Gun, Hidaka Prov. Anal. S. Komatsu. (Suzuki: 1940, p. 72)

(15) Prehnite-bearing hornblende albitite. Tributary of the Ugonai River, Nakagawa-Gun, Teshio Prov. Anal. S. Komatsu. (Suzuki: 1940, p. 79)

(16) Albitite (decomposed). Shinitto Mine, Saru-Gun, Hidaka Prov. Anal. S. Komatsu. (Suzuki: 1940, p. 72)

(b) *Trondhjemites and Micro-diorite*

The trondhjemites are composed essentially of plagioclase and quartz accompanied by a small amount of chlorite which was altered from biotite. In this case, plagioclase amounts to about 45% and quartz 35%

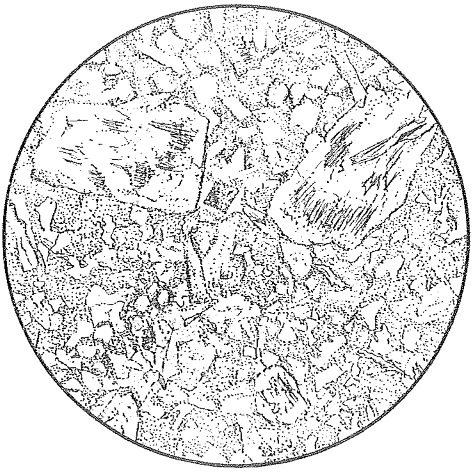


Fig. 5. Trondhjemite. Yamabe district. Idiomorphic of subidiomorphic plagioclase having oligoclase or andesine composition, shows sometimes porphyritic structure, and grows with quartz in the matrix.

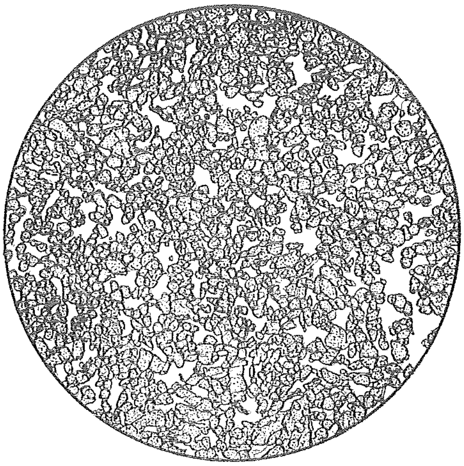


Fig. 6. Rodingite. Yamabe district. The rock is formed of mainly fine granules of almost pure andradite, and interstitial material may be carbonate mineral.

TABLE IV. Trondhjemites.

	(17)	(18)
SiO_2	70.45	68.54
TiO_2	0.10	—
Al_2O_3	16.43	17.09
Fe_2O_3	0.37	2.74
FeO	0.71	0.45
MnO	0.03	—
MgO	1.53	1.39
CaO	3.11	2.16
Na_2O	4.43	2.00
K_2O	1.07	1.84
P_2O_5	0.58	—
$H_2O(+)$	1.54	—
$H_2O(-)$	—	—
CO_2	—	—
Ign. loss	—	3.14
Total	100.35	99.35

(17) Trondhjemite. Horonari, Uryu-Gun, Ishikari Prov. Anal. T. Nemoto. (Suzuki: 1935, p. 160)

(18) Trondhjemite, Kishinosawa, Yamabe District Ishikari Prov. Anal. H. Konishi. (Suzuki: 1940, p. 126)

usually. The rocks are equigranular in texture but sometimes show porphyritic with holocrystalline groundmass. Idiomorphic or subidiomorphic stout crystals, 1~3 mm, of felspar are almost the oligoclase-andesine of $Ab_{70}An_{30}$. The grains of quartz are irregular, frequently sutured and vary from 0.2~1.0 mm in diameter. The rocks have quite similar characters to the original trondhjemite from Norway, originally named and reported by V. M. GOLDSCHMIDT. Two chemical analyses of trondhjemites are shown in Table IV.

(c) *Aplites and Pegmatites*

The aplitic rocks grouped under this heading are: albite aplite, diorite aplite, diorite-gabbro aplite and gabbro aplite. In general these rocks are fine- and even-grained and very compact, showing white to pale-grey color though in some rocks there are a number of scattered grains of mafic minerals.

The albite aplite is a white and compact rock composed almost entirely of a mosaic of fine grains 0.05~0.1 mm of albite, quartz and an accessory amount of potash-felspar. The rock is characterised by the lack of mafic mineral except for the existence of a negligible quantity of chlorite or colorless amphibole.

The diorite aplites are fine-grained grey to whitish grey rocks which consist chiefly of plagioclase of $Ab_{70}An_{30}$ and a small amount of hornblende, being sparsely dotted with fine grains of biotite. Chlorite may be plentiful in places and sphere and magnetite are characteristic accessory constituents. A minute amount of pyroxene and quartz may be present or almost absent.

Diorite-gabbro aplites take the form of even-grained compact rock in which felspar is more basic, $Ab_{55}An_{45}$, and mafic minerals distinctly more abundant than in the diorite aplite, just described. The mineral composition of the rocks is plagioclase, hornblende and augite; chlorite and brownish hornblende tend to be associated with one another often accompanied by small grains of sphene.

The gabbro aplites are somewhat similar to the diorite-gabbro aplites from which they differ mainly in the more calcic composition of plagioclase, $Ab_{25}An_{75}$ and in the presence of comparatively abundant pyroxene. The rocks lack almost the development of hornblende which is so characteristic of the diorite-gabbro aplites. The chemical composition of the aplitic rocks is as follows: (Table V).

A pegmatitic rock which is made up of comparatively large crystals

TABLE V. Aplites.

	(19)	(20)
SiO_2	53.48	51.11
TiO_2	0.05	0.25
Al_2O_3	17.83	14.14
Fe_2O_3	0.15	0.38
FeO	1.02	8.91
MnO	0.05	0.28
MgO	3.87	7.78
CaO	17.72	12.49
Na_2O	2.12	1.74
K_2O	0.10	0.24
P_2O_5	tr	tr
$H_2O(+)$	2.69	—
$H_2O(-)$	0.48	—
CO_2	0.25	—
Ign. loss	—	2.59
Total	99.81	99.91

(19) Diorite-aplite. Eastern Hill, Toikanbetsu, Nakagawa-Gun, Teshio Prov. Anal. S. Komatsu. (SUZUKI: 1940, p. 129)
(20) Diorite-gabbro-aplite. Takadomari-Penke, Uryu-Gun, Ishikari Prov. Anal. A. Kannari. (Suzuki: 1940, p. 130)

of quartz and orthoclase showing typical graphical texture, is known in the small serpentinite mass near Mitsuishi, Hidaka Province.

The laboradorite felses which consist almost entirely of plagioclase An_{65-76} and lack the development of mafic mineral, are found as small vein-like formation in association with the gabbro aplites in the valley near Usappu, Hidaka Province.

(d) *Rodingitic Rocks*

In addition to these various above-mentioned leucocrates, there can be found, in places, many blocks or dikes of some peculiar rocks in the serpentinite masses. On account of their petrological nature and mode of occurrence, these rocks suit the definitions of so-called rodingite, given by P. MARSHALL (1911) for the original rocks from the Roding River in the district of the Dun Mountains in New Zealand. On the character and genesis of the rocks one of the writers has presented a detailed description on a former occasion (SUZUKI: 1954) ; a short summary will be given in this paper.

The rodingites occur as irregularly rounded masses, 0.3~10 mm in maximum diameters, or as very narrow dikes, always in company with serpentinite masses. These small rock bodies are sparsely but very widely distributed only through the areas of serpentinite. The boundaries of these rock bodies are generally in sharp contact with surrounding serpentinites, though rarely the rocks merge gradually outward into the latter.

The rodingites are fine to medium grained compact rock, being milky white to greyish white in color. There is marked difference in mineral and chemical compositions between them and the above-described leucocratic rocks. Under the microscope, the rodingites are chiefly composed, as a rule, of grossularite or andradite, diopside and also a small amount of scattered minute grains of magnetite, and flakes of chlorite. In some places they may contain clinozoisite or vesuvianite as an essential constituent. For example, the approximate volumetric per cent of the constituents in the section in the central and marginal parts of the rodingite from Kanayama, Ishikari Province, is as follows: grossularite 70~75%, diopside 12~23%, vesuvianite 0.5~1%, chlorite and calcite 0.5±. The chemical composition of the central part and marginal zone of the typical rodingite dike at Kanayama, Ishikari Province is shown in Table VI.

TABLE VI. Rodingite.

	(21)	(22)
SiO_2	40.58	38.43
TiO_2	tr	tr
Al_2O_3	15.03	22.06
Fe_2O_3	3.56	1.70
FeO	3.90	1.95
MnO	—	—
MgO	4.45	2.41
CaO	26.62	28.56
Na_2O	1.51	1.35
K_2O	0.26	0.34
P_2O_5	—	—
$H_2O(+)$	3.56	2.50
$H_2O(-)$	0.50	0.10
Total	99.97	99.40

(21) Rodingite (Outer zone). Kanayama, Sorachi-Gun, Ishikari Prov. Anal. M. Sanbonsugi. (Suzuki: 1940, p. 134)

(22) Rodingite (Inner part). Kanayama, Sorachi-Gun, Ishikari Prov. Anal. M. Sanbonsugi. (Suzuki: 1940, p. 134)

So far as the writers are aware the rodingitic rocks in Hokkaido originated from metasomatic action especially on the pre-existing dioritic or gabbroic leucocrates by later lime-rich solutions liberated in the process of serpentinization of the surrounding ultra-basic igneous rocks. (SUZUKI, 1954, p. 424).

(e) *Melanocrates*

Melanocratic dikes which are considered to be related to the serpentinite in Hokkaido are very far smaller in number and in quantity than leucocrates. The representatives of these melanocrates are hornblendites and pyroxenites.

The hornblendites are found as narrow veins or dikes in the serpentinite masses and are occasionally associated with other leucocratic dikes. The hornblendite from both Usappu and Mitsuishi, Hidaka Province are composed principally of green hornblende and a small amount of plagioclase and rutile.

The pyroxenite has been known only as a narrow dike in the serpentinite lens on the eastern bank of the Ino river near the Kamuikotan valley. Under the microscope, it is found to consist essentially of fine grains of titaniferous augite with pale pinkish brown color.

In conclusion some account concerning the relation between the above mentioned dike rocks and the ore deposits originated in the sepentinite will be given. The writer has been led by field data to the view that the origin of some leucocrates may be closely related to the genesis of some ore deposits occurring in serpentinites such as those of chromite, mercury or asbestos. That is to say, it seems reasonable to consider that these dike rocks may have been precursors in the mineralization of these kinds of ore, though they are not always so.

For example, at the Shinnitto and Nukahira mines, Hidaka Province, massive chromite ore bodies cut respectively not only the serpentinites but the associated albititic rocks and partially enclose small fragments of albitite and serpentinite in their ore bodies themselves. The manner of the occurrences indicates that the origination of massive chromite deposits was later than the intrusion of the leucocratic dike rocks and may be not the so-called orthomagmatic deposit at least at those places. (SUZUKI: 1943).

In the two areas of the Onnenai deposit, Teshio Province and the Suigin-yama deposit, Ishikari Province, some differentiated leucocratics with micro-dioritic characters occur in association with serpentinite masses; there an immediate contact of dikes and mercury deposits has often been found.

This fact suggests that these dikes may be specially connected with the occurrence of the deposits. For another example: in the serpentinite area containing chrysotile veins at the Nozawa asbestos mine in the Yamabe district, Ishikari Province, there is often noted a tendency for trondhjemite dikes to intrude. From the field evidence, the occurrence of chrysotile veins seems to be genetically connected with the trondhjemitic dikes and would represent the latest phase of igneous activity in the area.

C. DIABASIC ROCKS

The diabasic rocks in the Kamuikotan zone are found as thin sheets, small dikes and occasionally lavas with pillow structure. They are compact rock with dark greenish color and the chiefly composed of plagioclase

TABLE VII. Diabases.

	(23)	(24)	(25)	(26)
SiO_2	49.12	54.38	48.79	41.10
TiO_2	1.00	2.88	0.58	0.68
Al_2O_3	16.44	8.90	9.25	10.58
Fe_2O_3	6.80	2.17	7.44	3.24
FeO	6.01	5.98	6.26	7.23
MnO	0.28	0.17	0.19	0.17
MgO	5.75	7.25	2.87	21.40
CaO	9.00	10.36	9.76	5.60
Na_2O	3.12	4.65	7.34	0.28
K_2O	0.47	0.67	0.50	0.24
P_2O_5	tr	0.25	0.41	0.04
$H_2O(+)$	—	1.98	5.72	8.55
$H_2O(-)$	—	0.74	1.24	0.54
CO_2	—	—	—	—
Ign. loss	2.66	—	—	—
Cr_2O_3	—	—	—	0.29
Total	100.65	100.38	100.35	99.94

(23) Diabase. Kamuimura, Kamikawa-Gun, Ishikari Prov. Anal. A. Kannari. (Suzuki: 1939, p. 30)

(24) Aegirine-augite-bearing diabase. Hakkinzawa, Yubari District, Ishikari Prov. Anal. S. Komatsu. (Suzuki: 1939, p. 30)

(25) Aegirine-augite-bearing diabase, Hakkinzawa, Yubari District Ishikari Prov. Anal. S. Komatsu. (Suzuki: 1939, p. 30)

(26) Diabase (Block in aggromerate). Inuushibetsuzawa, 5-Sen, Uryu-Gun, Ishikari Prov. Anal. T. Yamada and E. Omori. (IGI et al.: 1958, p. 13)

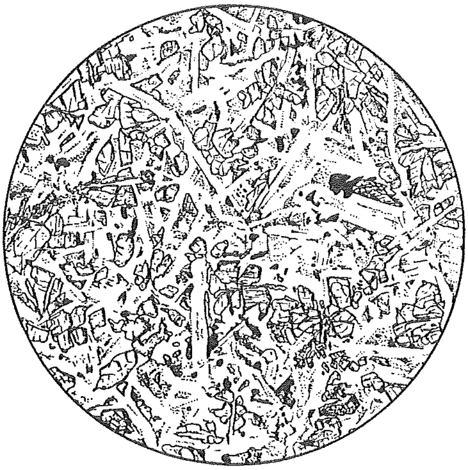


Fig. 7. Diabasic pillow lava. Kanayama near Sorachi River, Ishikari Prov. The rock from the central part of a pillow, is composed of basic plagioclase and clino-pyroxene. It shows ophitic and holocrystalline structure.

Fig. 8. Diabasic pillow lava. Locality ditto. The rock from the marginal part of the same pillow body showing in Fig. 7, is porphyritic and more or less glassy.

and augite or rarely titaniferous augite. Ophitic texture is common and amygdules are often present and sometimes partial alteration due to albitization or splitization may be observable in the rock.

In general the diabasic rocks intruded in the area of the Sorachi series appear to be identical with the rock natures and modes of occurrence of the diabase in the areas of the Kamuikotan metamorphic complex, excluding the lack of pillow lava in the latter. Although the serpentinites are important by virtue of their content of various mineral resources as above mentioned, the diabasic rocks are not important from the economic view point excepting that they may be related to the origination of some very small scale mercury deposits in the Hidaka Province.

The chemical composition of diabases in the Kamuikotan zone is given in Table VII.

The diabasic pillow lavas found only in the Sorachi series, are made up of numerous separated rounded bodies of compact diabasic rock being filled with fine rude fragments. The bodies take their forms of pillow, ellipsoidal, prolate, spheroidal, etc. varying in diameter from 0.3 m to 1.0 m. They have a fine grained and show commonly ophitic texture and the marginal zone of the mass is more or less glassy. The rounded masses are frequently cut by radial joints.

The chemical composition of the diabasic pillow lavas in the zone is as follows. (Table VIII)

TABLE VIII. Diabases (Pillow lavas).

	(27)	(28)	(29)	(30)	(31)	(32)
SiO_2	51.46	50.21	48.95	47.83	47.06	46.30
TiO_2	1.54	1.97	1.57	1.16	1.11	1.75
Al_2O_3	14.80	15.02	13.93	12.97	14.78	14.72
Fe_2O_3	4.73	6.51	5.46	4.36	4.29	6.24
FeO	7.11	4.82	6.04	7.75	5.44	6.72
MnO	0.23	0.31	0.20	—	0.24	0.21
MgO	4.95	4.15	6.54	8.66	7.34	6.61
CaO	7.54	9.27	11.04	11.10	10.48	8.73
Na_2O	4.06	3.95	3.80	2.74	4.17	2.47
K_2O	0.58	0.70	0.34	0.45	0.31	1.68
P_2O_5	0.19	0.28	0.26	—	0.09	0.11
$H_2O(+)$	1.87	1.64	1.01	2.07	3.69	3.84
$H_2O(-)$	0.75	0.46	0.25	0.69	0.45	0.58
CO_2	0.55	1.26	0.94	—	—	0.03
Cr_2O_3	—	—	—	—	0.05	0.02
Total	100.36	100.55	100.33	99.78	99.80	100.01

(27) Diabase (Pillow lava). N. Kanayama, Sorachi-Gun, Ishikari Prov. Anal. Y. Katsui. (Suzuki: 1954, p. 16)

(28) Diabase (pillow lava). Kokuriki Mine, Hiyoshi, Tokoro-Gun, Kitami Prov. Anal. Y. Katsui. (Suzuki: 1954, p. 16)

(29) Diabase (Pillow lava). East side, Ashibetsuzan, Sorachi-Gun, Ishikari Prov. Anal. Y. Katsui. (Suzuki: 1954, p. 16)

(30) Diabase (Pillow lava). Bank of the Tomamu River, Shimekappu, Yuhutsu-Gun Iburi Prov. Anal. Y. Katsui. (Suzuki: 1954, p. 16)

(31) Diabase (Pillow lava). Inuushibetsu 5-Sen, Uryu-Gun, Ishikari Prov. Anal. T. Yamada and E. Omori. (Igi et al.: 1958, p. 13)

(32) Diabase (Pillow lava). Kokuriki Mine, Hiyoshi, Tokoro-Gun, Kitami Prov. Anal. K. Maeda. (A. Takabatake: C. R. XX Congr. Geol. Intern. (Mexico) 1956, p. 212)

IV. THE MINERALOGY OF THE KAMUIKOTAN METAMORPHICS

As is given in Table XIV, there are great varieties of crystalline schists in the Kamuikotan metamorphic complex and they show a complicated paragenesis of various kinds of rock-forming minerals both essential and accessory constituents. Most of the minerals are a recrystallized product, though some of them may be occasionally contained as a relic of the original mineral in the parent rocks, or as a secondary altered product.

It is noteworthy that there exist some peculiar minerals in the special facies of the crystalline schists; such minerals were probably originated from pyrometasomatism due to the action of some hydrothermal solution which emanated from the adjacent igneous bodies. In addition to the above, some minerals take the characteristic form of veins or lenticles in the metamorphic rocks.

Before treating the petrographical characters of the rocks of the Kamuikotan metamorphic complex, a summarizing note on every rock-forming mineral in the rocks may be necessary in order to avoid repeated description hereafter. A very detailed investigation would be necessary to determine exactly the nature of some minerals, but recorded here is only an outline of their nature for petrographical description.

1. Quartz

Quartz is a most important constituent of all the varieties of siliceous schists. It is especially the chief and often nearly the only, member of some quartzite or quartz schist. It occurs usually as irregular minute grains with rounded or rugged outlines, which are coarse to fine or rarely tending toward cryptocrystalline. In a highly schistose siliceous schist, the quartz grains are frequently elongated parallel to one another. In this case the ratio of the greatest to the least diameter of each grain may be 2:1 to 3:1. These grains show microgranoblastic aggregation, commonly associated with various amounts of felspars and the other minerals. In the mosaic coarse grained aggregate, the greatest diameters of these grains may be arranged in certain direction, while it does not always seem that they show a quite uniform crystallographic arrangement. For instance, in a glaucophane quartz schist, the quartz grains may have their longer diameters generally parallel to those of the glaucophane.

Most of the quartz grains in the crystalline schists are usually very fresh and clear, though in places they show more or less undulatory extinction which may be due to the action of a distortion. Sometimes such a grain may contain numerous extremely small particles of any or some of garnet, amphiboles, epidote, rutile, etc. These inclusions show often no sign of regular arrangement, but commonly they are disposed in parallel strings and are, in some cases, arranged poikiloblastically across the border of the quartz and adjacent albite individual grains.

There are small grains of quartz mingled with minute crystals of calcite in some parts of the calcareous schist near Kamuikotan station, where the quartz grains may comprise at least 20 per cent of the whole composition. These grains occur usually in rounded form; they are very fresh and almost free from inclusions.

Small patches of quartz grains are found sparingly among the crystals of the ferromagnesian minerals in some kinds of greenschist, though the amount of the quartz is very small or negligible. These quartz grains are considered to be a by-product formed when the original materials were metamorphosed to recrystallized minerals.

Finally quartz is a very common mineral, forming much of the veins which penetrate the various kinds of Kamuikotan metamorphics. In the veins quartz is often associated with albite, calcite or zoisite.

2. Felspars

Felspars occur in the Kamuikotan metamorphics as comparatively small crystals very widely distributed, though they are not always an essential ingredient. Frequently they occur so subordinately as to be merely accessories or, in some of the rocks they are almost absent. From their occurrences and mineral properties, the felspars in the Kamuikotan metamorphics may be roughly divided into two: albite and basic plagioclase.

2 a. Albite

Albite is found in the siliceous and basic schists, as well as commonly in some crystalline schists produced by contact metamorphism. In the siliceous schists, albite occurs as rounded or more or less elongated crystals with irregular outlines, mingled with an aggregation of quartz grains; on the other hand in the basic schists it fills the interspaces in the aggregation of the mafic components. In the former case, it is distinguished from quartz by its optical biaxiality and lower refringence.

