HOKKAIDO UNIVERSITY

Title	Petrography of the Kamuikotan Metamorphic Belt at the Ubun-Orowen Cross Section, Central Hokkaido, Japan
Author(s)	Hervé, Francisco
Citation	Journal of the Faculty of Science, Hokkaido University. Series 4, Geology and mineralogy, 16(4), 453-470
Issue Date	1975-02
Doc URL	http://hdl.handle.net/2115/36038
Type	bulletin (article)
File Information	16(4)_453-470.pdf

Instructions for use

Hokkaido University Collection of Scholarly and Academic Papers : HUSCAP

Jour. Fac. Sci., Hokkaido Univ., Ser. IV,
vol. 16, no. 4, Feb., 1975, pp. 453-470.

PETROGRAPHY OF THE KAMUIKOTAN METAMORPHIC BELT AT THE UBUN-OROWEN CROSS SECTION, CENTRAL HOKKAIDO, JAPAN.

by

Francisco Hervé*

(with 8 Figures)

(Contribution from the Department of Geology and Mineralogy, Faculty of Science, Hokkaido University, No. 1382)

Abstract

At the Orowen river-Ubun river cross section of the Kamuikotan belt in central Hokkaido, three metamorphic zones can be established. Zone I is characterized by the presence of pumpellyite, chlorite and jadeitic pyroxene in feebly recrystallized volcanic rocks. Aragonite is present in veins together with calcite. Basic rocks of Zone II are characterized by the presence of crossite, jadeitic pyroxene, pumpellyite, lawsonite and actinolite. Zone III is characterized by the occurrence of actinolite, chlorite and epidote in basic rocks. Basic and pelitic rocks have phengitic white micas in all three zones. Pelitic rocks bear abundant epidote only in Zone III. Metamorphic grade increases from east to west. The succession of mineral assemblage indicates high P/low T conditions of metamorphism, probably intermediate between the types I and II of Seki (1969). The westward increase in metamorphic grade, believed to indicate the direction of underthrusting (Ernst, 1971), is in contradiction with the currently proposed hypotheses of generation of the Kamuikotan belt by eastward plate subduction.

Introduction

The Kamuikotan metamorphic belt extends in a meridional direction through central Hokkaido (Fig. 1). It is mainly composed of metabasites, metapelites, metapsammites, metacherts and minor amounts of metalimestones. Along the whole of its extension, abundant serpentinite bodies, large and small, are associated to the metamorphic rocks. Of the two main outcrop areas of the Kamuikotan belt rocks, in the northern one, located west of Asahikawa city, schistose rocks are predominant. On the contrary, the southern one, is mainly composed of non-schistose rocks, in which original bedding

* Departamento de Geología, Universidad de Chile, Santiago de Chile.

planes, pillow structures, breccia structures, etc., are well preserved.

Low grade metamorphic minerals such as Na-amphibole, Na-pyroxene, aragonite, lawsonite, pumpellyite, stilpnomelane, etc. which are commonly regarded as indicating high P – low T conditions of metamorphism, are extensively developed along the belt. The metamorphic event that produced these minerals is thought to have taken place near the Cretaceous – Tertiary boundary, mainly affecting rocks of pre-late-Jurassic age, including rocks as old as Triassic (Igo et at, 1974).

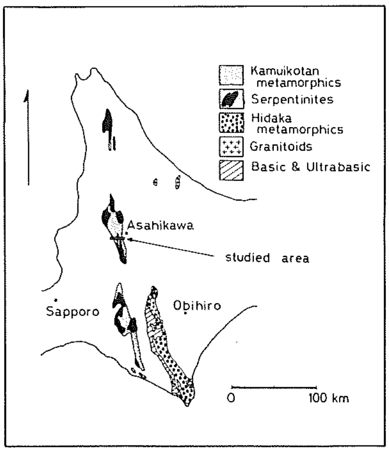


Fig. 1. Distribution of the Kamuikotan and the Hidaka Metamorphic Belts along Central Hokkaido.

The Kamuikotan belt is considered to constitute a paired belt system of the circum-Pacific type with the high T – low P Hidaka metamorphic belt that lies further east, beyond a belt of practically unmetamorphosed Cretaceous sedimentary rocks. At least part of the Kamuikotan metamorphics would be the metamorphic equivalent of the volcanic and volcaniclastic Sorachi series of late Jurassic age, which lies in transitional contact with them, towards the east. The west contact of the Kamuikotan belt is an overthrust of the metamorphic rocks over the Cretaceous and Cenozoic sedimentary formations.

The Kamuikotan belt became well known through the pioneer works by J. Suzuki, who pointed out the peculiar mineralogy present in the metamorphic rocks in numerous papers, and synthetized in 1959 (J. Suzuki and Y. Suzuki, 1959). A synthetic study on the Kamuikotan and the Hidaka belts was reported by Hunahashi (1957) and Minato et al ed. (1965). The Geological Surveys of Hokkaido and Japan have mapped most parts of the metamorphic belts and reported in 1:50,000 sheet maps with explanatory texts (e.g. J. Suzuki, 1955, M. Suzuki et al, 1964). Shido and Seki (1959) first pointed out the existence of jadeitic pyroxene in the metamorphic rocks of the Kamuikotan belt, at the well known outcrops of the Kamuikotan gorge. Banno and Hatano (1963) established a metamorphic mineral zoning at the Horokanai area, where Na-amphibole rich schists are well developed. The same area was studied by Shibakusa (1974) who refined the previously established zonation and gave more detailed data on the metamorphic minerals.

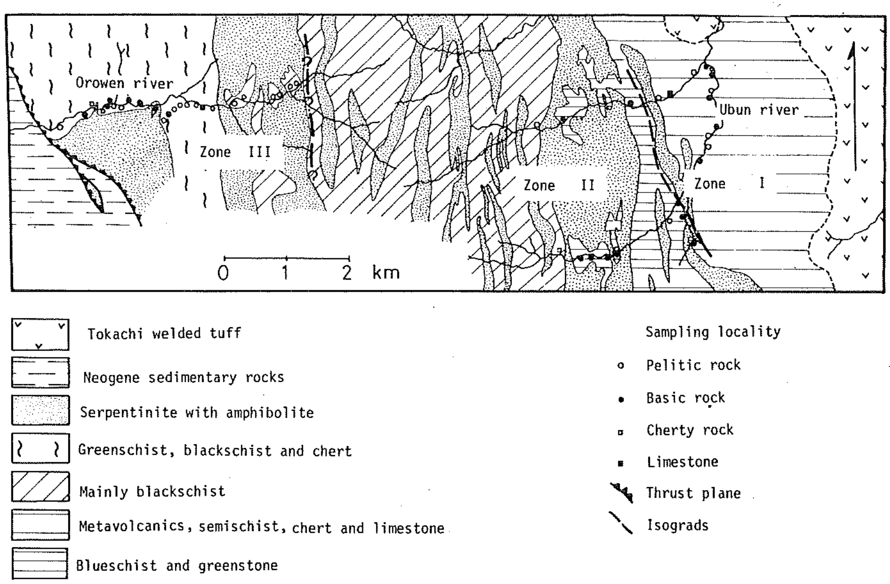


Fig. 2. Geological map of the studied area showing location of the studied samples. Geology simplified from Tazaki (1964)

The Orowen-Ubun area was studied by Tazaki (1964). He established a mineral zoning in the area, with metamorphic grade increasing from east to west. Zone I, lowermost in grade, is characterized by chlorite-pumpellyite assemblages. Zone II is characterized by the presence of Na-amphibole and lawsonite, and Zone III by the presence of epidote and blue-green hornblende in metabasic rocks. He also concludes that the metabasic rocks are rather poor in alkalies and higher in Fe_2O_3 / $FeO + Fe_2O_3$ ratio than basic rocks in non-glaucophanitic metamorphic areas.

The present paper deals with the results of mineralogical and petrographical study of 60 specimens collected during 5 days of field work at the Ubun-Orowen area. Location of studied samples is shown in Fig. 2, on a geological map simplified from Tazaki (1964). Petrographic study of 70 thin sections and X-ray investigation of the mineral species were carried out at the Department of Geology and Mineralogy, Hokkaido University, during a 15 month stay of the author.

General Description of the Area

In the studied region, the Kamuikotan belt constitutes a heavily forested north-south trending range with a maximum height less than 1000m. Outcrops are continuous along the Orowen river bed and flanking roads on the west slope of the range, and sporadic along the road cuts on the eastern slope, as well as on the flatter upper part of the range, which is composed of blackschists and serpentinites. Studied samples were obtained from the outcrops along the mentioned roads and the river bed of the Orowen river, their location is shown in Fig. 2.

Geologic Structure

No systematic study of the structure of the area was undertaken. The rocks located further east are weakly foliated, if at all, and preserve many relic primary structures. Deformation and recrystallization of the rocks increases to the west, and in the Orowen river, many rocks show the presence of two foliations of tectonic origin. Isoclinal folding of a previous planar structure with development of NS axial plane foliation is a prominent feature at the middle part of the Orowen river. Downstream, EW foliation and lineation predominate.

The serpentinite bodies are usually in tectonic contact with the surrounding rocks, roughly along NS shearing planes. Magnitude of the differential movements along these planes is not known, but the over-thrusting of the metamorphic belt over the Neogene formations to the west, and the relation between serpentinite bodies, and sharp mineralogical changes in the metamorphics, would indicate that along some of them, at least, they have been of rather big magnitude. After Tazaki (1964) a block structure due to NS and EW faults and shear planes is developed in the area.

Original Lithology

The easternmost, feebly recrystallized rocks allow to establish the nature of the original rocks. Lava flows, in which massive portions grade into brecciated protions, are recognized. Pyroclastic breccias and tuffs, sometimes finely banded, are also recognizable. Pelitic and psammitic stratified alternations, cherty horizons and occasional lime-stone beds constitute the sedimentary terms of the sequence.

To the west, relic textures and minerals become scarcer, and, at the westernmost part, completely recrystallized greenschists, blackschists and cherts are observed, with no trace of the original textures or minerals.