In some rocks the albite tends to form small porphyroblasts a little larger than the surrounding grains of quartz,[1] and in some epidote chlorite quartz schists, there can be recognized narrow bands of quartz

[1] The so-called spotted schists containing numerous porphyroblastic crystals of albite, are very widely distributed in the areas of the Sambagawa crystalline schists in Shikoku etc. but such rocks have not been known in the Kamuikotan zone except some rare examples of the greenschists from the Horokanai Pass. (J. SUZUKI: Petrological study of the crystalline schist system of Shikoku, Japan. Jour. Fac. Sci. Hokkaido Imp. Univ. Ser. IV, Vol. 1, No. 1.)

and albite alternating with those of chlorite and epidote.

Albite, in the common schists, is of various grain sizes between 0.05 mm and 0.3 mm, but as a rare case the mineral in the glaucophane quartz schist from the Horokanai Pass reaches 5 mm or more, occurring as white porphyloblasts in the rock. In general, the albite grains are a little larger than the quartz grains in the same siliceous schist though they are usually far less in amount than the latter.

Albite is colorless, usually fresh, and sometimes twinned after the albite law but zonal structure is rarely seen; cleavage is often absent. 2 V is rarely 75° and optic character positive. A refractive index of the mineral is as follows, n_1 (010) or (001) =1.531~1.535 indicating that it is seen to be slightly poor in lime and to have the composition of Ab_{97} to Ab_{85} .

Minute inclusions, such as amphiboles, chlorite, epidote or garnet, are sometimes contained in the mineral. It is not seldom that albite forms about the borders and along the cleavage planes of the relict crystals of plagioclase in the slightly metamorphosed rocks such as diabase schists and schistose diabases, in the Kamuikotan zone. Albite of this kind may be produced by alteration of the original plagioclase, due to metasomatic action of an ascending soda-rich hydrothermal solution.

Albite occurs also as veins in the Kamuikotan metamorphics where it is often associated with quartz. Usually these veins are extremely small in scale and in amount in comparison with the cases of real quartz veins.

2 b. Plagioclase

Besides albite, minute grains of basic plagioclase, containing appreciable amounts of anorthite molecules, have also been observed in the Kamuikotan metamorphics. Concerning the modes of occurrence, there are two kinds of basic plagioclase in the rocks: one is the recrystallized products in the highly metamorphosed argillo-siliceous and basic schist, and the other occurs mostly as relics of the original plagioclase in the slightly altered greenschists and diabase schist.

In the crystalline schists, the metamorphic plagioclase is scattered in irregular grains through the quartz mosaic in comparatively small amount. In the plagioclase, cleavages are usually good, but not so distinct; a simple twin can often be observed, while zonal structure is not prominent in most crystals and polysynthetic lamellae are almost absent. The mineral shows inclusions of various kinds which serve as pigments, and is distinguished from albite and quartz by its higher indices of refraction.

Relict plagioclase occurs as small crystals sparsely, but very widely distributed in the diabase schists, commonly associating with chlorite and augite relic. The rock containing abundant relics of plagioclase and augite, may rarely retain the ophitic structure of the original diabasic rock.

These relics are largely confined to diabase schists only, because they are almost completely altered in highly metamorphosed green schists. The felspar relics may be partially or completely replaced by sericite, chlorite or others. Fresh relics of plagioclase are rarely found in the rocks and the majority of these relics are cloudy and may prevent accurate measurement of refractive index. By determination of comparatively fresh relics, properties may be shown quite similar to those of plagioclase in fresh diabase.

Plagioclase crystals are commonly narrow prismatic in habit, 0.2-0.5 mm in length; zonal structure and multiple twinning after the albite laws are frequently recognized in these crystals. With the aid of the universal rotation stage the plagioclases are a labradorite-bytownite with an anorthite percentage composition An_{65}.

As is mentioned before, some of the plagioclase relics may be partly altered into chlorite or albite and some carbonate. Occasionally the felspar has been zeolitized.

3. Micas

3 a. Sericite

Sericite is one of the most common minerals in all sorts of the Kamuikotan metamorphics, though its amount in each rock is usually very small, and is frequently almost negligible. The mineral is found as a comparatively important constituent, especially in the sericite quartz schists, black siliceous schists and phyllites.

Sericite forms minute scales or fibers, 0.05 to 0.1 mm in length, and occurs in the interstices between the crystals of the main constituents of the rock, and is usually arranged parallel to the bands of quartz and other mineral grains. Sometimes a linear arrangement and a folded band of the mineral can be recognized in the sections in the granoblastic aggregation of quartz. Sericte is almost colorless but is very slightly tinted with very weak pleochroism in rare cases. It shows high index of refraction and refringence and is characterized by its comparatively wide optic angle.

Primary sericite may often be difficult to distinguish from secondary sericite produced by alteration of original constituents. In rare cases, in some glaucophane quartz schist and glaucophane schist comparatively large flakes of white mica, 0.3-2 mm in length, are found, which may be rather called muscovite.

3 b. Biotite

As a rule, biotite is nearly absent in the Kamuikotan metamorphics. It is found, however, on a small scale in certain parts of some rocks, such as black quartz schist, chlorite quartz schist, phyllite, mylonite, etc. It occurs in the rocks as very small flakes sparsely distributed, and is commonly associated with quartz and felspar. The largest flake may be 0.1 mm in length, in which basal cleavage is distinct. In some places, bent flakes can be observed. Mineral character is negative and optic angle very small, practically uniaxial. Color is pale brown or pale brownish yellow with no pleochroism. There is often marginal transition between the biotite and chlorite.

4. Chlorite

Chlorite is a very common mineral, being very widespread in its occurrence in almost all rocks of the Kamuikotan metamorphic complex, as is seen in the cases of other metamorphic regions. It is often found sparingly in less important amounts in siliceous and calcareous rocks but it may be sufficiently abundant occurring especially in connection with the hornblende in some basic types, even forming an essential constituent of chlorite schists and chlorite hornblende schist in some cases. Not only does the mineral occur as a recrystallized component in the rock but it forms a secondary alteration product and vein-forming mineral in the various metamorphic rocks. In some cases chlorite takes the form of micro-vermiculite included in large grains of quartz.

Chlorite is commonly the most important constituent of the chlorite schist, hornblende chlorite schist and some kind of diabase schist, in which it occurs as irregular greenish flakes, 0.1~0.3 mm in diameter. Separate flakes of chlorite occur in random aggregates or exhibit a regular distribution throughout the rocks.

The mineral occurs in ragged flakes with perfect cleavage (001) faintly pleochroic in pale green colors, and shows biaxial negative, with small optic angle. The double refraction is usually very low, and often almost isotropic but occasionally marked anomalous prussian blue interference color may be seen. Color is variable, pale green, green, pale yellow green, pale brownish green rarely or almost colorless; and pleochroism is usually very weak. As special example, chlorite in the lawsonite and aegirine-augite-bearing glaucophan schist, shows brilliant grass-green color.

Minute scales of chlorite occur as an alteration product along the edges and then along the cleavage planes of amphiboles, pyroxenes and felspars, being usually intergrown with those minerals. Chlorite may occasionally occur as psudomorphs after them. It may be observed in all its stages in various rocks. Very minute grains of magnetite are sometimes produced by alteration as when an amphibole may be changed to chlorite.

5. Amphiboles

Amphiboles found in the Kamuikotan metamorphics are roughly classified into five main types: actinolite, common hornblende, glaucophane, crossite and riebeckite, though there may be some transitional varieties among them.

5 a. Actinolite and Hornblende

Actinolite is found predominantly in the actinolite schists intercalated in the other greenschists and actinolite-felses enclosed in the serpentinite masses, though minute prisms of the mineral may be embedded in wide areas of chlorites or quartz and in small quantity in the various kinds of crystalline schists. These actinolite schists and felses have been known from Numaushi, Uryu district and Horaisan, Mitsuishi district.

Actinolite occurs as comparatively long prisms in the rocks and sometimes it may apparently attain a size exceeding 5 cm or more in length. Actinolite is the same as green hornblende in respect of that the (110) cleavages are distinct and optic plane is parallel to (010), but the former differs especially from hornblende by its lighter color, low relief and small extinction angle. The optical properties of three examples of actinolite are as follows:

A) Actinolite in chlorite hornblende schist from Numaushi, Ishikari Province:
$c:Z=14$. $(-)2V=78$, X=very pale green, Y=pale yellowish green, Z=pale green, $n_1=1.640$, $n_2=1.653$, $n_2-n_1=0.013$.

B) Actinolite in the actinolite schist from Mitsuishi, Hidaka Province:
$c:Z=12°$. $(-)2V=74°$. X=pale greenish yellow, Y=greenish yellow, Z=pale green. $n_1=1.646$, $n_2=1.656$, $n_2-n_1=0.010$.

C) Actinolite in the actinolite fels in serpentinite from Mitsuishi:
$c:Z=17°$. $(-)2V=84°$. X, Y=colorless, Z=very pale greenish blue. $n_1=1.623$, $n_2=1.640$, $n_2-n_1=0.017$.

Sometimes an actinolite prism may be converted to bastite along its margins.

Hornblende is found as the essential constituent especially in the chlorite hornblende schists and amphibolites, though the short needle or hairs of the mineral may be sparsely, but very widely, distributed in the various kinds of siliceous and basic schists in the Kamuikotan metamorphic rocks. It is also not seldom that the very minute crystals of the mineral are enclosed as inclusions in quartz, albite or other minerals. Hornblende in the chlorite hornblende schists or amphibolites, is present in well-formed slender prismatic crystals, 1~2 mm or so, in length; it occasionaly amounts up to 80 per cent of the whole constituents of the rocks.

The prisms of hornblende always lie parallel to the foliation flakes of the chlorite hornblende schists, their general direction being the direction of stretching on these planes, but in some cases they may be randomly arranged in the amphibolite. The terminal parts may be frequently broken up into numerous fibres which are 0.1 mm in length, and show pleochroism varying from colorless to deep green.

Under the microscope prisms of hornblende show distinct cleavages parallel to (110) and (110) making an angle of about 124° in the basal section. Simple or multiple twinning on (100) may be commonly observable in the basal section. The optic axial plane is in the longitudinal direction of the crystal. The character of mineral is negative and that of elongation is positive usually, whilst other optical properties are considerably variable, maybe due to variations in composition. Some hornblende in the Kamuikotan metamorphics is occasionally characterized by showing peculiar pleochroism with more or less bluish or violet blue tint or by showing local blue rims. This may suggest the presense of the glaucophane molecule as an isomorphous mixture.

For reference some examples of data on the optcial properties of the hornblende in the Kamuikotan metamorphics will be given as follows:

A) Hornblende in the chlorite hornblende schist from the Horokanai Pass:
$c:Z=18\sim23°$. $(-)2V=60°$. X=pale yellowish green, Y=yellowish

green, Z=bluish green, $X<Y<Z$. $n_1=1.651\sim1.658$, $n_2=1.658\sim1.664$, $n_2-n_1=0.006\pm$, or partly $n_1=1.669\sim1.677$, $n_1=1.680\sim1.687$, $n_2-n_1=0.010\pm$.

B) Hornblende in the hornblende schist from Mitsuishi:
$c:Z=22°$. $(-)2V=52°$. X=yellow green, Y=yellowish green, Z=blue green, $X<Y<Z$. $n_1=1.673$, $n_2=1.681$, $n_1-n_1=0.008$.

C) Hornblende in the garnet amphibolite from Mitsuishi:
$c:Z=3\sim4°$. $(-)2V=50°$. X=pale yellow, Y=dark yellowish green, Z=dark greenish blue, $X<Y<Z$. $n_1=1.656$, $n_2=1.670$, $n_2-n_1=0.014$.

It is not seldom that some prisms of hornblende may contain extremely minute inclusions in their core, such as epidote, quartz, garnet, etc.; on the other hand an aggregate of minute needles or hairs of hornblende serves as a core of quartz, albite or others. It is also observable in some cases that some crystal of hornblende may be secondarily replaced along borders and cleavages by either chlorite, glaucophane or riebeckite. When the prisms of hornblende are surrounded by these secondary products, the prisms may show intricate intergrowths with them. The fibrous hornblende sometimes occurs as reaction-rims to the relict pyroxene.

5 b. Glaucophane and Crossite

The existence of glaucophane in the Kamuikotan metamorphic rocks has been well known for many decades; it has been reported by many authors, such as K. JINBO (1892), B. KOTO (1900), H. S. WASHINGTON (1901), H. HACHIYA (1902), and S. NAKAO (1925). These authors, however, give nothing but short accounts of the mineral in the pebbles or boulders found from the Kamuikotan Valley and others places, and no original localities of the glaucophane bearing rocks were known in those times. Since the senior writer (J.S.) found outcrops of various glaucophane-bearing rocks in the Kamuikotan Valley and the Uryu district in 1932, the modes of occurrence of these rocks have become clear by degrees in many other places.

The mineral occurs in various kinds of crystalline schists, siliceous to basic, in association with some kinds of quartz, albite, chlorite, epidote, garnet, aegirine-augite, lawsonite, stilpnomelane, etc. Consequently the glaucophane-bearing rocks can be grouped into numerous classes from the mineral combination and the comparative relation of every mineral to the whole. In an extreme case, the mineral may occupy almost the greater part of the rock, forming, what is termed a "glaucophanite", in this paper.

The glaucophane may show various properties according to the kinds and the modes of occurrence of rocks in which the mineral is contained. For example the intensity of the pleochroic colors in thin section may show a very great variation in the different rocks. In some portions of the longitudinal section, color and extinction may show a great variation in places even in a single prism. Sometimes the parts with different characters may be distributed in zones or bands in a crystal.

Accordingly some material in regard to the general properties of typical glaucophane in the Kamuikotan metamorphics is presented as follows. In many cases, the glaucophane-bearing schists are finely crystalline and compact with light or dark bluish grey color and schistose structure owing to the parallel orientation of the glaucophane crystals in the rock.

In general, the crystals are stout or narrow idioblastic prisms which typically show sharply-defined boundaries in the prism zone. However, two sets of cleavage planes parallel to (110), are usually absent. Their terminations of the prisms are often irregular and jagged. Fine cracks, commonly normal to the long axis are often seen. It is not seldom that the mineral occurs in form narrow needle-like or fibrous. The prisms are usually in the neighbourhood of some tenths of a mm in length and when the rock is comparatively coarse-grained, they occasionally may attain a length of several mm.

Under the microscope, nearly all of the crystals show zonal structure and an undulate extinction may be due to the action of a distorting factor. Optic plane is parallel to (010) and $b=Y$. Mineral character is always negative and the character of elongation is positive though extinction angle and optic angle are variable. The pleochroism is usually distinct and characteristic: X=pale yellowish violet, Y=pale violet~pale bluish violet, Z=blue~pale prussian blue. $X<Y<Z$.

Some physical properties of the typical four examples of the glaucophane from separate localities are shown as follows:

Glaucophane in the epidote glaucophane schist from the Kamuikotan Valley, Province of Ishikari,
$c:Z=5\sim7°$. $(-)2V=35\sim40°$. $n_1=1.651\sim1.663$, $n_2=1.660\sim1.669$, $n_2-n_1=0.009\sim0.006$.

Glaucophane in the aegirine-augite glaucophane albite quartz schist from the Obirashibe River, Prov. of Teshio,
$n_1=1.664\sim1.666$, $n_2=1.665\sim1.668$.

Glaucophane in the garnet-bearing aegirine-augite glaucophane schist

from Harushinai, the Kamuikotan Valley.
$c:Z=18°$. $(-)2V=20\sim28°$. $n_1=1.652$, $n_2=1.660$, $n_2-n_1=0.008$.

Galucophane in the garnet-bearing albite glaucophane quartz schist from the Horokanai Pass, Prov. of Ishikari,
$c:Z=8\sim14°$. $(-)2V=10\sim15°$. $n_1=1.652\sim1.663$, $n_2=1.659\sim1.667$, $n_2-n_1=0.004\sim0.007$.

In some sections, the large glaucophane prism in the epidote glaucophane schist may be sieved with minute xenoblastic grains of quartz and albite, a structure suggesting recrystallization of these minerals concerned here. The chemical analysis of pure glaucophane crystals in the garnet-bearing albite glaucophane quartz schist from the Horokanai Pass was made by T. NEMOTO, showing result recorded as follows:

Glaucophane

	Wt%	Mol. prop.
SiO_2	59.30	9,834
TiO_2	0.25	31
Al_2O_3	8.66	847
Fe_2O_3	5.21	326
FeO	8.05	1,120
MnO	0.12	17
MgO	9.37	2,324
CaO	1.24	221
Na_2O	6.11	985
K_2O	0.55	58
P_2O_5	—	—
$H_2O(+)$	1.42	788
$H_2O(-)$	0.32	—
Total	100.60	

Glaucophane, Horokanai Pass (Anal, T. NEMOTO). Molecular formation: $(O\cdot OH)_{2.00}(Na, Ca, K)_{1.86}(Mg, Fe'', Fe''', Ti, Mn, Al)_{4.82}[Si_{8.13}O_{22.00}]$. The ratio of bases of the mineral may be represented as follows: $R_2'O : R''O : R_2'''O_3 = 17.7 : 62.4 : 19.9$.

Besides the above-stated, there is another kind of glaucophane which is occasionally found as a secondary product in diabase schists and other greenschists. In this cases, most of the glaucophane prims may form about the borders and then along the cleavage planes of the mafic minerals. The boundaries between newly formed glaucophane and original mafic minerals are usually sharply defined but are sometimes obscure. The glaucophane may be produced by alteration of original mafic minerals due to the partial replacement by a soda-rich solution. As a rule, the glaucophane of this kind may be light in color and weak in pleochroism, showing X occasionally almost colorless.

Some of the alkali amphiboles in the Kamuikotan metamorphics show a property of crossite. This material, though not as frequently present as glaucophane, was recorded in several samples of greenschists. In the rocks, crossite has much the same appearances as those of glaucophane, it is distinguished by its special properties as is shown in the following examples from the Horokanai Pass.

Optic plane is perpendicular to (010), consequently $b=Z$. Extinction angle, $c:Y=18\sim25°$, so that the character of elongation is positive or negative. $(-)2V=45°\sim64°$. It has distinct pleochroism with $X=$ pale yellow~pale yellowish violet, $Y=$blue~prussion blue, $Z=$violet, $X<Y>Z$. $\rho \ll v$. The crossite shows intermediate indices of refraction between glaucophane and riebeckite, as follows: $n_1=1.658\sim1.666$, $n_2=1.662\sim1.672$, $n_2-n_1=0.004\sim0.006$.

According to HARADA (1940) the crossite from Iburi Prov. shows following data: $c:Y=7°$, $n_1=1.665$, $n_2=1.668$, $n_2-n_1=0.003$.

5 c. Riebeckite and crocidolite

Most of the soda-amphiboles found in the Kamuikotan metamorphics are glaucophane but it is worthy of note that there are some interesting rocks which contain much riebeckite as an essential constituent. The localities of the rocks may be comparatively few and small outcrops of them have been known in only three places: in a rail-way 2 km northeast of Kamuikotan station, at Kamietanbetsu to the northwest of Asahikawa city, and at Takadomari in the Uryu district.

It is a remarkable thing that riebeckite may usually occur only in the high siliceous type schists, while glaucophane may be the chief constituent not only in the siliceous but also in the basic schists. So far as the writers are aware, the association of riebeckite and glaucophane has not been recognized in a single rock sample, though these minerals respectively occur together with aegirine-augite.

In general, riebeckite is found as narrow prisms with pointed or tasselled terminations; it is 0.5~3.0 mm in length and 0.1~0.3 mm in width. The mineral has (010) as optic axial plane and $b=Y$. Both the character of mineral and that of elongation are always negative. Comparing the riebeckite with the glaucophane noted already, one can see remarkable differences in character between them. For the sake of comparison the optical properties of typical riebeckite crystals in some quartz schists from Takadomari (A) and Kamietanbetsu (B and C) are given respectively as below.

A) Riebeckite in the riebeckite quartz schist from Takadomari.
$c:X=5\sim8°$. $(-)2V=70\sim75°$. $X=$prussian blue, $Y=$greyish violet blue, $Z=$pale yellowish brown. $X>Y>Z$. $n_1=1.678\sim1.682$, $n_2=1.683\sim1.686$. $n_2-n_1=0.005\pm$. $\rho \quad v$.

B) Riebeckite in the riebeckite quartz schist from Kamietanbetsu.
$c:X=0\sim3°$. $(-)2V=50°\sim53°$. $X=$dark prussian blue, $Y=$greyish violet blue, $Z=$pale yellowish brown, $X>Y>Z$.
$n_1=1.680\sim1.687$, $n_2=1.686\sim1.690$, $n_2-n_1=0.006\sim0.003$. $\rho \gg v$.
$n_1=1.689\sim1.699$, $n_2=1.697\sim1.705$, $n_2-n_1=0.008\sim0.006$. $\rho \gg v$.

In the special greenschist in the contact zone along a serpentinite mass, minute prisms or fibres of riebeckite occasionally develop on the peripheries, cleavages and cracks of the green hornblende, showing the partial metasomatism of the original constituent. Good examples of this kind are seen in the amphibolite from Horaisan near Mitsuishi. Judging from the mode of occurrence it seems that the secondary riebeckite might have originated at a part which was severely effected by comparatively high siliceous and sodiferous solution derived from the neighbouring serpentinite.

The riebeckite fibres, developing mainly on both the terminals of the green hornblende from Mitsuishi, are: (YOSHIMURA: 1936)
$c:X=0\sim3°$. $2V$ is medium. $X=$dark prussian blue, $Y=$reddish purple, $Z=$light yellow, $X>Y>Z$, $n_1 \doteqdot n_2=1.682\pm0.005$.

Most of the riebeckite is prismatic in form, however some special type of the mineral occurs as very slender needles or fine fibres, which may be rather considered more of a crocidolite than a riebeckite. Under the microscope the typical example of the fibre in the quartz schist from Kamuikotan shows the following properties:

Fibres are 1.0 mm in length and 0.01 mm in width in average, $b=Y$. Optic plane parallel to (010) and extinction angle $c:X=0\sim2°$. $(-)2V$ is unknown. $X=$dark prussian blue, $Y=$greyish violet blue, $Z=$pale yellowish brown, $X>Y>Z$, $n_1=1.700\sim1.706$, $n_2=1.712\sim1.719$, $n_2-n_1=0.012\pm$.

The mineral is distinguished from normal riebeckite by its fibrous form and high indices of refraction and high birefringence.

6. Pyroxenes

Pyroxenes known in the Kamuikotan metamorphics, are roughly classified into two main types; aegirine-augite and augite. The former is known in the character of a relict mineral in the slightly metamorphosed diabase schists and is often found in company with relics of plagioclase. The latter is found as a recrystallized product in the highly schistose crystalline schists and is usually associated with soda-amphiboles.

6 a. Augite

Common augite occurs only as a relict mineral of the original rocks, and is sparsely but sometimes abundantly distributed in the diabase schists and schistose diabase. The mineral may be associated with the relics of plagioclase which relics give occasionally an indistinct ophitic texture to the rocks.

The augite remaining in most rocks shows usually considerable alteration along the margins mainly into chlorite or uralite. Chloritization of the augite has occured with concomitant separation of iron ore. Fresh parts of the mineral are commonly irregular in form and very variable in size, 0.1 mm to 1.0 mm in length, indicating that it occurs in two forms viz., in comparatively large phenocrysts and also as small grains in the groundmass.

The cleavages on (110) of the mineral are distinct and fine lamellar twinning on (100) is frequently developed. The optic axial plane is parallel to (010) and coincides to b-axis. $(-)2V=50\sim57°$ and extinction angle on (010) is, $c{:}Z=43\sim47°$. The index of refraction and double refraction are comparatively high as follows:
$n_1=1.690$, $n_2=1.712$, $n_2-n_1=0.022$. Pleochroism is very weak: $X=Y=$colorless to pale yellow, $Z=$pale greenish yellow. $X=Y<Z$.

It is noticeable that some schistose diabasic rocks from the Harushinai and Ino rivers are predominantly composed of titaniferous augite in association with a small amount of plagioclase and other materials. The general characters of the titaniferous augite are mostly common to those of common augite, but the former mineral is distinguished from the latter by its following properties.

Pleochroism is characteristic, such as X=pale pinkish brown~pale reddish violet, Y=light brownish violet, Z=light yellowish brown~light yellowish violet, $X<Y>Z$. Zonal structure is common and fine hour-glass structure is occasionaly observable. Extinction angle is partially variable in the crystal with hour-glass structure, for example on the central zone: $c{:}Z'=35\sim43°$ and on both sides of prism: $c{:}Z'=45\sim59°$.

Relics of common augite and titaniferous augite are sometimes rimmed with a thin reaction border of hornblende or aegirine-augite which is usually associated with small granules of iron ore, probably magnetite or titanite.

A noticeable thing is also that these relict pyroxenes in the diabase schists and schistose diabases, may partially or entirely alter into secondary aegirine-augite, where the rocks were effected by the action of penetration of albite or albite quartz veins which are to be considered as the residual material differentiated from the adjacent serpentinite. In these cases relics are sharply aegirinized only in the portion where the crystals are directly in contact with the veins. Such vein occasionally encloses entirely altered fragments of the relics, which obviously represent particles picked up by the veins during their penetration through the fissures in the rocks. There are some exceptions where the center of the large crystal of the augite may remain practically unaltred, and the aegirinized rims are mostly rather sharply separated from the cores. From the mode of occurrence, the origin of aegirine-augite in the vein is clearly due to the metasomatic action between the common augite and albite vein. A characteristic feature of the newly-formed aegirine-augite is its very fresh appearance containing no inclusion and its fine crystal form which is in marked contrast to the widespread relict augite in the parent rocks.

Aegirine-augite which was newly formed shows fine crystal form and usually very fresh appearance without any inclusions. When the aegirine-augite intergrows with the unaltered common augite in an individual crystal, both minerals may have a common optic plane after (010) in mutual position, though the former is distinguished from the latter by the following optical properties:
$c:Z=55\sim57°$, $(+)2V=60\sim74°$, $n_1=1.709$, $n_2=1.728$, $n_2-n_1=0.019$. X=pale grass green, Y=light green, Z=light yellowish green, $X>Y>Z$.

6 b. Aegirine-augite

In general soda-pyroxenes were considered in former times to be very rarely found as a rock-forming mineral in a crystalline schist, notwithstanding the fact that the presence of some kinds of soda-amphiboles had been frequently well known in the rock, for example glaucophane schist and so. Since the senior writer first found the aegirine-augite bearing schists in 1931 from the Uryu district, it has become clear that such rocks are to be found here and there in the areas of the Kamuikotan metamorphics; the localities include the Kamuikotan valley, Oroen zawa, Horokanai pass, and Mitsuishi.

Aegirine-augite is found in the various kinds of highly metamorphosed schists, though it occurs especially in the siliceous schists in connection with glaucophane or riebeckite. In some rock, aegirine-augite occurs as the main constituent next to glaucophane though the amount of the mineral may not exceed one-fifth of that of glaucophane and each crystal of the mineral is commonly smaller than that of glaucophane.

Aegirine-augite has commonly a rather short prismatic form with rounded ends or irregular outline; variable length of the crystals attains a length of some tenths of a mm in average. In rare cases comparatively large porphyroblasts, reaching about 2 mm in length, are found in some stilpnomelane-bearing glaucophane quartz schists from Kamuikotan and Horokanai.

In general the short prisms are sparsely distributed being arranged parallel to the elongations of soda-amphiboles in the rock, but in some places they occur in aggregates which form small spots in the granoblastic quartz field. The aggregates of aegirine-augite grains would seem to be of earlier crystallization than the quartz. Prismatic cleavages are comparatively distinct in the crystal and there are occasional traces of imperfect cracks generally at right angles to the c-axis. Consequently the crystal is frequently broken into irregularly shaped pieces. The cross-section of the prismatic crystals is often of rectangular shape with good prismatic cleavages intersecting each other at about right angles. Sometimes twinning on (100) may be recognized on the section.

Optic plane is parallel to (010) and $(-)2V=70°\pm$. The refractive indices may be about 1.71~1.73. Refringence is very high. Extinction angle measured on (010) $c:X=14\sim38°$. Pleochroism is strong and characteristic with the following axial colors: X=grass green~pale bluish green, Y=pale yellowish brown, Z=pale yellowish green, Absorption is $X>Y>Z$. Zonal structure and undulate extinction are often recognizable in the mineral.

In rare cases, there are bundle-like or irregular felted aggregates of minute aegirine-augite fibres which are wave-like crooked in some schistose diabases near serpentinites from Hakkinzawa, Yubari district; and Shimo-horokanai-zawa, Uryu district. Though the exact properties of the fibres may be not clear, they are characterized by their grass green color and negative sign of their elongation.

(P.S.) 6c Jadeite: Most recently Seki and Shido clarified the presence of jadeite in various metamorphic rocks from the Sambagawa and Kamuikotan belts. According to them these jadeites were identified by the optical as well as X-ray powder method. In most of them, the refractive indices are in the following ranges: $\alpha=1.650\sim1.655$, $\beta=1.657\sim1.661$ and $\gamma=1.667\sim1.673$. The optical angle ranges generally from 63° to 75°. (Personal communication from Y. Seki and F. Shido (1959))

7. Zoisites

7 a. Epidote

Epidote occurs in the Kamuikotan metamorphics as very small crystals sparsely but very widely distributed throughout siliceous and basic schist though in some cases it is a predominant member of some kinds of quartz schist and glaucophane schists, as well as of some veins which penetrate the above mentioned metamorphics. In general, it is found as idioblastic minute crystals as well as in shapeless minute grains, 0.1 mm in average length. The crystals are elongated to b-axis, with cleavages (001) and (100) ; they show an orientated arrangement as regards the plane of schistosity. The epidote is present either in clear crystals or in crystals where it surrounds remnants of plagioclase, hornblende, or in crystals where it is enclosed.

The epidote is the normal ferriferous type and in thin section it is usually yellow to light greenish yellow in color with weak pleochroism. Occasionally zonal structure may be developed. In such cases, the outer zone may be more ferriferous than the core. Optic plane is normal to the elongation of the crystal and the mineral character is negative, $(-)2V=75\sim80°$. The mineral is also distinguished by its very high refractive index and strong birefringence.

Occasionally epidote is found as inclusions in quartz and albite while the mineral itself may contain a number of very minute grains of magnetite, hematite and rarely rutile. It is not seldom that epidote occurs as a secondary product which is closely associated with hornblende or felspar forming about the borders and along the cleavage planes of these minerals. Epidote is also found as a predominant component in a vein which runs through or parallel with the schistosity of the rocks. As the general properties of the secondary epidote are quite similar to those of the primary, there may be no ways of distinguishing between them, except their occurrences.

7 b. Piedmontite

It has been certainly known from former times that the piedmontite quartz schists are widely distributed as an important member of the Sambagawa metamorphic complex in southwestern Japan.[1] But pied-

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[1] KOTO, B.: Some Occurrence of Piedmontite in Japan. Jour. Coll. Sci. Im. Univ. Tokyo, Vol. I, (1887), pp. 303-312; On the Occurrence of Piedmontite Schist of Japan, Q. J. G. S. (1887), pp. 474. SUZUKI, J.: On the Piedmontite Schists of Japan. Jap. Jour. Geol. Geogr. Vol. II, No. 3-4 (1924), 135-149.

montite-bearing rock had not been found in the Kamuikotan metamorphics, before a pebble of piedmontite quartz schist was found by K. SUZUKI in 1934 at the upper coarse of the Utsunai river, Kitami Province. (SUZUKI: 1935b) Subsequently real outcrops of similar rock were recognized by H. ASAI in 1942 at a hill to the east of Toikanbetsu, Teshio Province. The piedmontite occurs in subordinate quantity next to quartz in the rocks and is associated with minute amounts of albite, sericite, epidote, biotite, apatite, magnetite and rutile. The mineral may partly occupy nearly 10 per cent of the over-all composition of the rocks from Toikanbetsu.

It is commnoly 0.03~0.1 mm in length while rarely it reaches 0.5 mm. The crystals are sparsely found in the granoblastic aggregate of quartz and albite, and may show a more or less pronounced tendency to arrangement parallel with the plane of schistosity. The piedmontite commonly shows small idioblastic forms elongated parallel to b-axis, in which imperfect cleavages (001) and (100) are recognizable. Sometimes the crystal is traversed by cracks nearly normal to long axis and it may be often separated into several pieces.

The optic axial plane has a transverse position and $b=Y$ for the mineral. The pleochroism is characteristic as follows:
X=yellow~orange yellow, Y=violet~pinkish violet, Z=scarlet red~light carmine.

7 c. Clinozoisite

The mineral has in general been seldom known in the Kamuikotan metamorphics, though sometimes it is found as a subessential constituent in some crystalline schists, such a glaucophane quartz schists, or chlorite schists. The crystals of clinozoisite are often considerably larger than those of other minerals and the rocks show occasionally porphyroblastic texture. For example, clinozoisite in some kinds of the glaucophane-bearing quartz schist from the Horokanai Pass, reaches 1~2 cm in length and is an important component next to quartz in the rock.

It forms an elongated crystal along b, with perfect cleavage parallel to (001). Lamellar twinning is often observable. The optic plane is (010) and extinction angle of Z on cleavage (001) is approximately 12°. It is almost colorless or very pale brownish, and pleochroism is almost absent. The mineral character is negative and the character of elongation is ±. Optic angle is 87~90°. Index of refraction and double refraction are as follows:

$$\alpha_D=1.715,\ \beta_D=1.726,\ \gamma_D=1.736.\ \gamma-\alpha=0.021$$

Sometimes clinozoisite contains very minute grains of epidote; it is rarely penetrated by many narrow albite veins crossing nearly normal to the long axis of the crystal.

7 d. Allanite

Allanite crystals have been detected only in some aegirine-augite-bearing glaucophane quartz schists collected from Horokanai Pass. Allanite takes the form of minute single grains, 0.2~0.5 mm, which are sparsely distributed in the rocks. But in some places, several small grains aggregate together to make a lump 1 mm or more in diameter. The crystals are small irregular tablets parallel to b, without distinct cleavage.

Refractive index and birefringence are usually very high, while occasionally some parts of the crystal may be almost isotropic. An allanite crystal is characterised by its peculiar pleochroism with X=pale brownish yellow, Y=dark reddish brown, Z=dark reddish chocolate brown, $X<Y<Z$, though the color may be irregularly distributed even in a single crystal.

8. Lawsonite

Lawsonite had not been known in Japan before the senior writer discovered it in 1938 in the samples of the garnet bearing aegirine-augite glaucophane schists occurring as a small lens at the middle course of the Harushinai river, in a short branch leading into the Kamuikotan valley. (SUZUKI, 1938c) Subsequently the mineral was found by M. HUNAHASHI in 1942 in the glaucophane schists from Kamihorokanai-zawa in the Uryu district. The mineral may presumably be found hereafter in additional places in the areas of the Kamuikotan metamorphics. Under the microscope, lawsonite is found as an irregular aggregate filling up especially the interspaces between the crystals of glaucophane and other materials. Individual crystal in the aggregate, occurs in tabular form without definite outline, 0.5×0.2 mm or so. It has cleavages with perfect (010) and (100) and imperfect (001). A fine net of cleavages intersecting each other at about 90°, is clearly seen on the basal section. Sometimes the crystal shows twinning, the combination plane of which seems to be parallel to (001) from the relation between the cleavage and optical orientation. Optic plane is parallel to (010) and $(+)2V=84°$. It is commonly fresh and almost colorless though it shows very faint greenish color in places. Refractive indices and birefringence are as follows:

$$\alpha=1.665,\ \beta=1.671,\ \gamma=1.684,\ \gamma-\alpha=0.019$$

Sometimes lawsonite aggregate seems to be partly replaced by pumpellyite which occurs as veinlets penetrating through or along the aggregate.

9. Pumpellyite

In Japan, pumpellyite was first discovered by S. TSUBOI and K. SUGI (1936)[1] in the basic igneous rocks from the Chichibu mountainland, Honshu. After a while, the senior writer (1938) found new locality of the mineral in Hokkaido, at the Harushinai-zawa in the Kamuikotan valley. In that place, the mineral occurs as narrow veinlets in the lawsonite garnet aegirine-augite glaucophane schists which intercalate in the black siliceous schists which belong to the Kamuikotan metamorphic complex. The veins are 1~5 mm in width and to the naked eye seem tinged with whitish pale yellow green.

Under the microscope the veins are seen to be chiefly composed of fibrous and flaky crystals which are 0.1~0.2 mm in length. Though there are some obscure points in the properties, the flaky crystal may show thin platy form elongated to b-axis, and imperfect cleavage parallel to (001). Optic plane is normal to b-axis, character of elongation is positive or negative, so that maybe $b=Y$. $(+)2V=37°$. Index of refraction is:

$$\alpha=1.685,\ \beta=1.688,\ \gamma=1.698.\ \gamma-\alpha=0.013$$

Pleochroism is very weak; X=colorless, Y=pale green~pale brownish green, Z=colorless. $X<Y>Z$.

In the section cut nearly parallel to (010), the mineral often shows oak-leaf-like twinning, which is composed of two parts, in which the adjacent X'-axis may be at an angle of about 12~16° to the twinning plane. The special twinning is easily recognizable between crossed nicols. From the relation between cleavages and optical orientation, the composition may coincide with twinning plane; they are considered to be parallel to (h01).

Sometimes the pumpellyite vein cuts the aggregate of lawsonite in sections. In such cases there are signs of some lawsonite crystals having been replaced by pumpellyite. Where pumpellyite comes in contact with

1) TSUBOI, S.: Pumpellyite from Asahine, Tukikawa-mura, Titibu-gori, Saitama Prefecture. Petrological Notes (11), Jap. Jour. Geol. Geogr. Vol. XIII, Nos. 3-4 (1936), p. 333.

lawsonite the boundaries between the two are frequently not distinct at a glance, but under careful observation the former is distinguished from the latter by its poor cleavage, high index of refraction, low birefringence, partial very pale greenish color and peculiar oak-leaf twinning.

10. Stilpnomelane

Stilpnomelane is one of the minerals which were discovered and named in old times, and its occurrence has been known as comparatively ubiquitous in foreign lands. However it had not been found in Japan up to that time when J. KOJIMA (1944)[1] reported its presence in the Sambagawa crystalline schists. Subsequently it has become clear that the existence of the mineral may be recognized on not rare occasions in the Kamuikotan metamorphics. (SUZUKI: 1953d)

The mineral is not commonly found as an essential member but is comparatively widely distributed in various schists, siliceous to basic, of the Kamuikotan metamorphics. Though the quantity of the mineral in the rocks shows considerable variations it seems that it may rather usually occur in the rocks rich in glaucophane or riebeckite. The stilpnomelane occurs as a recrystallized product as well as a narrow vein along the schistosity plane of the rocks.

Under the microscope, the mineral appears practically to build aggregate and separate mineral forms, narrow micaceous flake or thin plate with irregular outline, 0.1~0.3 mm in length. The mineral occurs commonly in narrow lensoid patches, intercalated among subparallel bundles of glaucophane and other minerals. In some cases, the mineral shows distinct flexion-phenomena perhaps due to a deformation. Sometimes it occurs as a bundle-like or fan-like aggregate, being of divergent structure, in the granoblastic basis of quartz.

Commonly stilpnomelane has cleavages, parallel to (001) and only in traces normal to (001). Pleochroism is distinct with X=pale yellow to golden yellow, Y and Z=dark reddish brown to dark blackish brown $X<Y=Z$. In some crystals the pleochroic color may be partially variable even in a single crystal. Birefringence is very high indicating there is a wide difference between the highest and the lowest refractive indices of the mineral.

Stilpnomelane shows a striking resemblance to biotite in many points, but it is distinguished from the latter by its imperfect cleavage,

[1] KOJIMA, J.: On Stilpnomelane in Green-schists in Japan. Proc. Im Acad. Tokyo. 20, (1944), p. 322-328.

normal to (001) and more or less thin platy form.

11. Garnet

Garnet is not always found as an important constituent in the Kamuikotan metamorphics, excluding the garnet amphibolites and magnetite garnet quartz schist from the Mitsuishi district. If it is present, the mineral occurs as an accessory ingredient forming almost without exception equidimentional fine crystals or rounded grains, being small conspicuous in quantity only in the highly schistose siliceous schists, very rarely in the basic schist. The amount of the mineral in the rocks is widely variable. In general the grains may be arranged in rows, forming parallel bands with the elongation of the other minerals in the rocks.

Most of the garnet crystals are commonly well shaped after a rhombic dodecahedral form showing various sizes between 0.01~0.1 mm, very rarely 1.2 mm in diameter. The crystals are entirely free from inclusions in many instance. Under the microscope a crystal is clear and almost isotropic with no trace of optic anomalies and is of a nearly colorless or a very slight pinkish color. It is also characterized by its very high index of refraction.

It is noticeable that garnet is found as a very important constituent of the quartz garnet schists from the Mitsuishi district. In the field the rocks occur as thin layers or narrow lenses, 1 m or more in width, intercalating parallel to the schistosity of the adjacent hornblende schists, or garnet amphibolites. In the rock, garnet forms fine grained and nearly equigranular aggregate of reddish brown color. The interstices between the garnet grains are usually filled up by quartz. In some samples, the garnet may reach as much as 70 per cent of the total composition of the rock.

It is interesting that some parts of the quartz garnet schists from Mitsuishi, contain a considerable amount of large porphyroblasts of octahedral magnetite, which may be several mm in size or even as large as 2 cm or more. Garnet in the rock is usually round-grained less than 0.1 mm in diameter; sometimes it shows fine rhombic dodecahedral form. The crystals give $H=7.5$ and $S.G.=3.92$.

In thin section, garnet is very pale reddish brown in color but it may sometimes show a small scale of zoning parallel to (110) faces of the crystal. In such case, the central part seems to be a little darker than the outer zone of the crystal. It is almost isotropic with no sign of optic anomaly. The index of refraction is very high, $n=1.797$.

The chemical analysis is given by T. YOSHIMURA (1936) as follows:

	Wt%	Mol. prop.
SiO_2	39.33	6,522
TiO_2	tr	—
Al_2O_3	14.92	1,460
Fe_2O_3	8.99	563
FeO	9.42	1,311
MnO	12.96	1,827
MgO	6.42	1,592
CaO	7.45	1,328
Na_2O	0.54	87
K_2O	0.23	24
P_2O_5	—	—
$H_2O(+)$	0.40	222
$H_2O(-)$	0.18	—
Total	100.84	

Garnet in the quartz garnet fels from Mitsuishi (Anal: T. YOSHIMURA)

$RO : R_2O_3 : RO_2 = 298 : 100 : 321$,

Atomic ratio $(Fe_{130} Mn_{181} Mg_{157} Ca_{132}) (Al_{145} Fe_{55}) Si_{390}$

12. Calcite

It is of course true that calcite is usually the predominant, and often nearly the only, constituent of the calcareous schists. The mineral is not always an important ingredient of the siliceous and basic schists, but it may be frequently present in varying amounts, filling up the interestices of the other chief rock-forming minerals.

The typical calcareous schists under the Kamuikotan Bridge are chiefly composed of coarse-grained calcite, 1 to 2 mm in length, though they are partly made up of an aggregation of fine-grained calcite, 0.1 to 0.3 mm, and contain a considerable amount of minute grains of quartz. The calcite takes the form of xenoblastic grain with secondary lamellar twinning being usually clear; it is almost free from impurities though sometimes enclosing very scattered minute bits of sericite. Calcite grain in the rocks is irregularly outlined and is more or less elongated parallel to the trend of the layers of the calcareous schists, exerting much influence upon the schistosity of the rocks.