The metavolcanic rocks of the area, belong to a more extensive complex of volcanic rocks which outcrops in the axial zone of Hokkaido. M. Suzuki (1963) demonstrated that they constitute a sequence of spilitic nature. Compiled chemical data on the basic volcanics and metabasic rocks of the Sorachi Series and of the Kamuikotan belt (J. Suzuki and Y. Suzuki, 1959; M. Suzuki, 1963; and Tazaki, 1964) allow to characterize these rocks as belonging mainly to a tholeiite series, according to the diagrams presented by Miyashiro (1973). (Fig. 3)

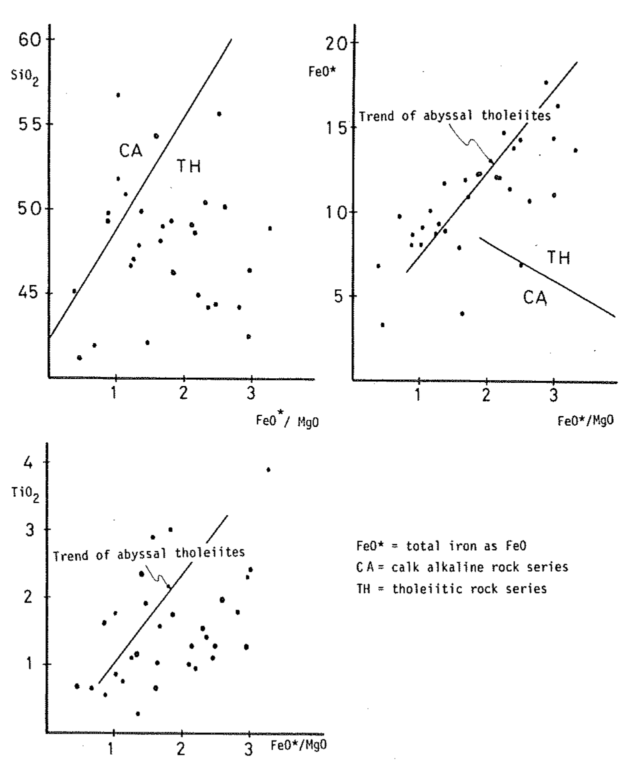


Fig. 3. Chemical variation diagrams of metabasites of the Kamuikotan Metamorphic Belt.

Petrography of the Metamorphic Rocks

The area was divided into three distinct metamorphic zones by Tazaki (1964). A similar scheme, with modifications as to the occurrence of some minerals, will be adopted here.

Zone I, the lowest grade one, is characterized by the presence of pumpellyite and chlorite in the metabasic rocks.

Zone II is characterized by the presence of Na-amphibole, mainly in the metabasic rocks. Pumpellyite and occasional lawsonite are also present. Na-pyroxene develops in coronas around relict clinopyroxene crystals.

Zone III is characterized by the presence of actionlite, epidote and chlorite in metabasic rocks.

The areal extent of the above mentioned zones is shown in Fig. 2. The isograd between Zones I and II is rather sharp and well defined in the field by the appearance of blueschists. The boundary between Zones II and III is more vaguely located. The cross section was not studied completely, and furthermore, only blackschists outcrop in the central portion. Tazaki (1964) extends Zone II until the western contact of the large NS serpentinite body at the Orowen river. From the studied samples it is clear that the epidote rich blackchists enclosed in that serpentinite are identical to those of Zone III. The boundary has been moved east on account of this fact, but its exact position remains unknown.

It should be noted that the serpentinite bodies have a close relation with the appearance of blueschists at the eastern side, and with the outcrop pattern of different rock types in general. Isograds as defined in this paper, could therefore represent tectonic disturbances which bring side by side blocks of differing metamorphic grade of the Kamuikotan sequence. Nevertheless, the westward increase in metamorphic gradw is hardly explained in terms of tectonic perturbations, and should reflect increased temperature in that direction during metamorphism.

Zone I

This zone is composed of feebly metamorphosed interbedded pelitic, psammitic, basic pyroclastic and volcanic rocks, with minor chert and limestone beds.

Pelitic and psammitic rocks are mainly composed of quartz, albite, white mica and chlorite in varying proportions. Calcite and stilpnomelane are occasionally present. Sphene and opaque minerals are abundant, tourmaline is sometimes observed. Porphyroclasts of strained quartz and plagioclase also occur, along with occasional detrital zircon and volcanic rock fragments. The principal foliation plane, parallel to which the micaceous minerals grow, is crenulated by a secondary foliation. Tectonic microgranulation of these rocks is common, giving rise to semi-schists.

Most basic rocks reveal a pyroclastic nature. Fragments of volcanic rocks are embedded in a matrix composed of non-oriented aggregations of quartz, albite, calcite, chlorite, and white mica, which contain partly altered plagioclase porphyroclasts. The rock fragments are porphyritic, with abundant clinopyroxene and plagioclase phenocrysts in a fine grained opacitized matrix with plagioclase microlites. The clinopyroxene phenocrysts and isolated porphyroclasts in the matrix, are crushed and partly transformed to chlorite-calcite aggregates. In the matrix of the volcanic fragments, symplectite-like aggreggates of Na-pyroxene as well as fine grained pumpellyite develop. Calcite and pumpellyite veins cut across the rocks. Aragonite is present in some of these veins.

Chlorite – calcite – pumpellyite – Na-pyroxene seems to be a stable assemblage in the basic rocks.

Zone II

This zone is characterized by the presence of more recrystallized rocks than in Zone I, with blueschists as the typical rock type.

Pelitic black schists are composed of quartz, albite, white mica, chlorite and opaque minerals. Occasionally, zoned Na-amphibole automorphs occur in them, showing a deep blue core and pale green, actinolitic rims. Relic pyroxenes are rare.

Cherty of psammitic black schists, composed of quartz, actinolite, stilpnomelane, some albite, and abundant dusty opaque minerals, are characteristic members of the sequence in this zone and also in Zone III.

Among the basic rocks, blueschists and massive greenstones are predominant. Porphyroclasts of clinopyroxene are abundant. Some rocks contain also plagioclase porphyroclasts, which appear to preserve original gabbroic textures. A mineral assemblage of Na-amphibole, Na-pyroxene, chlorite and pumpellyite is common in the porphyroclast-bearing rocks, accompanied eventually by smaller amounts of albite, actinolite, white mica, sphene and opaque minerals. Well foliated, banded blueschists, without relic minerals, are composed of Na-amphibole, chlorite, pumpellyite, lawsonite and leucoxene. Lawsonite appears to be replaced along S_2 planes by albite-calcite-actinolite assemblages.

Zone III

In this zone, the studied rocks are devoid of relic minerals, as well as of Na-amphibole, Na-pyroxene, lawsonite or pumpellyite. All the rocks are well foliated and mineralogically banded, indicating a thorough metamorphic crystallization.

Pelitic black schists are rich in quartz, and contain albite, chlorite, white mica, epidote, and minor sphene and opaque minerals. Calcite is present in bands or veins, together with quartz and albite. Stilpnomelane is common, and at some places, very abundant.

Cherty rocks are usually banded, with quartz or epidote-rich bands. Chlorite, stilpnomelane, albite and opaque minerals occur in subordinate amounts.

Basic rocks are represented by banded greenschists, composed invariably of albite, chlorite, actinolite and epidote. Sphene and opaque minerals are common accessories. White mica is very scarce. Green biotite was observed in one of the samples. Quartz and calcite occur in veins together with stilpnomelane. Albite-actinolite veins also exist.

Mineralogical Aspects

In this section, data on the nature of some mineral species as well as some selected textural relations between characteristic minerals will be presented.

White Mica

White mica is one of the main components of the pelitic schists and it is also present, in minor amounts, in the basic rocks, specially in Zone II. The white mica crystals are usually well oriented along the main foliation plane of the schists, concentrated in bands with chlorite in Zones I and II, and with chlorite and epidote in Zone III.

X-ray measurements of d_{006} of 16 white micas of pelitic schists and 5 of basic schists gave the following results:

a) No significant change in basal spacing is observed with metamorphic grade. (Fig. 4).

b) Average of calculated d_{001} is 9.939 Å in pelitic schists and 9.927 Å in basic rocks. General average is 9.936 Å.

c) The obtained values are comparable to those presented by Ernst et al (1970) for white micas of the Sambagawa metamorphic belt of Japan in the Shirataki district of Shikoku (average d_{001} = 9.939 Å) and slightly higher than the average for the white micas of the Fransiscan metamorphics in California (average d_{001} = 9.912 Å).

Though no chemical analysis of the studied white micas are available, its basal spacings strongly suggest that they are phengitic micas, as is well demonstrated for the micas of the Sambagawa and Franciscan rocks mentioned above.

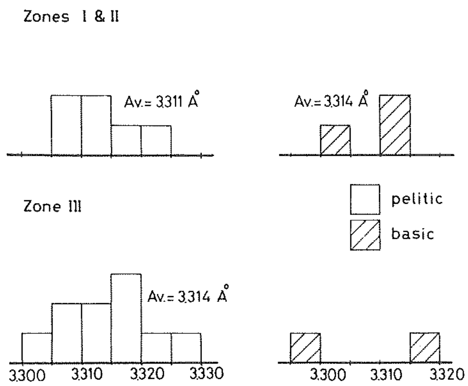


Fig. 4. Variation of d_{006} of $2M_1$ phengitic white mica with metamorphic grade.

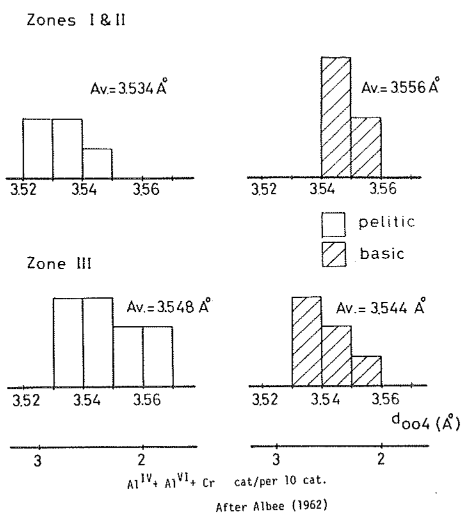


Fig. 5. Variation of d_{004} of chlorite with metamorphic grade.