Calcite is frequently found in the various kinds of siliceous schist, though it may be usually less significant in quantity in them. An exception is the calcareous chlorite quartz schists from west end of the Kamuikotan valley and the entrance of Shakin-zawa in Kamuikotan, where calcite grains often exceed 20 per cent of the whole composition.

13. Accessories

13 a. Apatite

Apatite is found only as very small accessory crystals sparsely distributed in varying quantities, in some kinds of siliceous and basic schists. Not seldom the mineral is associated with glaucophane or riebeckite in the rocks. It occurs usually as rounded grains or short prisms and rarely shows fine six-sided tablets, 0.2~0.3 mm in diameter. The crystal is fresh and colorless, and exhibits a distinctly uniaxial negative character.

13 b. Prehnite

Prehnite has been known as an uncommon accessory mineral in very small quantity in the diabase schists, hornblende schist and rarely in the black quartz schist. It is present interstitially or in vein.

It occurs as very minute thin tablets or narrow flakes with distinct (001) cleavage, associating usually with hornblende or chlorite. Twinning lamellae are not rare and they sometimes display a radiating fan-like structure between crossed nicols. Character of elongation is negative and birefringence is considerably high. Pleochroism is usually very weak, colorless to pale yellow or very pale blue. Sometimes the mineral is partly chloritized.

13 c. Magnetite and ilmenite

Magnitite is sparse but very widespread in its occurrence in various kinds of crystalline schists, as a universal accessory. It is found usually in minute xenoblastic grains enclosed in insignificant in quantities. The crystal is often fine octahedral in form but some are rounded grains without any crystal faces. In very rare case, a considerable amount of large porphyroblasts of magnetite is found in some parts of the quartz garnet schist from Mitsuishi. The magnetite in the rock is commonly octahedral in form and the large crystal apparently attains a size exceeding 2 cm or more in diameter. The crystal shows steel black with metallic luster.

The ilmenite may be found in poor quantity in some rocks and its occurrence seems probably analogous to that of magnetite. In some cases relict augite and biotite show slight chloritisation with separation of ilmenite. Under the microscope, ilmenite is very hard to distinguish from magnetite but the former is characterized by that it may be shown by the partial formation of leucoxene.

13 d. Hematite

Hematite may be found only as a negligible accessory in some siliceous types of the Kamuikotan crystalline schists, though it is contained in some hematite quartz schists occurring as thin layers or lenses in the schalstein zones belonging to the Sorachi series in Hidaka district.

The mineral, in form, is a very minute scale, which is commonly clear reddish brown in the marginal zone becoming absolutely opaque toward the center. In general, hematite flakes show a tendency towards concentration in quartzose patches but the minute flakes of the mineral are rarely found as an inclusion in felspar and epidote.

13 e. Rutile

The mineral may be rarely noted as an accessory mineral in some greenschist in very small quantity. It takes the form of minute rounded grains or narrow needles parallel to *c* with dark yellowish or dark brownish tints under the microscope. The size of crystal ranges 0.01 mm to 0.1 mm in length. Some crystals are twinned showing occasionally an example of the knee-shape.

The mineral is commonly mingled with chlorite, hornblende epidote and ilmenite. No alteration of the mineral was observed; it is commonly very fresh being easily identified by its deep color, high refractive index, extreme birefringence as well as occasionaly by its peculiar twinning.

13 f. Sphene

Sphene is one of the important accessory minerals, and is sparsely but widely scattered in various kinds of siliceous and basic schist. It is found usually in the form of minute irregular grains, occasionally small wedge-shaped crystals, 0.3~1.0 mm in length with browny to brownish green tints. In some glaucophane schists, the length comes to over 1 cm. It is usually accompanied by small grains of magnetite and rutile. The mineral is characterized by its very high birefringence.

13 g. Carbonaceous matter

Carbonaceous matter is found as an important member, next to quartz in amount, in the black quartz schists, giving dark color to the rocks. It forms minute grains or film without definite outline and is commonly arranged in linear or folded strings, or narrow bands in the granoblastic aggregate of quartz grains, which are often associated with albite grains. The matter is settled in the interstitial parts between the mineral grains as well as in the grains themselves.

V. DESCRIPTION OF THE KAMUIKOTAN MEAMORPHICS

The metamorphic rocks belonging to the Kamuikotan complex may be roughly divided into three main types, siliceous and argillo-siliceous schists, calcareous schists and basic schist. Each type may be again subdivided according to their chief mineral composition as shown in the following table.

A. Siliceous and argillo-siliceous schists
- (A) Black siliceous schists and phyllites
- (B) Quartzites and cherts
- (C) Mylonites
- (D) Quartz schists
- (E) Glaucophane quartz schists
- (F) Riebeckite quartz schists

B. Calcareous schists and silico-calcareous schists

C. Basic schists
- (G) Diabase schists
- (H) Chlorite schists
- (I) Hornblende schists
- (J) Glaucophane schists

A. SILICEOUS AND ARGILLO-SILICEOUS SCHISTS

(A) Black Siliceous Schists and Phyllites

The black siliceous schists are the most important member of the siliceous schists belonging to the Kamuikotan metamorphic complex; they are widely distributed in the terrains of the complex alternating with the greenschsts and others. They are mostly exposed continuously in the western part of the Kamuikotan valley and are in relatively sharp contact eastward with the thick zones of greenschist; to the west they are generally adjacent to younger formations, Cretaceous or Tertiary, with faults partly with unconformities. The rocks have been usually folded and cleaved showing a noticeable banded texture in the field.

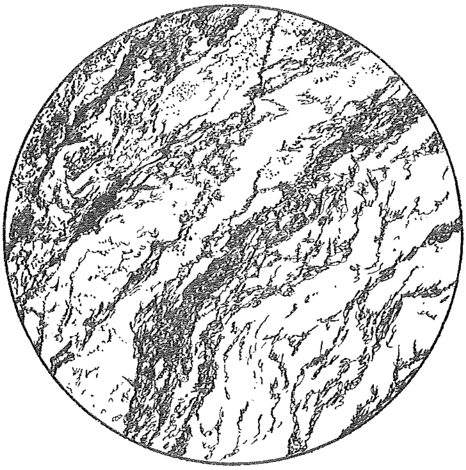

Fig. 9. Black siliceous schist. Kamuikotan Valley. The rock contains quartz, plagioclase and minor carbonaceous material.

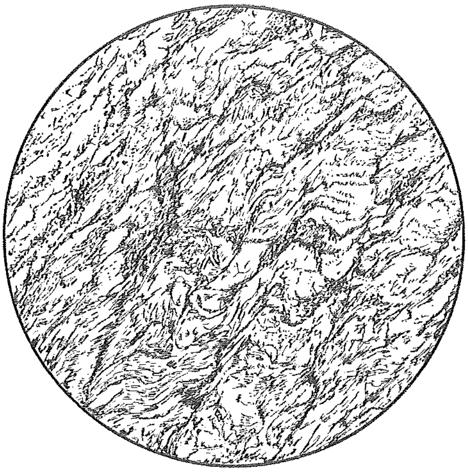

Fig. 10. Phyllite. Kamuikotan Valley. Composed of fine carbonaceous material and quartz with some plagioclase. Frequently the false cleavages are seen.

The rocks are an even-grained greyish black schist in which the schistosity is very marked and some parts of the rock show bands of different mineral composition which are often sharply defined. In these rocks dark black bands 1~3 mm in thickness alternate regularly with white laminae 0.5~1 mm thick. A prominent constituent of the white laminae is quartz or quartz and albite, while the color of the black laminae is given by the carbonaceous material. As a rule they contain as minor accessory fine grains or flakes of green hornblende, epidote, sericite, chlorite and occasionally prehnite. The carbonaceous matter occurs as black minute grains or flakes with narrow linear arrangement in the granoblastic mosaic of fine quartz grains. (Fig. 9).

Some part of the black quartz schist grades into the thin black chlorite hornblende albite quartz schist which contains a pretty large amount of chlorite flakes and light bluish green hornblende needles associated with a minute amount of very fine grains of garnet. Everywhere the rocks are penetraed by numerous veinlets of clear granular quartz or quartz and albite, which are parallel to or crossing the schistosity of the rocks.

The phyllites occur as thin layers comparatively small in volume; they may develop in the terrain of the black quartz schists, and of the mylonitic rocks. The phyllites are a soft grey or greyish brown or deep black in color with very distinct foliation. They are made up essentially of very fine quartz grains and minute flakes of sericite, and appear to be nearly uniform in character. Felspar grains may exist mingled with quartz grains, but they are too small to determine under the microscope. The black phyllites owe their color to the presence of very fine carbonaceous matter. (Fig. 10)

Some of the phyllites are severely corrugated and the original schistosity planes have been crumpled into close isoclinal folds. Some part of the rock bears very fine false cleavages which cross the schistosity of the rock itself. The width of each cleavage is irregular, 0.4~7.0 mm and minute biotite flakes are seen under the microscope to be arranged linearly along the cleavage planes. It is very common for the rocks to be penetrated by narrow veins of quartz or calcite.

(B) Quartzites and Cherts.

Numerous outcrops of the rocks are developed in the terrain of the black quartz schists and greenschists of the Kamuikotan metamorphic complex. They are intercalated as long narrow layers and lenses showing sharp boundaries against the adjacent schists. The trends of these rocks coincide with that of the Kamuikotan complex, extending N to S or NNW to SEE; the dip is generally high though its direction is variable because of the complicated folding of the complex. The large bodies of these rocks may be several km long and very thick between a fraction of 2 m and several m.

These siliceous rocks are roughly divided into two groups: that of rocks which consist of wholly recrystalline quartz and that of the other cherty rock with radiolarian remains in fairly small quantities.

The quartzites are very hard and compact crystalline rocks with a variable aspect in color, grey to brownish grey and in some csases dark greenish. Under the microscope the rocks are seen to be composed almost entirely of equigranular quartz, the average grain size of which is about 0.1 mm, though individual grains may occasionally reach 0.5 mm or more in diameter. As the remaining minerals in the quartzite, small scales of sericite and hematite and narrow needles of light colored hornblende, are not uncommon. The brownish quartzite owes its color to the presence of thin films of very fine crystalline hematite and earthy iron oxide. It is not seldom that the rocks are veined with coarser quartz with a pronounced undulose extinction. The reddish quartzite veined with quartz from Numaushi in the Uryu district has been used for brick-making, but it is not mined at present as its quality is not very suitable.

The general appearances of the chert are close to those of the normal quartzite described above, but under the microscope it is characterized frequently by a content of radiolarian remains though they may not be found in any great quantity as a usual thing. The species of these remains are not exactly determinable but the most of them are considered to be a kind of *Cenosphaera* from their outlines.

As has already been stated, some cherty rocks in the Sorachi series in the Kamuikotan zone, contain various radiolarian remains in very large amount, but such a cherty rock has not been known in the terrain of the crystalline schists belonging to the Kamuikotan metamorphic complex.

(C) Mylonites

The mylonitic rocks have been known in limited localities in the vicinity of Daiba in the eastern part of the Kamuikotan Valley, where they develop as an irregular thick zone, extending approximately north and south, dip being generally high. The width of the zone varies between a fraction of 1,000 m and 1,500 m westward the rocks are seen to grade into phyllites, while with increasing metamorphism they pass eastwards into quartzose schist.

The mylonitic rocks are as a rule light brownish to light yellowish greyish compact schistose rocks, though some part of them has the appearance of loose sandstone in which schistosity is not very well developed. Under the microscope, the most of the mylonitic rocks are seen to be composed dominantly of irregularly angular fragments of 1~2 mm of original quartz and felspar in highly variable proportion, which are filled up with fine siliceous or argillo-siliceous matrix showing a blasto-psamitic or blastopsephic structure. (Fig. 11)

Some of the large crystals of quartz and feldspar have been completely granulated. In the matrix either chlorite or sericite are always present as a common additional constituent, whilst biotite and magnetite are rare accessory clastic minerals. Sometimes the matrix contains large grains of quartz which are clearly of detritic origin. The felspar shows alteration into colorless mica, zoisite, carbonate and chlorite. The crystals of felspar and quartz have been locally broken down into fine grained aggregate.

Though the majority of these rocks which show signs of dynamic

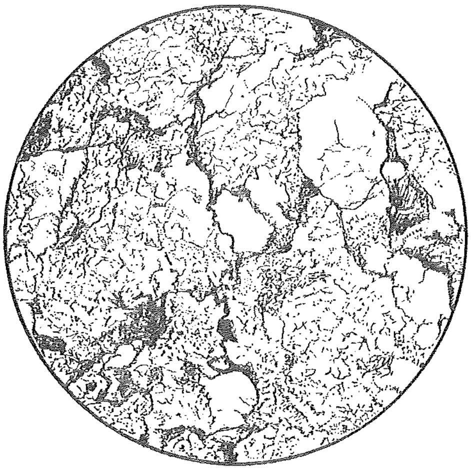

Fig. 11. Mylonite. Kamuikotan Valley. Coarse, partially granuled crystals are quartz and plagioclase. The granulated matrix is composed of quartz, plagioclase and dusty material.

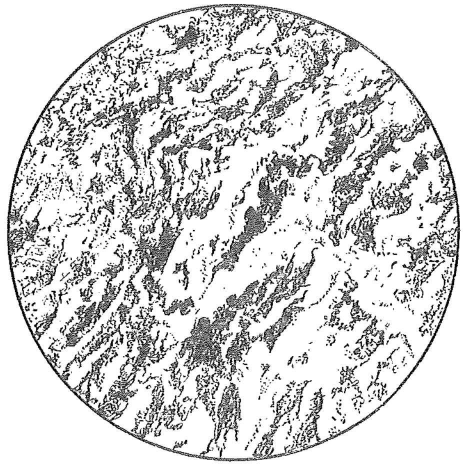

Fig. 12. Chlorite albite quartz schist. Onnenai-zawa, Kamuikotan Valley, Composed of chlorite, albite, quartz and dusty material.

action resulting from shearing are much influenced by cataclastic process, there are partially recognizable in the rock aggregation fine and fresh grains of recrystallized quartz in which comparatively fine flakes of sericite, biotite and carbonaceous material are contained.

(D) Quartz Schists

(D 1) Sericite quartz schist and albite quartz schist.

Quartz schists and albite quartz schist, are intercalated as comparatively thin layers in the black quartz schists and greenschists in the areas along the Kamuikotan valley and other areas. Generally they are fine-grained, silky white or grey rocks with a highly perfect schistosity. The quartz, the essential component of the rocks, is as a rule fine grained; the grains attain a size of 0,1~0.05 mm and show mosaic aggregation with other minerals. Linear arrangement of the elongated quartz grains and the undulate extinction of these grains are not uncommon. The albite grains, if present, mingle with those of quartz; the former are usually larger in size than the latter. Though their amounts are variable, epidote, chlorite, sericite, hematite, hornblende, rarely biotite, are usually recognizable in every quartz schist as common accessories. Most of them are set in the quartz grains with linear arrangement. (Fig. 12)

These quartzose schists may be divided into several main types on the basis of the amounts of the chief associated mafic minerals, such as sericite quartz schist, hornblende quartz schist, chlorite quartz schist or rarely biotite quartz schist. In general they are very intimately associated and pass very gradually into one another. There exist various intermediate types between them so that it is very hard to distinguish them exactly in the field, though in some cases a certain schist many show comparatively sharp boundaries with the adjacent quartzose schist.

Of these normal quartz schists the biotite quartz schist may be very rarely known in the complex. It has been known only as a thin layer in the thick black quartz schist at the western part of the Kamuikotan valley. The rock is invariably highly schistose with sharply marked thin layers alternately rich in biotite which shows zonal arrangement. In the rock, light brownish yellow flakes of biotite, 0.5 mm or more in length, occur as an essential constituent next to quartz, though the mineral is now partly or wholly altered to chlorite.

(D 2) Calcareous chlorite quartz schist.

Rocks of this type have been known as thin layers from western part of the Kamuikotan valley and the entrance of Shakinzawa in Kamuimura. The essential feature of the schists is presence of plentiful calcite which in some cases exceeds 20 per cent of the rock. As is usual with schist of this composition, the chlorite and sericite are interlaminated in the quartz and calcite bases.

(D 3) Garnet quartz schist.

Rocks carrying rich amount of garnet have been rarely known in the complex, though crystalline schists are not uncommon which contain minute amounts of fine garnet grains as an extraordinary accessory constituent. The typical garnet rich quartz schists have been found only from the following two localities: just near the western entrance of the Horokanai tunnel in the Uryu district and at the top of Mitsuishi hill on the northeastern side of Horaisan in the Mitsuishi district. The rock from Horokanai occurs as a part of the normal sericite albite quartz schist near the serpentinite mass at that place.

The rock has the close appearance of the normal sericite albite quartz schist but differs from the latter by the presence of a plentiful amount of garnet grains as essential constituents, which form the narrow bands in the section. Garnet grains in the rock are invisible under the naked eye, but they show individually isotropic and colorless rhombic dodecahedral form under the microscope. (Figs. 13, 14)

The garnet quartz rock from Mitsuishi, Hidaka Province develops

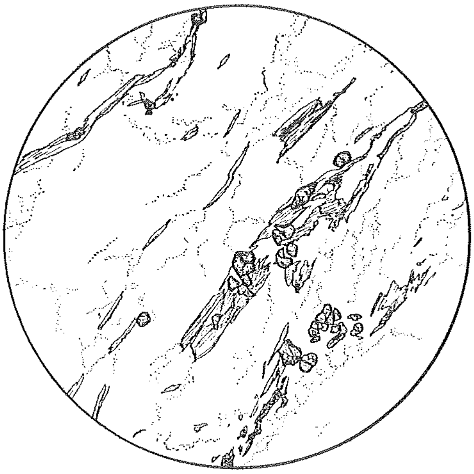

Fig. 13. Garnet sericite quartz schist. Horokanai Pass. The minerals shown are garnet, chlorite, sericite and quartz.

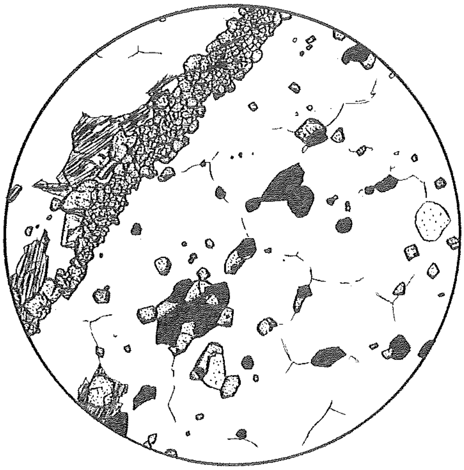

Fig. 14. Garnet magnetite quartz schist. Mitsuishi. Large amounts of garnet and magnetite arranged in a band in a matrix of quartz, with a small amount of green hornblende and apatite.

on a comparatively small scale associating with the glaucophane bearing amphibolite along the small serpentinite mass. The rock is hard and compact and has alternate bands which consist of garnet and subsidiary quartz in variable proportions. In this case quartz may occur interstitially among the crystals of garnet which make up the bulk of the rocks. It has quite similar appearance to the special garnet quartz fels, so-called "Habu" which has been well known with special association with the cupriferous pyrite deposits at the Besshi mine, Shikoku. Concerning the garnet quartz rock from Mitsuishi, a point of interest is that the whole rock is sparsely dotted with numerous large porphyroblastic knots of perfectly idiomorphic crystals of magnetite. The average grain size of the magnetite is seen to be about 0.5 cm though individual crystals may often reach 2 cm or more in diameter.

(D 4) Piedmontite quartz schist.

It has been well known that there occur many layers of piedmontite quartz schists in the terrains of the so-called Sambagawa metamorphic complex in the outer zone of southwestern Japan. The rocks are, however, not only rarely found in the Kamuikotan metamorphic complex, but the modes of occurrence of them somewhat differ from those in the terrain of the Sambagawa complex. The two localities of the piedmontite bearing quartz schist hitherto known in the Kamuikotan metamorphic complex, are: (1) Utsunai, Tonbetsu-mura, Kitami Province, (2) Nakatoikanbetsu, Horonobe-mura, Teshio Province.

No piedmontite bearing rock had been found in Hokkaido before a specimen was collected by the late K. SUZUKI in 1934 at the uppermost course of the Utsunai. The outcrop of the rock in question is not known being only represented by a boulder in the Utsunai river. Though the area along the upper course of the Utsunai have not been explored in detail, it appears highly probably that the bouder was derived from the contact zone between the siliceous rocks and serpentinites developing along the boundary of the Kitami and Teshio Provinces. (SUZUKI: 1935)

The specimen is well foliated rock which is conspicuous by reason of its light pinkish grey color and silky luster. The most abundant minerals in the rock are quartz, albite, sericite and piedmontite while minor accessories are magnetite, apatite, rutile, and garnet, together with small amounts of epidote in some parts. A section cut parallel to the foliation analysed as piedmontite 8 per cent.

The piedmontite quartz schist from Nakatoikanbetsu was first found by H. ASAI in 1941. The rock occurs as a partial facies of the albite hornblende quartz schists associating alternately with the albite epidote hornblende schists in a huge xenolithic rock mass, approximately 70 m wide and 50 m high, enclosed in serpentinite body. The rock bears a close resemblance to the specimen from the Utsunai river. The essential components are quartz, piedmontite, epidote and sericite, in which piedmontite reaches about 10 per cent of the rock.

As far as is known, piedmontite has not been found in any of the similar quartz schists occurring widely in the main areas of the Kamuikotan complex.

(D 5) Stilpnomelane-bearing quartz schist.

The rocks under consideration were found at the Harushinai-zawa and near Daiba in the Kamuikotan valley and in the Oroen-zawa. An unusual feature of the rocks is the invariable presence of abundant crystals of brown and yellowish brown stilpnomelane as subessential constituents. (Fig. 15) The rocks are altered products of the normal quartz schist or quartzite and there are various graduations between them. Besides quartz and stilpnomelane, minute amounts of albite, epidote, chlorite, hornblende, and calcite are recognized in the rocks.

(D 6) Aegirine-augite-bearing hornblende quartz schist.

Such rock specimens have been collected only from Horaisan in Mitsuishi district. The rocks consist chiefly of quartz, hornblende, chlorite

Fig. 15. Stilpnomelane chlorite quartz schist. Oroen-zawa, near Kamuikotan. Radiating flakes of stilpnomelane, banding aggregation of chlorite, in quartz matrix.

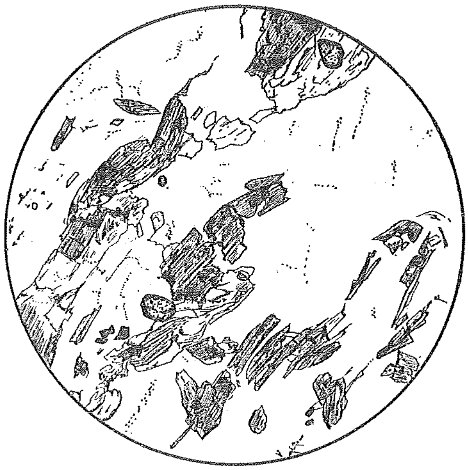

Fig. 16. Garnet-bearing glaucophane quartz schist. Near Horokanai Pass. Composed of glaucophane, quartz, and a small amount of garnet.

and aegirine-augite but no alkali-amphiboles are recognizable in them. The aegirine-augite occurs often as tussel-forming fibres along both terminals of the prisms of common green horndblende, indicating that the aegirine-augite is a secondary product due to metasomatic action of soda-rich solution on the horndblende.

(E) Glaucophane Quartz Schists.

(E 1) Glaucophane quartz schist and glaucophane albite quartz schist.

The members of this group vary considerably in composition, but usually contain both quartz and glaucophane, sometimes also albite, in abundance. They have been known from many places in the contact zone between siliceous schists and serpentinite masses in the areas of the Kamuikotan metamorphic complex; their localities are too numerous to enumerate. The excellent exposures of these rocks for instance as outcrops occur mostly at various parts in the following districts: the Kamuikotan valley, the Oroen-zawa and Horokanai pass.

In general the glaucophane-bearing quartz schists are well foliated rocks which are conspicuous in a hand specimen by reason of their distinctive light to dark bluish color and often silky luster. Sometimes the glaucophane prisms are recognizable without the aid of the microscope on the schistosity planes.

Under the microscope the schistose texture is marked usually by sharply defined banding, in which colorless layers appear to consist mainly of elongated grains of quartz and often albite, while the dark layers owe their color to the presence of glaucophane with parallel orientation. As accessory minerals sericite apatite, epidote sphene, calcite, chlorite and magnetite are common, with allanite rarely accompanying them though not usually plentiful. It goes without saying that the glaucophane is the chief essential member next after quartz in the rocks; its modal proportion is, however, not invariable occupying 10 to 40 per cent of the rocks. The size of glaucophane prisms in these rocks is not uniform; generally they are 0.01~0.5 mm in length though some may in rare cases reach 2 cm or more. (Figs. 16, 17)

As a usual thing the glaucophane prisms show parallel arrangement in the rock, but in rare case they occur as bundle-like aggregations, 0.5~1.0 cm in length, which are set in an enwrapping matrix composed of fine crystalline quartz grains. The rock with scattered spots of dark bluish bundles showing upon a schistosity plane, seems to be a kind of so-called "Garbenschiefer." The typical locality of this rock has been known at the area near the southern entrance of the tunnel under the Horokanai pass.

In some cases, it is not uncommon that the glaucophane quartz schists contain besides glaucophane, one or some of various special minerals such as clinozoisite, garnet, stilpnomelane, aegirine-augite and lawsonite as essential constituuents of rocks. Accordingly with increasing development of these essential minerals the normal glaucophane quartz schists pass into various special glaucophane quartz schists the nature of which will be described below in the description dealing with rock of that kind.

(E 2) Clinozoisite-bearing glaucophane quartz schist.

The rock may be rarely known and only one specimen has been known from Horokanai pass. Quartz, clinozoisite and glaucophane are the dominant minerals of the rock; they are invariably accompanied by minute amounts of epidote and garnet. The clinozoisite occurs as light brownish prisms, 1~2 mm in length, which are penetrated by many narrow albite veins crossing nearly normal to the long axis of the clinozoisite. It is noticeable that the small glaucophane needles develop only in the albite veins.

(E 3) Garnet epidote albite glaucophane quartz schist.

Fig. 17. Garnet-bearing glaucophane quartz schist. Horokanai Pass. The rock character is similar to that of Fig. 16.

Fig. 18. Garnet-bearing glaucophane quartz schist. Etanbetsu. Minute grains of garnet, glaucophane and epidote, arranged in a band, and quartz and some plagioclase in a matrix. Here the vein is composed of actinolite and quartz. Dislocation by the vein is easily seen.

The rocks may be found in comparatively large amount at Horokanai pass and in small amount at the Kamuikotan valley. In both cases they grade gradually to garnet sericite albite quartz schists then to normal sericite quartz schists. (Fig. 18) Quartz, albite glaucophane and garnet are the chief constituents whilst sericite, sphene, magnetite, chlorite, and apatite are common accessories in the rocks. In these rocks, garnet though not usually plentiful is known and may sometimes be moderately abundant. The nature of the garnet is quite similar to that of the minerals in the garnet albite quartz schist, already noted. As is the case of the rocks of Horokanai pass, numerous secondary veins of albite and calcite cut across the schistosity.

(E 4) Stilpnomelane-bearing glaucophane quartz schist.

The rock was collected as a boulder in the alluvival plain of Kamietanbetsu. In handspecimen, it is a blue schist closely similar to the normal glaucophane quartz schist described above, but with yellowish brown flakes of stilpnomelane which are scattered in the quartz glaucophane basis.

(E 5) Aegirine-augite-bearing albite glaucophane quartz schist.

These rocks have been found in a partial facies of the glaucophane

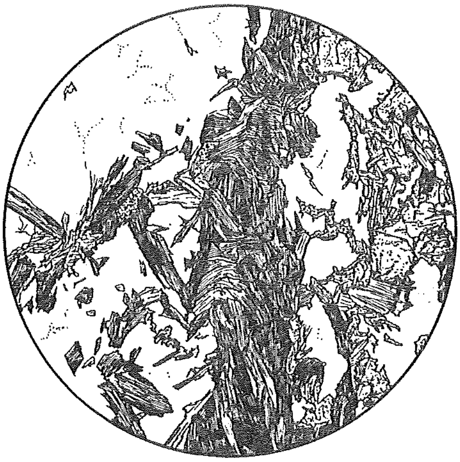

Fig. 19. Aegirine-augite-bearing glaucophane quartz schist. Horokanai Pass. Composed of aegirine augite at right, glaucophane and quartz.

Fig. 20. Stilpnomelane-bearing aegirine-augite glaucophane quartz schist. Horokanai Pass, Principally quartz and aegirine-augite, minor minerals are fine glaucophane and stilpnomelane. Here the large crystals are aegirine-augite.

albite at Horokanai pass and are characterized by showing the paragenesis of glaucophane and aegirine-augite in the normal quartz schists. Aegirine-augite is concentrated in well-defined bands consisting entirely of glaucophane, in the basis of granoblastic quartz and albite, in which the amount of aegirine-augite is more minute than that of glaucophane. The aegirine-augite occurs generally as short prisms or grains 0.2~0.3 mm with grass green color but some of them occur in small rounded mass being made up of an aggregation of light green fibres with jadeitic appearance. It is also noticeable that there are a number of spots, 1 mm in diameter consisting of a mixture of glaucophane, aegirine-augite and allanite in the granoblastic base of quartz and albite in the section. (Fig. 19)

(E 6) Garnet stilpnomelane aegirine-augite glaucophane quartz schist.

The rocks have been known from the Kamuikotan valley and Horokanai pass. In comparison with normal glaucophane quartz schist, it is characteristic that the rocks contain as essential constituents special minerals such as aegirine-augite, stilpnomelane and garnet though their mutual proportions are variable. Worthy of note regarding the rocks is the fact that there can be found large porphyroblasts of aegirine-augite which attain a length of about 1.0~2.0 mm; some of them bear remarkable traces of rotation which took place during their growth under metamorphism. (Fig. 20)

The chemical analyses of some glaucophane quartz schists are given in Table IX.

TABLE IX. Glaucophane quartz schists.

	(33)	(34)	(35)	(36)	(37)
SiO_2	90.57	87.96	85.80	84.42	84.40
TiO_2	0.05	0.60	tr	0.30	0.53
Al_2O_3	3.58	2.43	2.73	6.49	2.80
Fe_2O_3	1.12	0.69	1.70	0.82	1.18
FeO	1.07	1.68	2.60	2.44	1.54
MnO	0.04	—	0.28	0.14	0.42
MgO	1.25	3.33	3.00	1.62	2.27
CaO	2.53	0.47	1.20	0.74	1.62
Na_2O	0.19	1.59	1.90	0.97	1.30
K_2O	0.44	—	0.86	0.60	0.82
P_2O_5	—	—	0.31	tr	0.50
$H_2O(+)$	0.14	1.21	—	—	1.50
$H_2O(-)$	—	—	—	—	0.44
CO_2	—	—	0.10	—	—
Ign. loss	—	—	—	1.84	—
Total	100.98	99.96	100.48	100.38	99.32

(33) Glaucophane quartz schist (Garbenschiefer). Horokanai-Pass, Uryu-Gun, Ishikari Prov. Anal. T. Nakayama. (Suzuki: 1952, p. 189)

(34) Albite-bearing glaucophane quartz schist. Horokanai-Pass, Uryu-Gun, Ishikari Prov. Anal. A. Kannari. (Suzuki: 1934, p. 24)

(35) Aegirine-augite-bearing glaucophane quartz schist (Pebble found in Neogene Tertiary conglomerate). The Obirashibe River, Teshio Prov. Anal. A. Kannari. (SUZUKI: 1931, p. 285)

(36) Glaucophane quartz schist. Horokanai-Pass, Uryu-Gun, Ishikari Prov. Anal. A. Kannari. (Suzuki: 1934, p. 24)

(37) Garnet-bearing albite glaucophane quartz schist. Horokanai-Pass, Uryu-Gun, Ishikari Prov. Anal. A. Kannari. (Suzuki: 1939, p. 516)

(F) Riebeckite Quartz Schists.

(F 1) Riebeckite quartz schist (proper).

The rocks were firstly found in the rail-road cutting 2 km north of Kamuikotan station on the west side of the Kamuikotan valley. Then small outcrops of the rocks have also been found in the Kamietanbetsu and Mitsuishi districts. As a rule, they consist chiefly of quartz, riebeckite

Fig. 21. Riebeckite quartz schist. Kamuikotan Valley. Riebeckite at random orientation in a matrix of quartz.

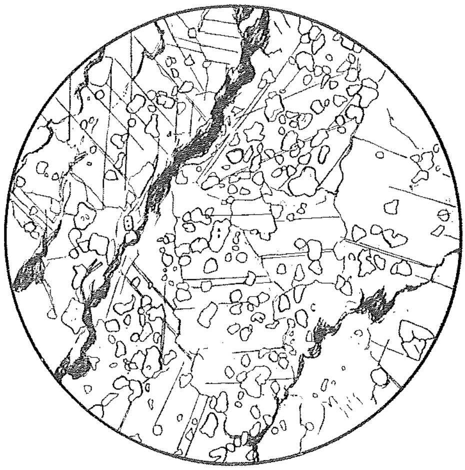

Fig. 22. Quartz-bearing crystalline limestone. Near Kamuikotan Station. Quartz, chlorite and stilpnomelane are embedded in calcite.

and considerable magnetite, epidote, chlorite, and albite; further more hematite and garnet are observed as accessory constituents.

The riebeckite commonly forms needly-like crystals, 1 mm or more in length, some of which may be considered to be crosidolite. These crystals are irregularly distributed or in places roughly arranged together in parallel the granoblastic quartz. But in the specimen from Mitsuishi the mineral shows tasselated form or minute prisms developing along the terminal mergins and cleavage planes of bluish hornblende and chlorite crystals. A noticeable thing is that fine octahedral crystals of porphyroblastic magnetite, 0.3~1.0 mm are often scattered through the rocks. (Fig. 21)

Though it is not exactly known from where they were derived, there are many large rounded or irregularly formed blocks of riebeckite quartz schist, 1 m or more across, on the floor of the Kamuikotan valley. These fantastic stones or blocks fashioned by hand of time are very hard and compact rock with dark bluish color and resinous luster. They are collected for valuable Japanese garden stones on account of their peculiar appearances.

Though the rock does not belong to the Kamuikotan metamorphic complex, the riebeckite quartz schists with close appearance to those of the complex have been found from the contact zone between siliceous rocks belonging to the Sorachi series and serpentinite mass at the Penchamite-zawa, eastern part of Kanayama, Sorachi district.

(F 2) Stilpnomelane-bearing riebeckite quartz schist.

These rocks occur in close association with the normal riebeckite quartz schists but differ from the latter by containing considerable amount of stilpnomelane. The mineral shows minute yellowish brown narrow flakes which develop not only with riebeckite needles but with quartz grains.

(F 3) Aegirine-augite-bearing riebeckite quartz schist.

The rocks are closely related in occurrence with the above noted riebeckite quartz schists and are characterized by the presence of small amounts of aegirine-augite crystals as a subordinary component of the rocks. In specimens collected from a certain locality in the Kamuikotan valley, aegirine-augite grains 0.05~0.1 mm are mingled in well defined bundles of crosidolitic riebeckite; on the other hand, in the specimen from Mitsuishi riebeckite develops as minute bundles of narrow needles along the terminal margin of light bluish green hornblende.

Two chemical analyses of riebeckite quartz schists are given in the following Table.

TABLE X. Riebeckite quartz schists.

	(38)	(39)
SiO_2	84.19	76.77
TiO_2	0.20	—
Al_2O_3	4.11	0.59
Fe_2O_3	2.77	9.40
FeO	3.59	7.19
MnO	0.85	—
MgO	1.85	1.50
CaO	0.47	—
Na_2O	1.12	2.78
K_2O	—	0.08
P_2O_5	—	0.26
$H_2O(+)$	0.97	1.14
Total	100.12	99.71

(38) Riebeckite-bearing albite quartz schist. Kamietanbetsu, Kamikawa-Gun, Ishikari Prov. Anal. A. Kannari. (Suzuki: 1933, p. 618)

(39) Aegirine-augite-bearing riebeckite quartz schist. Rail-road cut near Kamuikotan Station, Ishikari Prov. Anal. A. Kannari. (Suzuki: 1933, p. 618)

B. CALCAREOUS SCHISTS AND SILICO-CALCAREOUS SCHISTS

Calcareous schists are comparatively rarely known compared with the siliceous and basic schist in the Kamuikotan metamorphic complex. The main type of the rocks may be found in a small limited area in the western terminal part of the Kamuikotan valley. The rocks there occur as thin layers 1~2 m in thickness intercalated conformably in the black quartz schists and are severely cleaved and folded with adjacent schist. Thin layers and lenses of crystalline limestone are also known respectively at Kakuregenya in Uryu district and Mitsuishi in Hidaka Province, but they are both extremely small in scale. The rocks from the Kamuikotan valley are white or greyish white in color and consist almost entirely of calcite grains which vary in different bands from 0.3 mm to 0.5 mm in diameter though sometimes comparatively large grains, 1~2 mm, are enclosed in the rocks.

It is noticeable that a certain rocks facies of the calcareous schists under the bridge near Kamuikotan station, shows a distinct pseudoporphyritic structure owing to the presence of comparatively large rounded grains of quartz which occupy in places about 20 per cent of the whole rocks. With decreasing development of the quartz the rock passes into the normal crystalline limestone. The calcite grains in the silico-calcareous schists occationally enclose minute flakes of grains of sericite, plagioclase, amphibole and often stilpnomelane in fairly small quantities. These inclusions are arranged in regular parallel strings cutting through the calcite grains. The course of the strings seems to bear no relation to the direction of elongation of the calcite grains themselves . (Fig. 22)

C. BASIC SCHISTS

(G) Diabase Schists.

(G 1) Diabase schist (proper).

These rocks, one of the important members of the Kamuikotan metamorphic complex, develop in very wide areas as thick layers alternating with black siliceous schists and the other basic schists. As faulting and folding are common in the rock, the real thickness of the layers of the diabase schists cannot be measured but they outcrop over a distance of several km along both sides of the eastern and western parts of the Kamuikotan valley.

In general, the diabase schists are dark greenish and slightly schistose

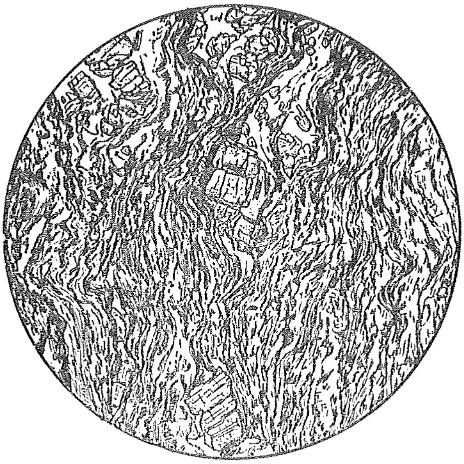

Fig. 23. Augite glaucophane-bearing diabase schist. Kamuikotan Valley. Composed of relic augite and surrounding chlorite. The latter occasionally is replaced by glaucophane.

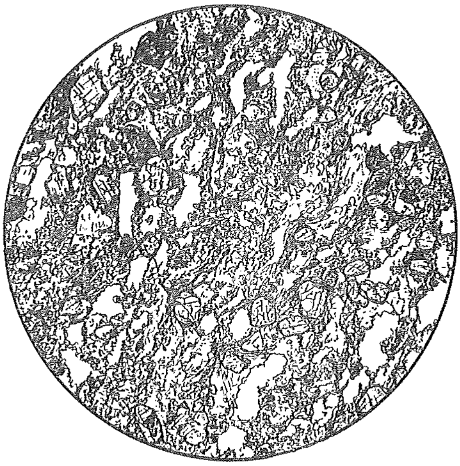

Fig. 24. Diabase schist. Kamuikotan Valley. Relict clino-pyroxene in a sheared, partially recrystallized matrix of chlorite and quartz.

rock and are characterized by the presence of some unaltered relic minerals and by showing often a palimpsest structure of original rock. The most important constituents of the typical diabase schist are chlorite, green-hornblende, epitote, relict grains of common augite and plagioclase, and it appears to contain a subordinate amount of sericite, magnetite and calcite. It is not uncommon for minute grains of quartz to be found in them. These mineral grains have occasionally been arranged in certain directions along the planes of foliation. Chlorite is developed parallel to the edges of the hornblende and relic pyroxene and wraps around curved faces indicating that most of chlorite was derived from these latter minerals. (Figs. 23, 24 & 25)

The amount of the relict minerals is variable in the rock and they are often very poor, or often almost absent. With decreasing development of the relict minerals, the rock grades into the common greenschist. The relict pyroxene shows as a rule the natures of light yellowish common augite but that in the rocks from Kamietanbetsu and Harushinai is titaniferous augite with pinkish brown color and hour-glass structure. The grains of relict plagioclase are usually smaller in amount than those of the pyroxene and most of them are partially altered to calcite, albite and other minerals. From the petrological appearance some of the diabase schists are quite similar to the main green rocks in the Mikabu metamorphic complex in the outer zone of western Japan.

The chemical composition of typical diabase schist is as follows:

TABLE XI. Diabase schist.

	(40)
SiO_2	50.88
TiO_2	0.75
Al_2O_3	13.29
Fe_2O_3	1.67
FeO	8.60
MnO	0.28
MgO	8.78
CaO	8.99
Na_2O	3.62
K_2O	0.38
P_2O_5	tr
Ign. loss	3.04
Total	100.28

(40) Diabase schist. Near Harushinai, Kamuikotan Valley, Ishikari Prov. Anal. A. Kannari. (Suzuki: 1939, p. 27)

It is not seldom that the diabase schists are penetrated by veins of various kinds of minerals such as albite, quartz, calcite, chlorite or epidote. A noticeable thing is that where the green hornblende and relict augite were enclosed in the albite vein, the former has been altered to glaucophane and the latter to aegirine-augite.

(G 2) Glaucophane-bearing diabase schist.

It is noticeable that some facies of diabase schists include separately or together both glaucophane and aegirine-augite, though the amounts and mutual proportions of them may be variable. Glaucophane-bearing diabase schists have been frequently known from several places in the Kamuikotan valley, Horokanai pass and other localities.

In general the glaucophane prisms in these rocks are 0.2~0.5 mm in length and are a more slightly colored variety than those in the glaucophane schists, the pleochroism being light violet to nearly colorless. The amphiboles in the diabase schists may be either green or violet in color but in sections where both varieties are present, the violet type appears as an intermediate product formed during replacement of green hornblende by glaucophane molecule by means of the action of sodic solution. The quite similar rock was also found from the vicinity of the Pepeshiru river in the area of the Sorachi series.

Fig. 25. Stilpnomelane-bearing diabase schist. Harushinai River. Green hornblende, plagioclase, iron ore and radiating stilpnomelane. The rock reserves the original igneous texture.

Fig. 26. Aegirine-augite diabase schist. Kamuimura, near Kamuikotan. The minerals shown are aegirine-augite, chlorite and ilmenite.

(G 3) Aegirine-augite-bearing diabase schist.

Rocks of this kind have been known from only two localities, Kamuimura and Harushinai-zawa though the rocks may be expected to occur in comparatively many places in the terrain of diabase schist, because the aegirine-augite in the rocks is commonly originated in the contact facies between relict augite and albite or quartz albite vein penetrating the rocks themselves. In such case, the grains of common augite enclosed in the vein, are partly or entirely altered into aegirine-augite. The boundaries between the original common augite and aegirinized part are comparatively sharp. (Fig. 26)

The rock from Harushinai is characterized by the presence of titaniferous augite, in which similar aegirinization is recognizable, as in the case of common augite.