Chlorite

The d_{004} dimension of 14 chlorites of blackschists and 10 of basic rocks was determined with an estimated error of 0.0025 Å.

A variation in the d_{004} spacing of chlorite with metamorphic grade is observed (Fig. 5). It is noticed that the basal spacing of chlorite increases with the metamorphic grade in pelitic rocks and decreases with the grade in basic rocks. Average values of d_{004} for each zone are given in Fig. 5.

General average of d_{004} is 3.545 Å which is very similar to that for the chlorites from low grade rocks of the Franciscan metamorphics (average = 3.546 Å), and higher than that for the chlorites from the metamorphic rocks of the Sambagawa belt in the Shirataki district (average = 3.538 Å) (Ernst et al, 1970).

After Albee (1962), the Al content of chlorites is inversely proportional to their basal spacing. The chlorites of pelitic schists from the studied area are thus depleted in Al with increasing metamorphic grade, while those in basic rocks are enriched in Al with grade. If a continuous variation in bulk rock composition in the studied area is precluded, varying mineral paragenesis associated to chlorite schould account for observed compositional variation in the chlorites themselves. The appearance of abundant epidote in the black-schists of Zone III could account for the lower Al content of the chlorites in them as compared to those in the epidote free pelitic schists of Zones I and II.

Al enrichment in chlorites from the basic rocks of Zone III might be related to the replacement of aluminium-rich minerals such as pumpellyite or lawsonite to Al-poor actinolite and epidote.

Optically negative chlorites are largely predominant, with blue anomalous interference colors. Isotropic or nearly isotoropic chlorites are also common. They could be named as Fe-Mg chlorites after Albee (1964). Optically positive chlorites with brown interference colors, i.e. Mg-Fe chlorites, are rarely found only in Zone III. Thus, a certain enrichment in Mg content of chlorites with metamorphic grade is suggested.

Epidote

Epidote is a common and abundant mineral in pelitic, basic and cherty rocks of Zone III. On the contrary, it is not found in rocks of Zone I, and is a rare mineral in rocks of Zone II.

The epidote of Zone III is mainly pistacite, with yellow pleochroic scheme. In some cases, opaque-inclusion rich yellow cores are surrounded by limpid paler colored rims. Also, post tectonic (?) crosscutting automorphs of clinozoisite are occasionally observed in the blackschists.

The epidote from Zone II occurs as very small crystals, both in pelitic and basic rocks. Its identification is by no means easy with optical inspection, and its quantity in the rocks is so small that X-ray confirmation of its presence was impossible. It is present only in 3 of the studied samples of Zone II.

Myer (1966) proposed an X-ray method for estimating the Fe^{+++} content of epidotes. Values obtained for epidotes from Zone III are presented in Fig. 6. Average Fe^{+++} content per 8 cations of formula unit (Fe_X) in epidotes of basic rocks is 0.353, in pelitic rocks it is 0.307, and in cherty rocks is average 0.270.

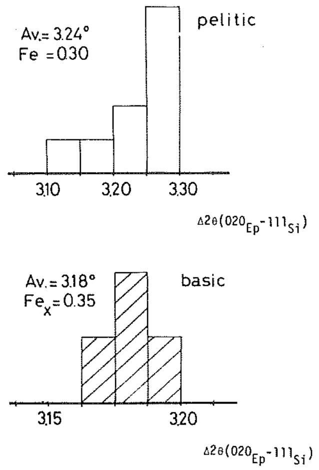


Fig. 6. $\Delta 2\theta$ (020_{Ep}-111_{Si}) values for epidote in basic and pelitic rocks of Zone III.

Relic Clinopyroxene and its Metamorphic Transformation

The basic rocks of Zones I and II frequently contain relic clinopyroxene crystals. These crystals range in size from very small fragments up to 1cm porphyroclasts. They are usually fractured and the larger crystals are wrapped around by foliation. In some rocks they are very abundant, constituting up to 15–20% of the rock. In some cases they are accompanied by coarse grained relic plagioclase crystals, suggesting a gabbroic rock origin. More frequently, the relic pyroxene bearing rocks are derived from pyroclastic rocks or lava flows.

The relic clinopyroxenes are mostly augite, and some crystals exhibit well developed hourglass structure. They show different kinds of transformation to metamorphic minerals.

The relic clinopyroxenes from Zone II, usually have a corona or rim composed of pale green aegirine-augitic clinopyroxene. The boundary between core and rim is very sharp, Becke line can be observed, the rim having higher index than the core. The outer border of the rim is indented, usually blue amphibole prisms are intergrown with the aegirine-augite, and form an irregular outer aureole, which in turn is relayed outwards by chlorite and or actinolite. In some cases, only the rim is preserved, the relic pyroxene of the core being replaced by an aggregate of Na-amphibole, calcite and chlorite.