(H) Chlorite Schists.

(H 1) Epidote albite chlorite schist.

The rocks occur in close association with diabase schist mentioned above, and may be regarded as a special facies of the latter. Thin layers of the rock have been known everywhere the diabase schists are distributed. In sharp contrast, the rocks are composed chiefly of completely recrystal-

Fig. 27. Aegirine-augite glaucophane epidote rock. Horokanai. The main constituents are glaucophane and epidote. The interstitial fine-grained material is mainly quartz.

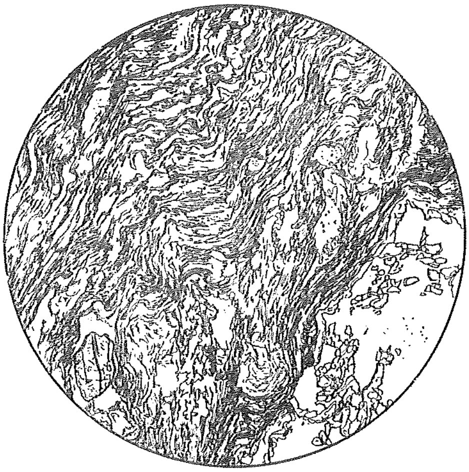

Fig. 28. Epidote chlorite schist. Kamuikotan Valley. The recrystallized schistose matrix consists of chlorite, epidote and carbonaceous material. Relict grains are clinopyroxene. At lower right chlorite developes.

lized products and neither any traces of relict minerals nor of the structure of the original rock have been observed in them. (Fig. 28)

In general the rocks are made up essentially of chlorite and a subordinate amount of albite, epidote and magnetite as well as often minute accessories such as calcite, quartz, sericite, clinozoisite rarely prehnite. The mineral assemblage indicates typical low grade metamorphism. These constituents have been arranged in parallel and impart to the hand specimen a distinct schistose appearance. In some cases, the folding of the rock is considerable.

(H 2) Epidote hornblende chlorite schist.

These rocks may be considered as an extreme member of the diabase schist in which no relics of original plagioclase and augite are observable. The rocks show similar occurrence and appearance to the above mentioned epidote albite chlorite schists and sharp difference is not recognizable between them in the field. They are characterized under the microscope by contents of chlorite and hornblende in nearly equal proportion as the dominant minerals with commonly observed bands especially rich in epidote. Accessory constituents in the rocks are as follows: magnetite, calcite, quartz and often rutile. The hornblende is narrow prisms and usually light yellowish green in color though sometimes is light greenish blue probably may rich in glaucophane molecule.

(H 3) Stilpnomelane-bearing greenschist.

In the common greenschists such as chlorite schists and hornblende schists from Naidaibu, Kamuikotan and Mitsubishi, there can be often seen special yellowish brown parts containing abundant small flakes of stilpnomelane clearly visible in the hand specimens. It seems that most of the flakes of stilpnomelane are especially arranged parallel to the elongated crystals of chlorite and hornblende, along the planes of schistosity. The typical rock is composed essentially of albite, green hornblende, chlorite besides stilpnomelane, while minute amounts of muscovite, rutile, sphene and apatite should be mentioned as subordinate constituents.

(H 4) Glaucophane chlorite schist.

Such rocks which are composed almost entirely of chlorite and glaucophane are often found as thin layers of irregular small lenses intercalating in the various kinds of greenschist. The accessory constituents may be all the same as those of normal chlorite schist and chlorite hornblende schist.

(H 5) Lawsonite aegirine-augite chlirote schist.

These rocks occur in close association with the normal epidote glaucophane schists at Horokanai-zawa, but the rocks differ from the latter chiefly in the presence of lawsonite, in much greater abundance of aegirine-augite, and in the absence of epidote and glaucophane. In the rock minute grains of magnetite are a universal accessory while those of sphene were occasionally noted.

Similar greenschists which contain considerable amounts of epidote besides lawsonite and aegirine-augite, namely epidote lawsonite aegirine-augite chlorite schist have been found as pebbles in th alluvial deposits along the Obirashibe river.

(I) Hornblende schists.

(I 1) Hornblende schist (proper) and amphibolite.

The rocks have been known from several places in the Kamuikotan complex, viz. at the Horokanai district, northern foot of Kamuidake, Mitsuishi, etc. Megascopically the rocks are typically greyish green to dark green in color, fine grained or less commonly of medium grain, and they consist essentially of green hornblende. Since hornblende composes the greater part of all rocks, the arrangement of the hornblende prisms mainly determines the texture of the rocks. When the rocks are usually

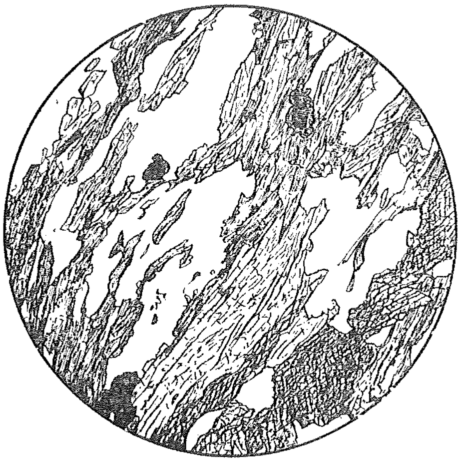

Fig. 29. Plagioclase amphibolite. Horaisan, Mitsuishi district. Main materials are basic plagioclase, and green hornblende. Black iron ore enclosed by sphene.

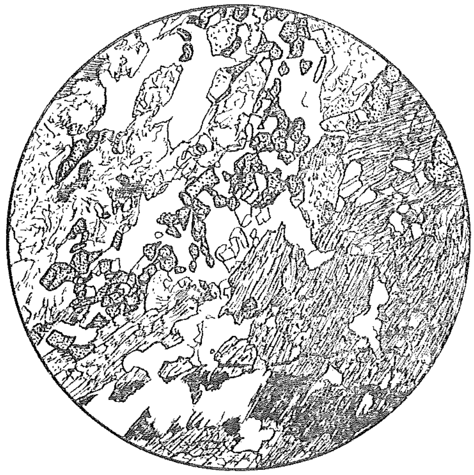

Fig. 30. Amphibolite. Horaizan, Mitsuishi district. The minerals shown are green hornblende, chlorite, sphene and plagioclase. Here the vein is composed of glaucophane after hornblende and quartz.

schistose in which condition the narrow prisms of hornblende are elongated parallel to one another while when the rocks are massive without visible foliation, hornblende prisms may be arranged haphazardly, showing no sign of schistosity. The massive type may be rather designated amphibolite.

The hornblende schist may be divided into three types on the basis of the associated subessential mineral: chlorite hornblende schist, albite hornblende schist and epitote hornblende schist though intermediate types among them can be recognized. Minute accessories in every schist are commonly magnetite, sphene, rutile, apatite, quartz and garnet. (Figs. 29, 30)

In the hornblende schist from Horaisan in the Mitsuishi district, there are observable secondarily originated fine riebeckite needles along the terminal part, cleavage place and cracks of th green hornblende prisms which were effected by albite quartz veinlets penetrating the rocks.

(I 2) Aegirine-augite-bearing hornblende schist.

The hornblende schist which contains isolated grains of aegirine-augite may be rarely known; only one sample has been collected from the Kamuikotan valley. The occurrence of the rock bears intimate relation to the common chlorite hornblende schist; the chief components of it are green hornblende, clinozoisite, aegirine-augite, epidote and sphene.

(Fig. 31)

The chemical analyses of some hornblende schists and amphibolites in given in Table XII.

TABLE XII. Hornblende schists and amphibolites.

	(41)	(42)	(43)	(44)	(45)
SiO_2	51.78	45.16	44.36	42.16	39.22
TiO_2	0.86	2.12	2.42	1.90	2.35
Al_2O_3	15.20	14.34	14.84	13.85	14.74
Fe_2O_3	2.01	1.02	12.01	5.02	4.36
FeO	7.25	5.90	5.45	11.74	11.36
MnO	0.19	0.12	0.17	0.15	0.23
MgO	7.79	17.08	5.44	11.03	10.91
CaO	9.10	10.97	8.62	9.47	12.13
Na_2O	3.70	2.23	2.26	2.00	2.06
K_2O	0.42	0.07	0.93	0.14	0.21
P_2O_5	0.06	0.01	0.24	—	0.30
$H_2O(+)$	1.20	0.94	2.72	—	1.01
$H_2O(-)$	0.18	0.08	0.10	—	0.08
CO_2	—	—	—	—	1.18
Cr_2O_3	0.06	0.01	—	—	0.01
Ign. loss	—	—	—	2.61	—
Total	99.80	100.05	99.56	100.07	100.15

(41) Amphibolite (banded, A). Inuushibetsu, 5-Senzawa, Uryu-Gun, Ishikari Prov. Anal. T. Yamada and E. Omori. (Igi et al.: 1958, p. 18)

(42) Amphibolite (banded, B). Inuushibetsu, 5-Senzawa, Uryu-Gun, Ishikari Prov. Anal. T. Yamada and E. Omori. (Igi et al.: 1958, p. 18)

(43) Aegirine-augite albite epidote hornblende schist. Horaisan, Mitsuishi District, Hidaka Prov. Anal. M. Ishibashi. (Ishibashi: 1937, p. 448)

(44) Glaucophane-bearing amphibolite. Horokanai-Pass, Uryu-Gun, Ishikari Prov. Anal. A. Kannari. (Suzuki: 1939, p. 27)

(45) Amphibolite (fine). Inuushibetsu 5-Senzawa, Uryu-Gun, Ishikari Prov. Anal. T. Yamada and E. Omori. (Igi et al.: 1958, p. 16)

(J) Glaucophane schists.

(J 1) Glaucophane schist (proper)

The special feature of this rock is that at least 80 or more per cent consists of short prisms of glaucophane, while minute amounts of very small grains or flakes of rutile, quartz, plagioclase, chlorite and sericite are associated with them. Under the microscope the average size of the glaucophane prisms is seen to be about 0.5~1.0 mm though individual prisms may occasionally reach several mm in length. The rock may be regarded as an extreme member of the glaucophane schists in which any

Fig. 31. Aegirine-augite-bearing amphibolite. Kamuikotan. Fine-grained aegirine-augite associates with green hornblende.

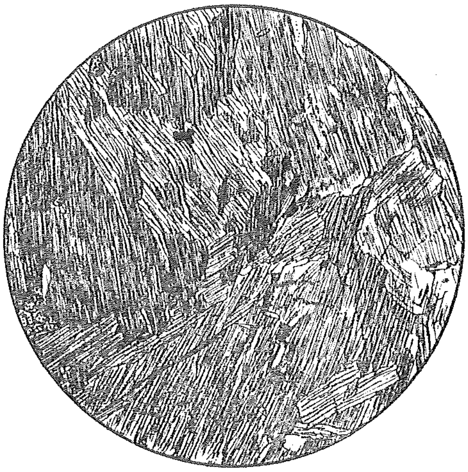

Fig. 32. Glaucophanite. Harushinai, Kamuikotan Valley. Large crystals of glaucophane with a small amount of sphene, stilpnomelane and iron ore.

other important constituent is nearly absent and it may be called by the name "glaucophanite" in this paper. The rock may comparatively rarely occur; the typical specimen has been only found at the eastern part of Horokanai pass.

It is worthy to note there are many variaties of glaucophane schists which contain various minerals, such as epidote, stilpnomelane, aegirine-augite, and lawsonite as an essential constituents besides glaucophane. (Figs. 32~35) A very great variation may be observed in the relative quantities and assemblage of these minerals and there is often a certain amount of gradation from one group to another, so that many transitional types may be recognized among them. As for characteristic features of representative types of the modified glaucophane schist or "glaucophanite," the essential points will be briefly stated as follows.

(J 2) Epidote glaucophane schist.

The rocks of this type are the commonest one of the glaucophane schists; they are comparatively easily recognizable in the fields of green-schist where masses of serpentinite are intruded. They are particularly well exposed in the Uryu and Kamuikotan districts where their localities are too numerous to be enumerated though the respective exposures are not very large.

The rocks consist dominantly of glaucophane and epidote, in variable

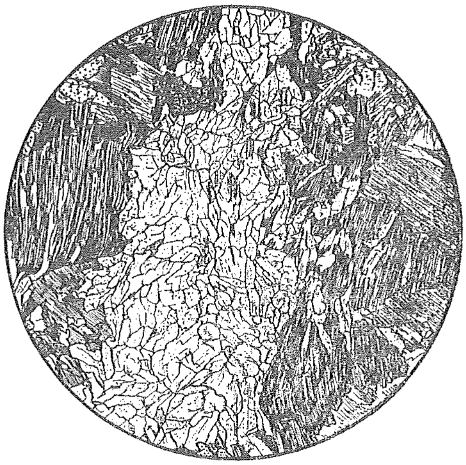

Fig. 33. Lawsonite pumpellyite vein in glaucophanite. Harushinai-zawa, Kamuikotan Valley. The vein composed of pumpellyite and lawsonite, cuts glaucophanite. The minerals of the rock are glaucophane, sphene and stilpnomelane.

Fig. 34. Glaucophane schist. Kamuikotan Valley. Ovoid relict crystals of quartz and plagioclase, in a matrix of glaucophanized chlorite. Chlorite at left alters to glaucophane at right. In the field the rock locates about 10 m apart from a serpentinite mass.

proportions; in usual cases they are orientated parallel to the schistosity. Typically these minerals are accompanied by fairly plentiful magnetite, sericite, sphene, rutile and albite while in some cases any of them may be almost or completely absent. The rocks attract the attention of geologists in the field on account of their peculiar color due to the presence of large amounts of blue glaucophane and yellow epidote. (Figs. 36, 37)

It has been known for many decades that the rocks just described occur plentifully as alluvival bounders in the course of the Obirashibe river, Teshio Province. From field evidence, it may be said that these boulders have probably been washed out and brought down from the conglomeratic layers in the Neogene Tertiary formation which is distributed widely along the upper coarse of the river. It seems that the ultimate source of the materials of the conglomerate maybe lie in the terrain of the Kamuikotan metamorphic complex in the Uryu district.

(J 3) Epidote albite glaucophane schist.

The rocks are one of the commonest type of glaucophane schists and have been found everywhere in the terrain of greenschists near serpentinite masses. The rocks are also schistose and dark greenish blue in color with

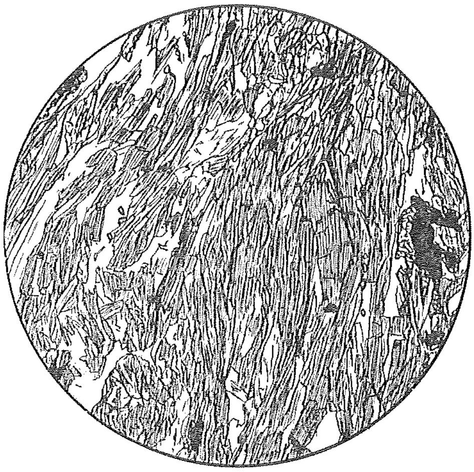

Fig. 35. Glaucophane schist. Horokanai. Composed essentially of glaucophane, with accessory quartz, plagioclase, sphene and iron ore. Sphene encloses magnetite at right.

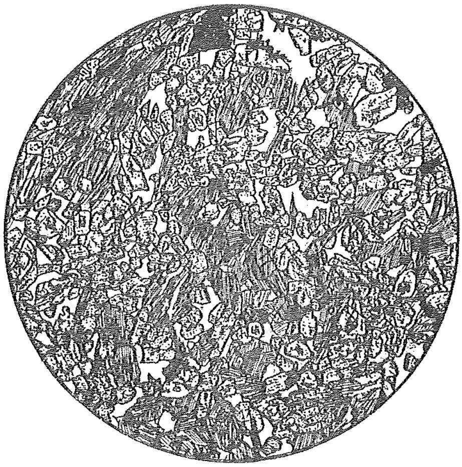

Fig. 36. Epidote glaucophane schist. Horokanai. Main constituents are epidote and glaucophane with small quantities of interfilling plagioclase and quartz.

narrow yellowish stripes. The important constituents of the rocks are glaucophane, epidote and albite while the latter two, though constantly present, are comparatively much less plentiful. The rocks furthermore contain small amounts of muscovite, chlorite, magnetite and rarely stilpnomelane and quartz. (Figs. 36, 37)

(J 4) Stilpnomelane glaucophane schist.

The glaucophane schists rich in stilpnomelane being accompanied by small amount of chlorite and sphene, are known from a part of Kamuiiwa near Kamuikotan station. The rocks show a distinct schistose structure, owing to the presence of orientated glaucophane, sometimes with lamellar intercalation of stilpnomelane though the latter mineral is not regularly distributed through the rock. Both minerals in the hand specimens of the rocks can be recognized with the naked eye.

(J 5) Lawsonite stilpnomelane glaucophane schist.

A small exposure of the glaucophane schists which contain both of the mineral stilpnomelane and lawsonite as essential constituents, are known at Harushinai-zawa in the Kamuikotan valley. Lawsonite occurs as small aggregations filling up the interspaces among the glaucophane prisms. In the rock, chlorite, albite and calcite, in variable proportions, are minute accessory minerals. (Fig. 38)

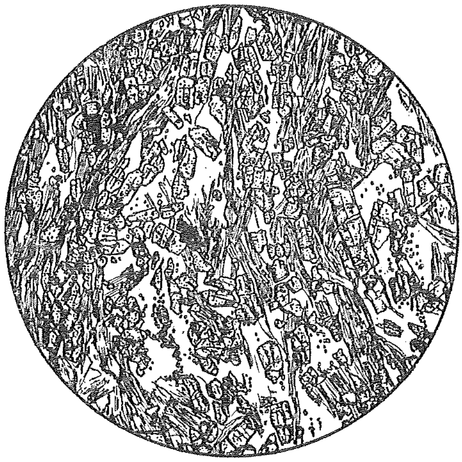

Fig. 37. Epidote glaucophane schist. Near Horokanai Pass. The rock character is same to that of Fig. 36.

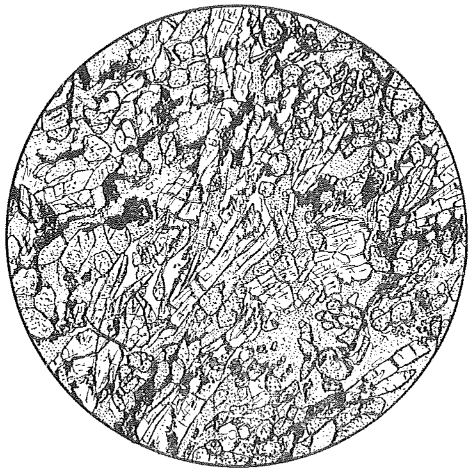

Fig. 38. Epidote lawsonite chlorite schist. Horokanai. Epidote and tubular lawsonite are embedded in a matrix of chlorite.

(J 6) Aegirine augite epidote glaucophane schist.

Concerning the occurrence and general appearance, the rocks from Horokanai Pass are approximately analogous to the normal epidote glaucophane schists. They are characterized, however, by containing a comparatively large amount of aegirine-augite besides glaucophane and epidote. In this case aegirine-augite is not real primary mineral and it seems that the grains of the aegirine-augite may be a metasomatized product due to the penetration of numerous veinlets of albite in the rocks.

(J 7) Lawsonite stilpnomleane aegirine-augite chlorite albite glaucophane schist.

The rock is represented by one specimen collected from the upper course of the Harushinai river. In section it is a coarsely crystalline schist of variable composition, the chief constituents being glaucophane, chlorite, sphene, aegirine-augite, stilpnomelane and lawsonite in order of abundance. A second point of interest is that the rock is penetrated by veinlets of pumpellyite and a part of aggregation of lawsonite crystals may be replaced by pumpellyite. A noticeable thing is that the discovery of lawsonite for the first time in Japan and that of pumpellyite in Hokkaido were based on this very specimen. (Fig. 33)

The chemical analyses of some glaucophane schists are as follows;

TABLE XIII. Glaucophane schists.

	(46)	(47)	(48)
SiO_2	48.88	48.56	46.72
TiO_2	3.90	2.50	4.08
Al_2O_3	13.44	13.90	15.20
Fe_2O_3	5.32	9.31	4.02
FeO	8.96	6.25	5.12
MnO	tr	0.15	0.13
MgO	4.21	2.94	7.23
CaO	5.80	12.61	9.18
Na_2O	3.73	1.24	3.62
K_2O	1.71	0.23	1.50
P_2O_5	—	0.11	0.24
$H_2O(+)$	3.42	—	3.12
$H_2O(-)$	0.36	—	0.07
Ign. loss	—	2.18	—
Total	99.73	99.98	100.23

(46) Epidote glaucophane schist. Kamuikotan Valley, Kamikawa-Gun, Ishikari Prov. Anal. H. S. Washington. (H. S. Washington: Am. Jour. Sci. 11. 1901, p. 35)

(47) Epidote glaucophane schist. Horokanai Pass, Uryu-Gun, Ishikari Prov. Anal. A. Kannari. (Suzuki: 1939, p. 27)

(48) Garnet-bearing aegirine-augite lawsonite glaucophane schist (with pumpellyite). Harushinaizawa, Kamuikotan Valley, Kamikawa-Gun, Ishikari Prov. Anal. A. Kannari. (SUZUKI: 1938, p. 237)

D. MINERAL VEINS IN THE CRYSTALLINE SCHISTS

There are various and numerous mineral veins or veinlets throughout almost all kinds of crystalline schists except some specially hard and compact rocks. The minerals occurring in the veins are as follows: quartz, calcite, chlorite, epidote, zeolites, chalcedony, sulphides, etc. These minerals may be genetically divided into at least into two types; deuteric and secondary. The vein minerals of deuteric origin are considered to have been derived from a source related to autometasomatic solution or metamorphism. These veins usually show somewhat regular arrangement relatively to the schistosity planes of the crystalline schist.