On more advanced recrystallization, the relic pyroxenes are replaced by a symplectite-like aggregate of aegirine-augite, Na-amphibole, actionlitic amphibole with minor amounts of chlorite and calcite.

The relic clinopyroxene from Zone I is always fractured and sheared, it is mainly replaced by calcite along cracks and borders, being sometime surrounded by a pumpellyite felt. It becomes inhomogeneous, with opaque dust bearing areas beside limpid ones. But no clear rim develops in them. The matrix of the rocks bearing relic clinopyroxene, contain, generally, abundant pumpellyite and Na-pyroxene in small subautomorphic needles.

Alakli Amphibole

Na-amphibole is a typical and widespread mineral in Zone II.
It occurs in two distinct manners:

a) In association with relic clinopyroxenes as described above. In this case Na-amphibole is not abundant in the rocks, and restricted only to the immediate surroundings of the relic clinopyroxene crystals.

b) In blueschists, in which it is a predominant mineral. Banded schists with centimetric bands of almost pure Na-amphibole alternating with lawsonite-rich bands, with minor quantities of pumpellyite, chlorite and leucoxene, constitute a remarkable rock type in the area. Blueschists of this type, do not contain any relic minerals, and may be derived from banded tuffs.

Na-amphiboles of the blueschists have d_{310} values of 3.061 ±0.002 Å (4 samples) which indicates roughly a crossite composition (Ernst et al, 1970).

Pumpellyite

It is a fairly aboundant mineral in Zones I and II, especially in the metabasic rocks. In Zone I it is yellowish in color, with very high refractive indices. It occurs sparsely in the matrix of volcanic fragments, replacing partially the plagioclase phenocrysts, or in contorted irregular veins. In zone II, it is usually pale green in color, and occurs mainly in rounded aggregates of acicular slender prisms. These aggregates constitute distinct dark grey spots on some of the metabasites.

Lawsonite

It is not a widerspread mineral, though being very abundant in the banded blueschists mentioned above. Lawsonite is transformed to albite and calcite aggregates along the S_2 foliation planes.

Plagioclase

Relic calcic plagioclase is observed in the feebly recrystallized metavolcanics of Zone I. It occurs as isolated crystals, as well as phenocrysts and groundmass minerals in the fragments of basaltic rocks. It is usually transformed partially into calcite and pumpellyite. Detrial plagioclase is present in psammitic semischists, together with quartz, some micas, tourmaline, and detrital zircon grains.

Albite appears in veins parallel to or crosscutting the foliation planes, both in basic and pelitic rocks of Zones II and III. Its abdundance seems to increase with metamorphic grade. Only in the westernmost portion of Zone III, albite microporphyroblasts develop in the micaceous bands of the pelitic schists.

Apparent compositions of albite as determined by the $\Delta 2\theta$ $(131-1\bar{3}1)$ method (Smith and Yoder, 1956) are restricted to the range An_{01} – An_{04} in crystals of low structural state.

Carbonate Minerals

Carbonate minerals have a wide but discontinous distribution in the studied area. They are present mostly as veins, in 2/3 of the studied basic rocks and in 1/3 of the pelitic ones. X-ray study of 12 carbonate samples of veins or vugs in basic rocks from all three metamorphic zones, indicated that calcite is widely predominant in all the samples, and that aragonite is present in two samples from Zone I. Veins from Zones II and III apparently contain only calcite.

In Zone I, the carbonate minerals appear in monomineralic veins, as a replacement product of the relic clinopyroxenes or plagioclase crystals, and in irregular shaped patches disseminated in the rocks. The crystals are usually strained, and their contours extremely irregular and indented.

In Zone II calcite is usually present in crosscutting veins. In Zone III calcite forms veins together with quartz and albite. The calcite crystals are usually unstrained and form characteristic aggregates of polygonal calcite grains with quartz and albite showing a poikilitic texture. These veins are usually folded together with the main foliation plane of the host rocks.

Biotite

A small outcrop of basic rock completely surrounded by serpentinite, located at the middle course of the Orowen river in Zone III, is composed of albite, biotite, blue-green amphibole-epidote rock. Biotite is abundant, whereas chlorite is completely lacking. The biotite occurs as subautomorphic plates, 1mm in size, with strong pleochroism: X = colorless and Z = green, and with high interference colors. The nature of the mineral was established by X-ray. Apparently, this is the first description of green biotite from the Kamuikotan metamorphics.

Stilpnomelane

Ferristilpnomelane is a common mineral in rocks belonging to the three metamorphic zones. Its abundance and grain size is bigger in Zone III. Its presence is discontinuous, the rocks existing near by with a similar mineralogical constituent may carry abundant stilpnomelane or none. In all, one third of the pelitic and basic rocks contain it.

In the basic rocks stilpnomelane is best developed in veins associated with calcite. In this case, stilpnomelane concentrates near the border of the veins, and in bundles which extend into the neighboring rocks, where it seems to replace the chlorite.

In the blackschists, on the contrary, it seems to be antipathetic to calcite. It is best developed in siliceous blackschists lacking muscovite or chlorite, and associated with slender prisms of actinolite. In muscovite and chlorite bearing pelitic schists, it develops preferentially at the periphery of quartz veins, mainly replacing chlorite.

Successive Mineral Paragenesis and Metamorphic Environment

The sequence of metamorphic mineral assemblages present in the rocks of the studied area is exhibited in Fig. 7. The mineralogic evolution of the basic rocks with increasing metamorphic grade can be summarized as follows:

Zone I: Pumpellyite – chlorite – Na-pyroxene
Zone II: Pumpellyite – chlorite – Na-pyroxene – Na-amphibole – actinolite
Pumpellyite – lawsonite – Na-amphibole
Zone III: Actinolite – chlorite – epidote

Seki (1969) presented a classification of low grade facies series types on the basis of observed sequences of mineral paragenesis in different metamorphic terranes of the world. According to this classification, the mineral sequence of the studied cross section of the Kamuikotan belt, appears to be intermediate

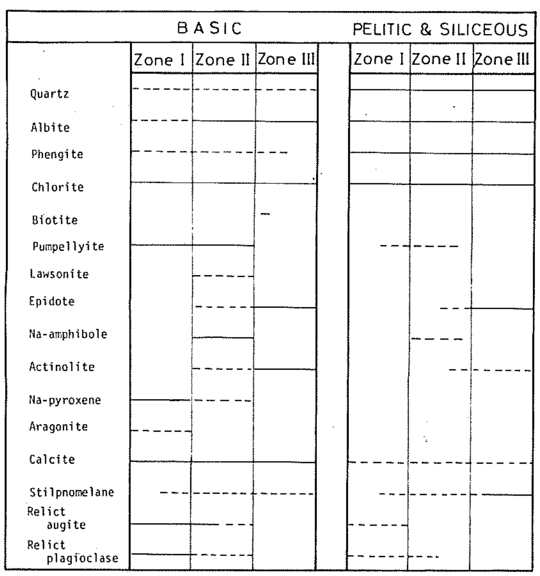
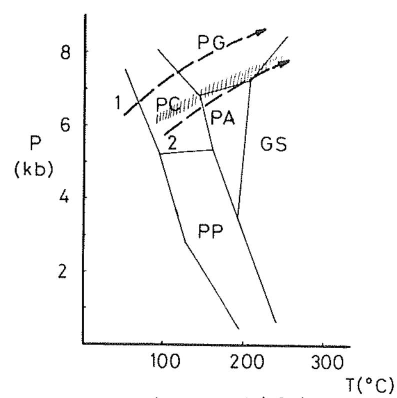


Fig. 7. Successive mineral paragenesis at the Orowen – Ubun river cross section of the Kamuikotan Metamorphic Belt.

between what is observed at the Sambagawa metamorphic belt and the Franciscan terrane of California. In fact, Seki (1969) states that in the Sambagawa belt, the association of pumpellyité and glaucophane is very rare or absent, while it is of common occurrence in the Franciscan metamorphics. On the contrary, actinolite is absent in the Franciscan, while common in the Sambagawa. In the studied area, pumpellyite and glaucophane, occur together, accompanied by lawsonite or actinolite. Widespread occurrence of jadeitic pyroxene and presence of aragonite in the Kamuikotan, match the occurrence of these minerals in the Franciscan, while the grading into higher grade greenschists in similar to what is observed in the Sambagawa.

These considerations would allow, according to the Seki's (1969) scheme, to estimate the P-T conditions of formation of the studied rocks as shown in Fig. 8, which correspond to intermediate between the supposed gradients for the rocks of the Kanto Mountains of the Sambagawa belt and the Franciscan rocks.



PP = prehnite - pumpellyite (metagraywacke) facies

PC = pumpellyite - chlorite facies

PG = pumpellyite - glaucophane facies

PA = pumpellyite - actinolite facies

GS = Actinolite - greenschist facies

Studied area

Curve 1 Probable P-T relationships in metamorphism of the Franciscan belt, California. (After Seki, 1969)

Curve 2 Probable P-T relationships in metamorphism at Kanto Mts., Sanbagawa belt, Japan (After Seki, 1969)

Fig. 8. Probable P-T condition during metamorphism in the studied area according to Seki's (1969) diagram for low-grade metamorphic facies.

Some General Considerations of the Geotectonic Setting

The Kamuikotan-Hidaka paired metamorphic belts are peculiar because of their reversed disposition with the high P – low T belt at the continental side, as compared with other metamorphic belts around the Pacific ocean. To explain these reversed disposition several hypotheses based on plate tectonics have been suggested. Matsuda and Uyeda (1971) proposed two possibilities on the basis of the assumption that paired metamorphic belts generated at the plate margins, i.e. 1) during the metamorphism the present Japan sea basin was underthrusting eastwards, or 2) Hokkaido was rotated clockwise by 90 degrees after the formation of the metamorphic belts in a "normal" position facing the Pacific Ocean. Den and Hotta (1973), based on geophysical and geological data, suggested that the Kamuikotan-Hidaka system was generated in a subduction zone at the western margin of the westward moving "Okhostk plate", that finally collided with and thrusted over the crust of western Hokkaido along the present location of the metamorphic belts. In this conection, Ernst (1971) showed a strong evidence that in the Sambagawa, the Franciscan, and the Alpine belts, the direction of increase in metamorphic grade in the high pressure belts indicates the sense of movement of the underthrusting plate. In the studied area, however, the metamorphic grade increased from east to west, that would be in conflict with the above mentioned hypotheses for the generation of the belts. More detailed informations and considerations on this problem are still needed before applying simple models to the Kamuikotan-Hidaka system.