The veins of secondary mineral have been intruded in the crystalline schists at a time when metamorphism had ceased. In this case the source of vein materials should be considered to have been derived from outside rocks. The vein minerals are found filling the fissures, which run parallel or cross at some angle to the schistosity of the rocks. It is not rare that veins of quartz, calcite and chalcedony belong to this type.

VI. MINERAL ASSEMBLAGES OF THE METAMORPHICS

The crystalline schists in the Kamuikotan metamorphic complex are roughly classified into three main groups not only on the basis of their chemical composition but also on that mineral composition: siliceous and argillo-siliceous schists, calcareous schists, and basic schists. Most of these crystalline schists are chiefly composed of recrystallized minerals which originated because of regional metamorphism, but the rocks have occasionally attracted special attention because of the presence of some special minerals brought about by pyro-metasomatic action due to ultra-basic intrusion.

The relation between the above-mentioned two sets of minerals; re-crystallized products under dynamo-metamorphism and pyro-metasomatic products due to ultra-basic intrusion, is very complicated. Consequently there can be seen widely various sorts of mineral combination, with special reference, at least, to the essential minerals in these rocks. Besides the primary minerals the rocks may partly contain in some places the relic minerals of parent rocks as well as the secondary products originated because of the effect of later hydrothermal solution or later decomposition.

The assemblages of essential and subessential constituents in the metamorphic rocks of the Kamuikotan complex may be tabulated schematically as follows; (In each line, minerals are arranged without any attempt at order in quantity, though enclosure in parentheses means relatively small in amount.)

TABLE XIV.

Siliceous and argillosiliceous schists.

Quartz-(±sericite)
Quartz-(albite)-(sericite)-(±epidote)
Quartz-(albite)-(chlorite)-(epidote)-(±hornblende)
Quartz-(plagioclase)-(hornblende)
Quartz-(albite)-(hornblende)-(±aegirine-augite)-(±epidote)
Quartz-(albite)-(biotite)
Quartz-(chlorite)-(±calcite)-(±sericite)
Quartz-(garnet)-(±magnetite)
Quartz-(albite)-(piedmontite)-(±sericite)
Quartz-glaucophane-(±stilpnomelane)
Quartz-glaucophane-(clino-zoisite)
Quartz-glaucophane-(albite)-(±epidote)-(±garnet)

Quartz-glaucophane-(aegirine-augite)-(±garnet)-(± stilpnomelane)
Quartz-riebeckite-(±albite)-(± stilpnomelane)
Quartz-riebeckite-(aegirine-augite), etc.*

Calcareous schists.
Calcite
Calcite-(quartz)-(±chlorite)

Basic schists.
Chlorite-(epidote)-(±hornblende)-(± augite relic)-(plagioclase relic)
Chlorite-(aegirine-augite)-(±plagioclase relic)
Chlorite-(glaucophane)-(±plagioclase relic)
Chlorite-epidote-albite
Chlorite-hornblende-(sericite)-(garnet)
Chlorite-hornblende-epidote-(±stilpnomelane)
Chlorite-(albite)-(glaucophane)
Chlorite-aegirine-augite-lawsonite
Hornblende-(±plagioclase)
Hornblende-albite-(aegirine-augite)
Glaucophane-chlorite-(±aegirine-augite)
Glaucophane-epidote-(±albite)-(± stilpnomelane)
Glaucophane-epidote-lawsonite
Glaucophane-chlorite-lawsonite-(albite)-(aegirine-augite)-(±pumpellyite)-(±sphene), etc.*

(Here it must be noted that the place of glaucophane in the above cited table is sometimes taken by crossite and that the riebeckite often shows crocidolitic nature.)

Mineral assemblages of the normal crystalline schists which are regionally distributed in the area of the Kamuikotan metamorphic complex, represent commonly greenschist facies, while there may be in places either amphibolite facies or several series of an intermediate equilibrium facies between the amphibolite facies and the greenschist facies. It is noteworthy that some of the special crystalline schists seem to represent the so-called glaucophane schist facies. Concerning the conditions of origin of the various crystalline schists it may be sometimes not easy to make a distinction among stable minerals and metastable relics from the earlier facies, as well as the secondary products in these rocks.

* (P.S.) According to Seki and Shido, there are some rocks in the Kamuikotan Valley, having following assembalges; lawsonite-stilpnomelane-chlorite-jadeite-quartz, relic augite-jadeite-(chlorite)-(calcite)-(albite), lawsonite-jadeite-mica-chlorite-albite-quartz, etc. (SEKI & SHIDO (1959))

Glancing through the table, remarkable points can be noted on the combination of minerals. It is reasonable that quartz is always the essential constituent of siliceous schists, and is very poor or almost absent in the calcareous and basic schists. If minute grains of quartz are contained in these rocks, they may be considered to have recrystallized from of excessive silica yielded as a by-product during the alteration of the original rocks.

Sericite and chlorite occur in both siliceous and basic schists, while there is a tendency for the former to be rather rich in the siliceous schist and the latter rich in the basics. In spite of the fact that epidote is commonly found in both types of crystalline schists, siliceous and basic, it is noticeable that piedmontite always exists in high siliceous schists. This fact is well known on account of the various kinds of piedmontite-bearing schists which show comparatively wide distribution in the field of the Sambagawa metamorphic complex.

In the Kamuikotan metamorphics, garnet is rarely found in the normal crystalline schists and may usually occur as a subordinate constituent in the special quartz schists, associating especially with soda-amphiboles. As a restricted type, a peculiar garnet quartz schist has been found in the Mitsuishi district.

Lawsonite is known as a member of special basic rocks and it commonly associated with glaucophane. The intimate combination of lawsonite and pumpellyite is frequently recognizable in the rocks. Stilpnomelane occurs not only in certain siliceous schists as an essential or subordinate member but in some basic schists and even calcareous schist, as an accessory constituent. It combines with various kinds of metamorphic minerals.

Though the quantity is usually small, aegirine-augite occurs dispersedly but widely in siliceous and basic schists. In these rocks the mineral is associated as is the case everywhere with albite and soda-amphiboles, but sometimes it occurs in the rocks without the latter minerals. Secondary aegirine-augite produced by the reaction between the relic pyroxene and albite vein is sometimes found in the diabase schist.

Glaucophane occurs as an essential constituent in both siliceous and basic schists, but it is characteristic that riebeckite-bearing schists are always siliceous. As a rare exception, small amounts of riebeckite fibres occur associated around the prisms of green hornblende in the amphibolite from Mitsuishi. In this case, the fibres may, however, be secondary and are usually associated with an aggregation of minute quartz grains or fine quartz veinlets. The combination of glaucophane and riebeckite

TABLE XV. (Molecular values of the rocks)

Table Rock No.	Table I (p. 364) Serpentinites (1)	(2)	(3)	(4)	(5)	(6)	(7)
SiO_2	661	653	653	638	618	558	880
TiO_2	—	—	—	—	—	0	16
Al_2O_3	10	14	10	32	82	6	9
Fe_2O_3	33	18	32	20	45	25	34
FeO	53	78	53	72	31	31	62
MnO	—	—	—	—	—	1	4
MgO	894	938	883	901	699	1052	520
CaO	5	9	5	16	8	0	187
Na_2O	—	—	—	4	—	0	9
K_2O	—	—	—	—	—	0	1
P_2O_5	—	—	—	—	—	0	—
$H_2O(+)$	762	*	753	*	687	893	*

* Ignition loss (not calculated).

Table Rock No.	Table II (p. 366) Peridotites (8)	(9)	(10)**	(11)	Table III (p. 368) Albitites (12)	(13)	(14)	(15)	(16)
SiO_2	715	699	660	660	1,209	1,165	1,114	999	955
TiO_2	—	—	11	—	2	1	4	7	1
Al_2O_3	40	35	23	25	163	165	178	163	244
Fe_2O_3	59	59	33	53	2	1	3	2	2
FeO	—	—	105	—	7	12	9	20	5
MnO	—	—	3	—	—	—	1	3	—
MgO	992	998	702	1,157	11	18	27	131	18
CaO	17	9	83	4	8	16	16	129	32
Na_2O	—	—	0	—	120	111	153	109	58
K_2O	—	—	0	—	3	21	4	4	1
P_2O_5	—	—	0	—	—	—	—	—	—
$H_2O(+)$	—	20	554	34	27	48	51	73	534

** Partly serpentinized.

in any one individual sample of the Kamuikotan metamorphics has never been found.

Of the Kamuikotan metamorphics, soda-amphibole-bearing rocks are most conspicuous and show very complicated combination of essential minerals. For instance as is shown in the table, glaucophane occurs in the various kinds of the metamorphics associated with almost all sorts of metamorphic minerals.

Table Rock No.	Table IV (p. 369) Trondhjemites (17)	(18)	Table V (p. 371) Aplites (19)	(20)	Table VI (p. 372) Rodingites (21)	(22)
SiO_2	1,168	1,137	887	848	673	637
TiO_2	1	—	1	3	—	—
Al_2O_3	161	167	175	138	147	216
Fe_2O_3	2	17	1	2	22	11
FeO	10	6	14	124	54	27
MnO	0	—	1	4	—	—
MgO	38	35	96	193	110	60
CaO	55	39	316	223	475	509
Na_2O	71	32	34	28	24	22
K_2O	11	20	1	3	3	4
P_2O_5	4	—	—	—	—	—
$H_2O(+)$	86	—	149	—	198	139

Table Rock No.	Table VII (p. 374) Diabases (23)	(24)	(25)	(26)	Table VIII (p. 376) Diabases (Pillow lavas) (27)	(28)	(29)	(30)	(31)	(32)
SiO_2	815	902	809	682	853	833	812	793	780	768
TiO_2	13	36	7	9	19	25	20	15	14	22
Al_2O_3	161	87	91	104	145	147	136	127	145	144
Fe_2O_3	43	14	47	20	30	41	34	27	27	39
FeO	84	83	87	101	99	67	84	108	76	94
MnO	4	2	3	2	3	4	3	—	3	3
MgO	143	180	71	531	123	103	162	215	182	164
CaO	161	185	174	100	134	165	197	198	187	156
Na_2O	50	75	118	5	66	64	61	44	67	40
K_2O	5	7	5	3	6	7	4	5	3	18
P_2O_5	—	2	3	0	1	2	2	—	1	1
$H_2O(+)$	—	110	318	475	104	91	56	115	205	213

VII. CHEMICAL CONSIDERATION OF THE IGNEOUS AND METAMORPHIC ROCKS

There are 48 analyses of rocks under consideration which were quoted in the foregoing descriptive part. Of these analyses, 31 are of igneous rocks, (ultra-basics 11, leucocrates 11 and diabasic rocks 10) and the remainder are of crystalline schists (siliceous schists 7 and basic schists 9). For convenience, the molecular values of these rocks are given in table XV.

As can be seen from the table, each rock group shows its own chemical peculiarity and some distinct difference can be recognized within

Table Rock No.	Table IX (p. 413) Glaucophane quartz schists (33)	(34)	(35)	(36)	(37)	Table X (p. 415) Riebeckite q. schists (38)	(39)
SiO_2	1,502	1,459	1,423	1,400	1,400	1.396	1,273
TiO_2	1	8	—	4	7	3	—
Al_2O_3	35	24	27	64	27	40	6
Fe_2O_3	7	4	11	5	7	17	59
FeO	15	23	36	34	21	50	100
MnO	1	—	4	2	6	12	—
MgO	31	83	74	40	56	46	37
CaO	45	8	21	13	29	8	—
Na_2O	3	26	14	16	21	18	45
K_2O	5	—	9	6	9	—	1
P_2O_5	—	—	2	—	4	—	2
$H_2O(+)$	8	67	—	—	83	54	63

Table Rock No.	Table XI(p.418) Diabase schist (40)	Table XII (p. 423) Hornblende schists, Amphibolites (41)	(42)	(43)	(44)	(45)	Table XIII (p. 428) Glaucophane schists (46)	(47)	(48)
SiO_2	844	859	749	736	699	650	811	805	775
TiO_2	9	11	27	30	24	29	49	31	51
Al_2O_3	130	149	140	145	136	144	132	136	149
Fe_2O_3	11	13	6	75	31	27	33	58	25
FeO	120	101	82	76	163	158	125	87	71
MnO	4	3	2	2	2	3	—	2	2
MgO	218	193	424	135	274	271	104	73	179
CaO	160	162	196	154	169	216	103	225	164
Na_2O	58	60	36	36	32	33	60	20	58
K_2O	4	5	1	10	2	2	18	2	16
P_2O_5	—	0	0	2	—	2	—	1	2
$H_2O(+)$	—	67	52	151	—	56	190	—	173

the groups. If the molecular values of these rocks were included in some diagrams, the facts would be revealed that there are certain distinct regularities in the distribution of each. For comparison between the groups of igneous and metamorphics, diagrams A-F-C are given respectively in Figures 39 and 40, which may well illustrate the differences between them.

The diagrams show very clearly the familiar correspondence existing between the mineral assemblage and the chemical composition of the metamorphic rocks. It may also safely be asserted that the chemical composition of the metamorphics stands in close causal relationship with that of parent rocks. It is noteworthy that in the diagram (Figs. 39, 40)

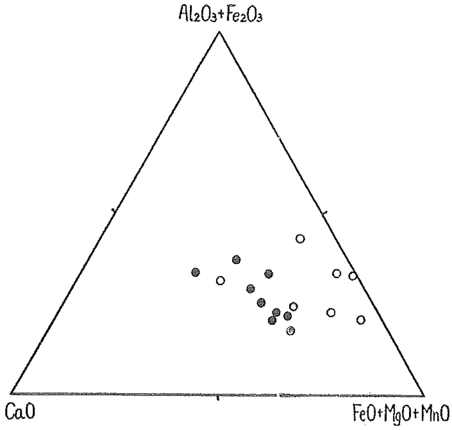

Fig. 39. A-C-F diagram illustrating variation in composition of the metamorphic rocks.
White circle: Siliceous schist.
Black circle: Basic schist.

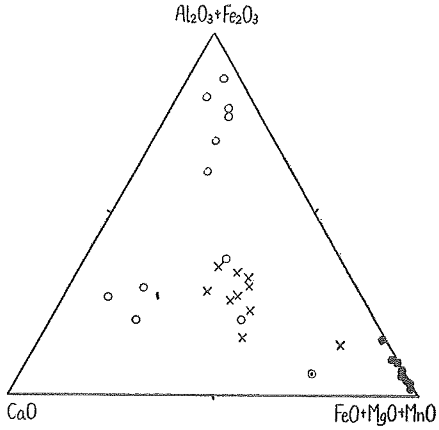

Fig. 40. A-C-F diagram illustrating variation in composition of the igneous rocks.
White circle: Leucocrate.
Black circle: Serpentinite and peridotite.
Double circle: Actinolite fels.
Cross: Diabase and pillow lava.

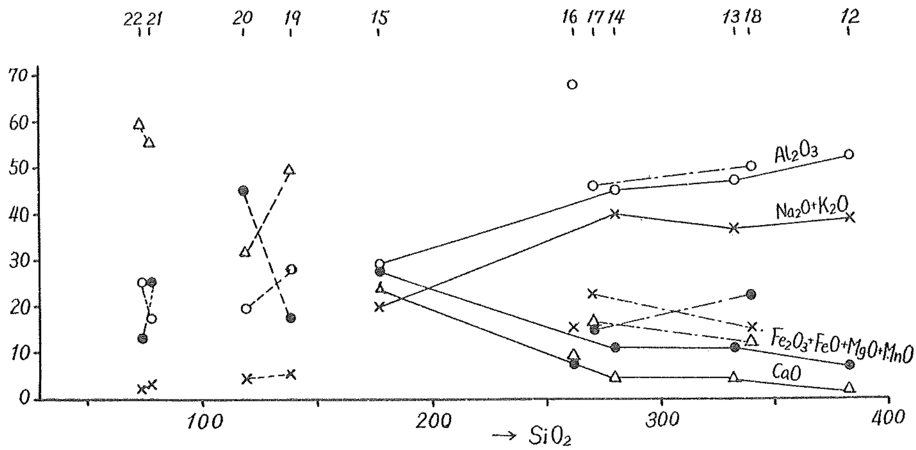

Fig. 41. Variation diagram for the leucocratic dike rocks in the serpentinite masses of Hokkaido.
Nos. 12~16: Albitites.
Nos. 17 and 18: Trondhjemites.
Nos. 19 and 20: Diorite-aplites.
Nos. 21 and 22: Rodingites.

the projection of the ultra-basic rock analyses concentrates in a small field.

Most of the ultra-basic rocks show extremely high values of MgO and H_2O and low figures for SiO_2 in comparison with those of diabasic rocks. The ultra-basic rocks can be petrographically divided into three types: peridotite, serpentinite and actinolite-fels. This classification can also be deduced from chemical data.

	SiO_2	MgO	CaO	H_2O
Peridotite	660~715	702~1,157	4~83	20~ 34
Serpentinite	558~661	699~1,052	0~16	687~893
Actinolite-fels	880	520	187	*

Though the SiO_2 and CaO show no marked difference in this case between peridotite and serpentinite, the former rocks show higher MgO and lower H_2O values than the latter rocks. The actinolite fels is characterized by the relatively high values of lime in comparison with the above two rocks, indicating that the rock is to be considered a result of lime metasomatism of earlier serpentinite.

The leucocratic rocks are petrographically classified into four main groups: albitites, trondhjemites, aplites and pegmatite, and rodingitic rocks. These groups also clearly differ from each other from the chemical point of view. This fact becomes especially conspicuous if the preceding variation diagram of molecular values be used, in connection with the analytical data.

As is shown in the A-F-C diagrams (Figs. 39 & 40), the loci of the analyses of the diabasic rocks gather together in a restricted area without one exception (Table VII, 26), indicating that these rocks have quite similar chemical composition. No distinct chemical difference can be recognized in any points between massive diabasic rocks and pillow lavas.

A closer inspection of the values obtained indicates, however, that there are in fact certain difference among the diabasic rocks. For instance, Table VII, 24 and 25 show a comparatively higher value of soda than the other diabasic rocks. This fact may correspond with the presence of aegirine-augite as an essential constituent in the rocks. Above mentioned exceptional specimen (Table VII 26) is a diabasic block from agglomeratic rock and it possesses extremely high values of MgO and H_2O in comparison with the other diabasic rocks. Such values, indicate that the rock is serpentinized to some degree.

In a comparison between the siliceous and basic schists, the former are seen always to be characterized by their extremely high content of SiO_2 (Wt.% 84.87 on average); it may safely be inferred that the siliceous schists are metamorphosed siliceous or argillo-siliceous sediments. A ternary diagram (A-C-F) (Fig. 39) gives good illustration of the relationship between the chemical composition of the siliceous and basic schists.

The molecular ratios A:F show no marked difference between these these two rock series; the basic schists always show high value of C in comparison with siliceous rocks. It is noteworthy that in the diagram, the projection of the basic rock analyses concentrates in a comparatively limited field, indicating that the rocks have an apparently small variation in chemical composition, notwithstanding the diversity of constituent minerals in them. It is obvious that the loci of the basic schists practically coincide with those of diabasic rock. As was already mentioned, some of the basic schists are petrologically related to the diabasic rocks. In the present case, it is also acceptable from the chemical point of view that the basic schists should be regarded as derivatives of basic igneous rocks allied to the diabases in composition and possibly consisting in part of schalstein.

Concerning the siliceous and basic schists, the following figure clearly

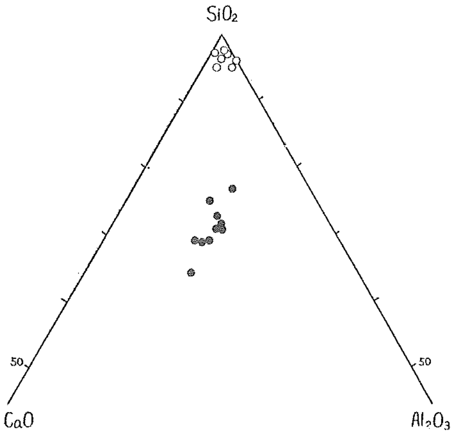

Fig. 42. SiO_2-Al_2O_3-CaO diagram of the metamorphic rocks.
White: circle: Siliceous schist.
Black circle: Basic schist.

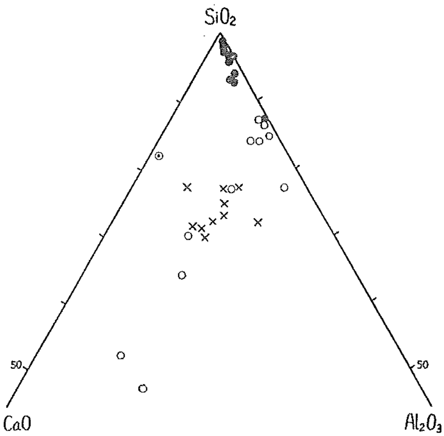

Fig. 43. SiO_2-Al_2O_3-CaO diagram of the igneous rocks.
White circle: Leucocrate.
Black circle: Serpentinite and peridotite.
Double circle: Actinolite fels.
Cross: Diabase and pillow lava.

indicates the comparatively speaking more essential differences in composition between them.

	SiO_2	Al_2O_3	CaO
Siliceous schist	1,273～1,502	6～64	8～ 45
Basic schist	650～859	130～149	103～225

This relationship becomes particularly clear, if the molecular values of the rocks are plotted in the same ternary diagram (SiO_2-Al_2O_3-CaO). (Figs. 42 & 43)

VIII. A SUMMARY OF VIEWS

As is described in foregoing sections there are various kinds of crystalline schist in the Kamuikotan zone, which are displayed at intervals along a belt of country stretching for approximately 300 km. These crystalline schists were not all metamorphosed at the same time or by one great epoch of movement, but they resulted locally from contact metamorphism due to the simultaneous intrusion of the igneous rocks, especially ultrabasic rocks. Of these crystalline schists, the fundamental types which were regionally metamorphosed, are extensively developed throughout the area of the Kamuikotan complex.