Acknowledgements

This paper is dedicated to Prof. M. Hunahashi at his retirement from Hokkaido University. The author received from him enlightening informations about the geology and petrology of Japan during a 15 month stay at the Department of Geology and Mineralogy of Hokkaido University. Profs. T. Ishikawa and Y. Katsui provided the adequate academic conditions for the realization of this work. Prof. Y. Katsui and Messrs. T. Watanabe, K. Niida and T. Uda provided helpful assistance and discussion during field work. Drs. Y. Oba and K. Onuma provided the necessary help during laboratory work. Prof. Y. Katsui greatly improved the final manuscript. Mrs. S. Yokoyama skillfully typed the manuscript. To all of them, and to all the staff members of the Department of Geology and Mineralogy of Hokkaido University, the author's hearty thanks are due.

Reference

Albee, A.L. (1962): Relationship between the mineral association, chemical composition and physical properties of the chlorite series. *Amer. Min.* 47, 851-870.

Banno, S. and Hatano, M. (1963): Zonation of metamorphic rocks in the Horokanai area of the Kamuikotan metamorphic belt in Hokkaido. *Jour. Geol. Soc. Japan.* 69, 388-393.

Den, N. and Hotta, H. (1973): Seismic refraction and reflecting evidence supporting plate tectonics in Hokkaido. *Pap. Meteo. and Geophy.* 24, 31-54.

Ernst, W.G. (1971): Metamorphic zonations on presumably subducted lithospheric plates from Japan, California and the Alps. *Cont. Min. and Petr.* 34, 43-59.

Ernst, W.G., Seki, Y., Onuki, H. and Gilbert, M. (1970): Comparative study of low grade metamorphism in the California Coast Ranges and the Sanbagawa metamorphic belt of Japan. *Geol. Soc. Amer., Memoir* 14.

Hunahashi, M. (1957): Alpine orogonic movement in Hokkaido, Japan. *Jour. Fac. Sci., Hokkaido Univ., Ser.* 4, 9, 415-469.

Igo, H., Koike, T., Igo, H. and Kinoshita, T. (1974): On the occurrence of Triassic conodonts from the Sorachi Group in the Hidaka Mountains, Hokkaido. *Jour. Geol. Soc. Japan.* 80, 135-136.

Kawano, Y., Matsui, K. and Shimizu, I. (1956): Explanatory text of the geological map of Japan, scale 1:50,000, Utashinal. Geol. Surv. Japan, 52p.

Matsuda, T. and Uyeda, S. (1971): On the Pacific-type orogeny and its model extension of the paired belt concept and possible origin of marginal seas. *Tectoniphysics.* 11, 5-27.

Minato, M., Gorai, M. and Hunahashi, M. (Editors) (1965): *The geologic development of the Japanese islands.* Tsukiji Shokan Pub. Co., Tokyo, 442p.

Miyashiro, A. (1974): Volcanic rock series in island arcs and active continental margins. *Amer. Jour. Sic.* 274, 321-355.

Myer, G.H. (1966): New data on zoisite and epidote. *Amer. Jour. Sci.* 264, 364-385.

Seki, Y. (1969): Facies series in low grade metamorphism. *Jour. Geol. Soc. Japan.* 75, 255-266.

Shibakusa, H. (1974): Glaucophane schists in the Kamuikotan metamorphic belt of the Horokanai area, central Hokkaido. *Jour. Geol. Soc. Japan.* 80, 341-353.

Shido, F. and Seki, Y. (1959): Note on rock forming minerals (11). Jadeite and hornblende from the Kamuikotan metamorphic belt. *Jour. Geol. Soc. Japan.* 65, 673-677.

Suzuki, J. (1955): Explanatory text of the geological map of Japan, scale 1:50,000, Asahikawa. Geol. Surv. Japan, 32p.

Suzuki, J. and Suzuki, Y. (1959): Petrological study of the Kamuikotan metamorphic complex in Hokkaido, Japan. *Jour. Fac. Sci. Hokkaido, Univ.*, Ser. 4, 10, 349-446.

Suzuki, M. (1963): On so called schalstein in the axial zone of Hokkaido. *Earth Science (Chikyu Kagaku),* 66, 15-22.

Suzuki, M., Watanabe, J. and Kasugai, A. (1964): Explanatory test of the geological map of Japan, scale 1:50,000, Biei. Hokkaido Develop. Agency, 26p.

Tazaki, K. (1964): Alkali amphibole-bearing metamorphic rocks in the Kamuikotan belt of the south-western part of Asahikawa, Central Hokkaido. *Earth Science (Chikyu Kagaku),* 71, 8-17.

Received on Oct. 26, 1974