The chief members of fundamental type are siliceous or argillo-siliceous schists, and greenschists associated with thin layers of quartzite, phyllite, crystalline limestone all of which are products due to slight regional metamorphism having effected the older original rocks throughout the wide-spread areas. Most of these rocks occur as thick or thin formations, probably largely submarine deposits, having originally sedimentary nature.

When shearing has reached an advanced stage during orogenic movement, the rocks became a typical crystalline schist, though there may be still enclosed small amounts of residual material in some rocks. In this case, the constituents in the original sediments react with one another in obedience to metamorphic conditions, to give various kinds of new recrystallized minerals. There has been considerable alteration of the rocks by shearing action during regional metamorphism.

The crystalline schist in the areas which are characterized by the absence of any adjacent igneous intrusions from which solutions could emanate, undergoes merely chemical reconstitution under simple shearing stress. That is to say, such schists are considered to have been originated under isochemical condition, unaccompanied by metasomatic action due to any additional external solution. When all of the factors of petrology, and of occurrence, are considered it is safely assumed that siliceous and argillo-siliceous schists, phyllites, quartzites and crystalline limestones in the complex are all the derivatives of real sediments by means of a deformation. For instance, the presence of carbonaceous matter in the black siliceous schist, and sometimes of radiolarian remains in certain cherty quartzose rocks may supply evidence in support of the argument. There may be some doubt that any derivatives of an acid tuff are enclosed in some of them, but circumstances do not admit of the presence of such derivatives. This is true because the schist contains too much silica in comparison with the other acid volcanics and has no sign of pyroclastic remains.

Summarising the petrological nature and modes of occurrence, it appears most probable that the greenschists are genetically related to the basic rocks. It can be said with certainty that the greenschists were mostly derived from basic pyroclastic sediment associated with diabasic rocks, but whether the latter themselves were sills, or lavas is not determinable because shearing movements have effected the igneous rocks giving the deformation and recrystallization to the rocks, especially along their shear zone.

As is mentioned before, the greenschists show petrologically various appearances; some are highly schistose being composed of entirely re-crystallized mafic constituents; some others are more or less foliated or massive containing sparsely or densely distributed relics of augite or both augite and felspar and occasionally exhibiting even the slightly ophitic texture of the original rocks. The presence of pyroxene and plagioclase relics would appear to indicate that the greenschists originated in most cases from schalsteins and diabase; at least a rock with ophitic texture is clearly considered to be a modification of real diabasic intrusives themselves. Though relics were not observed in any specimen of green-schist, it may safely be assumed from their chemical natures that they have been formed by recrystallization of diabasic rock under isochemical condition.

The essential dissimilarity in appearances between complete and incomplete metamorphosed greenschists may be considered to depend upon the microstructure and grain size of the parent rocks as well as the physical conditions which obtained during the metamorphism, as basic rocks are a type which is usually fairly sensitive to changes in temperature and pressure condition.

In short, the mineral assemblage of the normal crystalline schists, including siliceous to basic, suggests that these rocks have been originated under conditions equivalent to those of the lowest subzone of the chlorite zone of regional metamorphism. In all areas of the Kamuikotan complex, in the main period of orogenesis there occurred a regional metamorphism which was more or less contemporaneous with the emplacement of the serpentinite.

It is generally considered that peridotites have been intruded essentially in the solid state. The feature of low temperature intrusion of orogenic ultra-basics, is a common one with undoubted country rock at or in the immediate vicinity of ultra-basic contacts, showing no evidence of highly thermal induration. This may be applicable to the relationship between the normal Kamuikotan crystalline schists and the adjacent serpentinite mass; the crystalline schists are very poorly suited for the regeneration of new mineral due to a certain degree to the high thermal metamorphism. It can not, however, be passed over without notice that there is often impressed a comparatively intense local metasomatism in the vicinities of serpentinite masses in the Kamuikotan complex zone. These contact rocks, especially when adjacent to igneous mass, are almost always highly schistose, from which fact it is assumed that they were effected by a fair stress during metasomatism.

It is remarkable, as mentioned before, that in the contact zone various interesting metamorphic rocks locally develop between the normal crystalline schists and serpentinite masses. These rocks have attracted special attention because of the abundant presence of any amount such special minerals as albite, glaucophane, riebeckite, aegirine-augite, jadeite lawsonite, pumpellyite, stilpnomelane, piedmontite, garnet, etc. Most of these special minerals are considered to be contact metasomatic products caused by the introduction of especially soda-rich siliceous solution derived from the ultra-basic intrusion. Strictly the solutions were probably a late stage product of the residual magma which followed the ultra-basics. The appearance of these rocks indicates that the metamorphism which gave rise to the primary recrystallization and to the secondary replacement must have been intermittent.

At various points in the contact zone, the metamorphic rocks and serpentinite masses themselves are frequently penetrated by considerable numbers of obviously introduced veins of quartz, albite, calcite, epidote, etc. These veins run parallel with or sharply cut across the schistosity of the various kinds of crystalline schists suggesting that they are the latest products originated from ascending solution after the ceasing of main metamorphic action in these vicinities.

The typical modifications in the contact zone pass gradually into normal crystalline schist; the extent of the metasomatized part is partially variable and not clearly demarcated. In an area of normal crystalline schists far distant from known outcrops of serpentinite, where the grade of metasomatism seems to be very low, the occasional presence of glaucophane, aegirine-augite, albite veins, etc. may be found on a small scale. Probably some process of soda metasomatism is also involved in such a region. These facts indicate that the contact metasomatic action of a subjacent plutonic mass has influence on a considerable wide area.

The special crystalline schist in the contact zone may be divided petrologically into widely various classes, from the mineral assemblage, modal proportion of chief minerals, and chemical composition as well as micro-structure. Taking a general view of these special rocks, the mineral assemblages of certain rocks suggest that they may be considered to have originated under such conditions as were typical when the so-called "glaucophane schist facies" was formed. In the present state, however, most of the special minerals, such as glaucophane, riebeckite, aegirine-augite, etc. are believed to have occurred as a result of metasomatic process due to the soda-rich solution, and the conditions under which they were crystallized, are somewhat different from those of regional metamorphism. In the former condition, the metamorphism is effected largely by migrations between solid, and additional solution, on the other hand in the latter case, the recrystallization has taken place in the solids or semi-solids. That is to say, the origination of glaucophane schist in this case was not only controlled by the condition, low temperature and high pressures of water and load, as is generally believed, but obviously due to replacement of soda-rich solution, which was effected as a factor influential upon the original materials. As mentioned above, it is worthy of note that serpentinites have played an important role in the special metamorphic field in this region.

Petrologically speaking, from the rare presence of relicts of olivine and pyroxene, it seems probable that most serpentinites are derivatives of peridotitic rocks, which have composition of dunite and wehrite. It is assumed geologically that these ultra-basic invasion took place at a late stage in the metamorphic history of the area, specially along the tectonic lines.

Within the shear zones, foliation planes are developed and the materials are granulated. That is the schistose serpentinite has been developed under synkinematic condition, and the brecciated variety has been formed by mechanical deformation under localized intense stress in the shear zone. In some places there is another kind of brecciated serpentinite which is considered to have been produced as a plutonic body with proto-clastic texture being due to the intrusion along the fracture system or the result of violent eruption. The brecciated serpentinite is chiefly composed of minute angular blocks and the surrounding matrix has a similar nature, indicating that the blocks were solid at a time when the matrix was extremely plastic, and that there were two phases of ultra-basic activity at that time.

It is a remarkable thing that the serpentinite masses and rarely the surrounding rocks are traversed by various kinds of hypabyssal rocks, especially leucocrates, which appear to be co-magmatic and to represent a magmatically differentiated series being end phase derivatives of ultra-basic rock. It is probable that serpentinization results from auto-metasomatism of the original peridotite by concentration of magmatic waters after injection though in some places the action seems to have mostly taken place just after the intrusion of leucocrates as a result of metasomatism due to the ascending hydrous solution expelled from these hypabyssial rocks. Where the serpentinites have been intruded by later leucocratics some changes may occur in the vicinity of the contact itself, but this phenomenon may be hardly observable at the surface. The boring cores from several points in the asbestos mine in Yamabe indicate that the contact plane between serpentinite and trondhjemite is very sharp and that the serpentinite parts have been highly altered to talcose or hardened to quartzose and brown oxide iron-rich part.

As a very rare case, the crystalline schists around the large trondhjemite mass, have been thermally effected by the latter, producing hornfelsic rock with considerable amount of biotite flakes. The high increased temperatures necessary for the metamorphism of the rocks are best refered to hydrothermal solution or vapor expelled from trondhjemite at depth, suggesting that the temperature of the emanations accompanied with some of the leucocrates must have been considerably high.

Selected Literatures

(On the Kamuikotan metamorphic rocks and associated igneous rocks.
* indicates articles written in Japanese)

HACHIYA, H. (1902)*: Glaucophane Rocks from Obirashibe, Teshio Prov., Hokkaido. Jour. Geol. Soc. Tokyo, Vol. 9, pp. 98-105, 147-148.

HARADA, Z. (1934): Ueber einen neuen Pektolithfund in Japan. Jour. Fac. Sci.

Hokkaido Imp. Univ., Ser. IV, Vol. II, No. 4, pp. 355-359.
—— (1940)*: On Glaucophane and Crossite, newly Founded from Iburi and Hidaka Provinces, Hokkaido. Jour. Geol. Soc. Japan, Vol. 46, p. 575.
HASHIMOTO, W. (1936)*: Geology of Western Mountain Area of Hurano Basin, Sorachi-gun, Ishikari Prov. Jour. Geol. Soc. Japan, Vol. 43, pp. 493-530.
—— (1952)*: Jurassic Formations in Hokkaido. Geological Survey of Japan. Report Special Number (B).
—— (1953)*: Yamabe: Explanatory Text of the Geological Map of Japan, Scale 1/50,000. Hokkaido Development Agency.
—— (1955)*: Shimofurano: Explanatory Text of the Geological Map of Japan, Scale 1/50,000. Hokkaido Development Agency.
HUKADA, A. (1949)*: On Brachiopoda in the Schalstein-formation of the Central Mountaineous Zone of Hokkaido. (Abstract) Jour. Geol. Japan, Vol. 55, p. 123-124.
HUNAHASHI, M. (1944)*: Special Amphibole Schists Associated with Serpentinite in the Horokanai District, Ishikari Province. Jour. Geol. Soc. Japan, Vol. 51, pp. 119-131.
—— (1951)*: Rocks of the Hidaka and Kamuikotan Zones of Hokkaido. Geological Science (Chikyu Kagaku), No. 4, pp. 109-118.
—— (1950)*: On Two Types of Ultra-basic Igneous Rocks. Geol. Soc. Hokkaido, Bull. 15, pp. 1-3.
—— and HASHIMOTO, S. (1951)*: Geology of the Hidaka Zone. Monograph Ass. Geol. Collaboration, No. 6, pp. 1-38.
—— (1953)*: Kamietanbetsu: Explanatory Text of the Geological Map of Japan, Scale 1/50,000. Hokkaido Development Agency.
—— (1957): Alpine Orogenic Movement in Hokkaido, Japan. Jour. Fac. Sci. Hokkaido Japan, Ser. IV, Vol. IX, No. 4, pp. 415-469.
—— (1958): The Kamuikotan Tectonic Zone. Jubilee Publication in the Commemoration of Prof. Jun Suzuki, M.J.A. Sixtieth Birthday (in the press).
IGI, S., TANAKA, K., HATA, M. & SATO, H. (1958)*: Horokanai: Explanatory Text of the Geological Map of Japan, Scale 1/50,000. Geological Survey of Japan.
ISHIBASHI, M. (1939)*: On Rocks from the Environs of Horaisan near Mitsuishi Town, Hidaka Province. Geol. Soc. Hokkaido, Bull. 10, pp. 7-34.
—— (1937)*: On the Metamorphic Rocks of the Environs of Mitsuishi, Hidaka Prov. Jour. Geol. Soc. Japan, Vol. 44, p. 487-489.
ISHIKAWA, T. (1944)*: Kamikawa Nickel Mine, Ishikari Prov. Sub-Comm. No. 58th, Japan. Soc. Promotion of Sci., Report 72, pp. 1-25.
JINBO, K. (1892): General Geological Sketch of Hokkaido with special Reference to the Petrography. Hokkaido-cho.
LYMAN, B. S. (1874): Preliminary Report of First Season's Work of the Geological Survey of Yesso. Sapporo.
MURATA, S. (1926)*: Geology and Mercury Deposit of the Teshio Mine. Jour. Coal Mining Ass. Hokkaido, N. 262, p. 180.
NAGAO, S., OSANAI, H. & SAKO, S. (1954)*: Oyubari: Explanatory Text of the Geological Map of Japan, Scale 1/50,000. Hokkaido Development Agency.
NAKAO, S. (1925)*: Glaucophane Prisms in Soil in the Vicinity of Sapporo. Jour.

Geol. Soc. Japan, Vol. 32, pp. 117-121.

NEMOTO, T., SAMBONSUGI, M. & MIZUKUCHI, B. (1942)*: Noborikawa Sheet (1/100,000) and Explanatory Text. Ind. Labor. Hokkaido, Report No. 5, pp. 1-31.

OSANAI, H., NAGAO, S., MITANI, K., HASEGAWA, K. & HASHIMOTO, W. (1958)*: Ishikari-Kanayama: Explanatory Text of the Geological Map of Japan, Scale 1/50,000. Hokkaido Development Agency.

OTATSUME, K. (1940)*: Stratigraphical Relation between Lower Ammonite Bed and Schalstein Formation of Central Hokkaido: Geol. Soc. Hokkaido, Bull., 11.

SAKO, S. (1952)*: Okushibetsu: Explanatory Text of the Geological Map of Japan, Scale 1/50,000. Hokkaido Development Agency.

—— and OSANAI, H. (1955)*: Shimokawa: Explanatory Text of the Geological Map of Japan, Scale 1/50,000. Hokkaido Development Agency.

SASA, Y., MINATO, M., et al. (1944)*: A Geological Section of the Northern Ishikari Coal Field. Jour. Geol. Soc. Japan, Vol. 51, pp. 61-64.

SCHURMANN, H. M. E. (1956): The Geology of the Glaucophane Rocks in Turkey and Japan: A Summary Geol. en Mijnb. (nw. ser.), 18e Jaargang, p. 119-122.

SEKI, Y. & SHIDO, F. (1959): Finding of jadeite from the Sanbagawa and Kamuikotan Metamorphic Belts, Japan. Proc. Japan Acad. Vol. 35, No. 3. (in the press)

SUZUKI, J. (1924)*: Glaucophane Schists in Japan. Jour. Geol. Tokyo, Vol. 31, pp. 1-17.

—— (1931): Aegirite-augite Glaucophane Quartz Schist from the Province of Teshio. Proc. Imp. Acad. Vol. 7, pp. 283-286.

—— (1932a)*: Localities of Glaucophane-bearing Rocks in Hokkaido. Jour. Geol. Soc. Tokyo, Vol. 39, pp. 132-139.

—— (1932b)*: Some New Data on Glaucophane-bearing Rocks in Japan. Jour. Jap. Ass. Petr. Min. & Econ. Geol., Vol. 8, pp. 183-190.

—— (1933): Aegirine-augite-bearing Riebeckite Quartz Schist from Kamuikotan, etc. Proc. Imp. Acad., Vol. 9, pp. 617-620.

—— and YAMAGUCHI, S. (1933)*: On the Contact Metamorphic Effect of Ultra-basic Intrusions at the North-western Mountain-land of Asahigawa, Hokkaido. Jour. Geol. Soc. Tokyo, Vol. 40, pp. 387-390.

—— (1934a)*: Petrography of So-called Kamuikotan Metamorphics. Jour. Geol. Soc. Tokyo, Vol. 41, No. 7, pp. 392-394.

—— (1934b): On Some Soda-pyroxene and -Amphibole-bearing Quartz Schist from Hokkaido. Jour. Fac. Sci. Hokkaido Imp. Univ., Ser. IV, Vol. , No. 4, pp. 339-353.

—— (1935a)*: On Trondhjemite from Horonari, Uryu District, Ishikari Province. Jour. Jap. Ass. Petr. Min. & Econ. Geol., Vol. 14, No. 6, pp. 155-162.

—— (1935b)*: Piedmontite Quartz Schist Pebble from Utsunai, Kitami Prov. Ibid., Vol. 15, No. 2, pp. 285-289.

—— (1935c)*: On Selective Metamorphism. Science (Kagaku-Iwanami), Vol. 6, Nos. 4-6.

—— (1938a): On the Occurrence of Aegirine-augite in Natrolite Veins in Dolerite from Nemuro. Jour. Fac. Sci. Hokkaido Univ., Ser. IV, Vol. 4, Nos. 1-2, pp. 183-191.

—— (1938b)*: On Peculiarity of the Ancient Rocks of Japan. Jour. Japan. Ass. Petr. Min. & Econ. Geol., Vol. 19, No. 2, pp. 123-135.

—— (1938c)*: On Lawsonite and Pumpellyite from the Kamuikotan Valley, Ishikari Prov. Ibid., Vol. 20, No. 6, pp. 189-196.

—— (1939a): A Note on Soda-amphiboles and -Pyroxene in Crystalline Schist from Hokkaido. Jour. Fac. Sci. Hokkaido Imp. Univ., Ser. IV, Vol. 4, Nos. 3-4, pp. 507-519.

—— (1939b): On the Age of the Sambagawa System. Proc. Imp. Acad., Vol. 15, No. 1, p. 56-59.

—— (1939c)*: Petrological Study of the Mikabu and Kamuikotan Systems. Comm. No. 6, Jap. Soc. Promotion of Science, Bull. 1, pp. 7-35.

—— (1940)*: Leucocratic Rocks associated with Serpentinite in Hokkaido. Jour. Jap. Ass. Petr. Min. & Econ. Geol., Vol. 23, Nos. 2-3, pp. 65-80, 124-142.

—— (1941)*: On Asbestos from Hokkaido. Ibid. Vol. 20, Nos. 5-6, pp. 207-221, 265-281.

—— (1942)*: Chromite Ores from Hokkaido. Ibid. Vol. 27, Nos. 3-4, pp. 115-127, 183-194.

—— (1943)*: A Contribution to the Knowledge of the Origin of Chromite Ore Deposit. Ibid., Vol. 29, No. 2, pp. 56-62.

—— (1944)*: An Outline of the Geology of Hokkaido. Jour. Geol. Soc. Japan, Vol. 51, pp. 15-24.

——and INOUE, T. (1948)*: A Contribution to the Knowledge of the Origin of Chrysotile Vein (Abstract). Jour. Geol. Soc. Japan, Vol. 54, pp. 194-195.

—— (1952): Ultra-basic Rocks and Associated Ore Deposits of Hokkaido, Japan. Jour. Fac. Sci. Hokkaido Univ. Ser. IV, Vol. VIII, No. 2, pp. 175-210.

—— (1953a): On the Piedmontite-bearing Rocks in Hokkaido. Petrological Notes, No. 3, Geol. Soc. Hokkaido, Bull. 22.

—— (1953b)*: On the Aegirine-augite-bearing Rocks in Hokkaido. Petrological Notes, No. 5, Geol. Soc. Hokkaido, Bull. 24.

—— (1953c): The Hypabyssal Rocks Associated with the Ultra-basic Rocks in Hokkaido, Japan. Comptes Rendus XIXth Intern. Geol. Congress. Alger.

—— (1953d)*: Fukagawa: Explanatory Text of the Geological Map of Japan, Scale 1/50,000. Hokkaido Development Agency.

—— (1954a): On the Rodingitic Rocks in the Serpentinite Masses of Hokkaido. Jour. Fac. Sci. Hokkaido Univ., Ser. IV, Vol. VIII, No. 4, pp. 419-430.

—— (1954b)*: On the Pillow Lavas in Hokkaido. Geol. Soc. Hokkaido, Bull. No. 26, pp. 11-20.

—— (1955)*: Asahikawa: Explanatory Text of the Geological Map of Japan, Scale 1/50,000. Hokkaido Development Agency.

—— (1957)*: Pippu: Explanatory Text of the Geological Map of Japan, Scale 1/50,000. Hokkaido Development Agency.

—— and SUZUKI, Y. (1958)*: Kamuikotan Valley. Geological guidebook, Hokkaido Univ.

—— (1958): On Some Special Minerals in Kamuikotan Crystalline Schists. Mineralogical Jour., Vol. 3, No. 6, pp. 660-673.

SUZUKI, Y. and TAKAYANAGI Y. (1956)*: On the Garnet-bearing Crossite Quartz

Schist Pebble in the Zaimokuzawa Conglomerate Formation at Atsuta, Ishikari Province. Geol. Soc. Hokkaido, Bull. No. 32, Petrological Notes, No. 13.

SUZUKI, Y. (1958)*: On the Serpentinite Mass in Yamabe District. Jour. Geol. Soc. Japan, Vol. 64, No. 12.

TAKEUCHI, K. and SAMBONSUGI, M. (1938)*: Urakawa Sheet: Explanatory Text of the Geological Map of Japan, Scale 1/100,000. Rep. Ind. Labr. Hokkaido, No. 1, pp. 1-22.

WASHINGTON, H. S. (1901): A Chemical Study of the Glaucophane Schists. Am. Jour. Sci. 4, Ser. 11, 35.

YABE, H. and SUGIYAMA, T. (1939): Discovery of a Mesozoic Hexacoral in a "Green Schistose Rock of the Kamuikotan System" of Hokkaido. Proc. Imp. Acad. Tokyo Vol. 15, p. 86-89.

—— and —— (1941)*: Discovery of *Circoporella semiclathrata* Hayasaka in Hokkaido. Jour. Geol. Soc. Japan, Vol. 48, p. 41.

YOSHIMURA, T. (1936)*: Garnet from Mitsuishi, Hidaka Prov. Jour. Jap. Ass. Petr. Min. & Econ. Geol. Vol. 14, pp. 257-265.

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