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# IMPLICATION OF THE COMPOSITE MINERALIZATION ON THE MASSIVE SULFIDE DEPOSITS OF THE SHIMOKAWA MINE

*by*

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(with 12 text-figures, 8 tables and 13 plates)

*Abstract*

Study on massive sulfide ores of the Shimokawa mine disclosed that the ores have been created by two distinctive phases of mineralization; One is characterized by precursory cubic-colloform pyrites (py(I)) probably related to the formation of pillow lavas in a fore-arc basin. The other is marked by presence of chalcopyrite-pyrrhotite-sphalerite assemblage associated with accessory cubanite, cobalt-pentlandite, mackinawite and pyrite (py(II)).

Lead isotope data on the Shimokawa pillow lava, diabase and copper dominant ore, and gabbros in the Hidaka metamorphic belt suggest that copper dominant ore from the Shimokawa mine is not consanguineous with the Shimokawa pillow lava, but with the gabbros of the Hidaka metamorphic belt. From the lead isotope data, the Shimokawa ore deposits have been regarded as a composite type related to magmatic activities in both a fore-arc basin and an island arc system.

Based on the geologic and geotectonic relationships of the Shimokawa diabase complex and the adjacent Nisama igneous complex it is concluded that the Shimokawa diabase complex is a slab obducted onto the island arc system represented by the Nisama igneous complex. The ore solution related to the formation of Shimokawa copper dominant ores might have been created in relation to the magmatism forming the Nisama gabbroic mass possessing nickeliferous pyrrhotite deposits.

## Introduction

The Shimokawa mine is situated in the northern part of the Hidaka metamorphic belt, central Hokkaido. The mine exploited $680 \times 10^4$ metric tons of massive sulfide ores with an average of 2.3% Cu, 0.8% Zn, 0.22% Co and 20.3% S since 1942 until the mine closed in 1982. The scale of the ore depostits has been regarded to be 1800m long N-S, 600m in depth and 7.8m in average thickness. The ore deposits are constructed from seven orebodies; Hokubu-OREBODY, Shin-OREBODY, Shinshin-OREBODY, Honpi-OREBODY, No.17-OREBODY, Uwaban-OREBODY and Nanbu-OREBODY from north to south. The common mode of occurrence of these orebodies is a hanging-wall of black slate and a foot-wall of pillow lava or diabase sheet dipping steeply toward the east.

Genetic models of the Shimokawa massive sulfide ore deposits have long debated whether they are of epigenetic or syngenetic origin. Since the 1960's, based on the recognition of pillow lavas in the foot-wall and the appearance of colloform pyrites in some ores, the view of an exhalative sedimentary origin (Miyake, 1965) has been put forward.

Recently the black slates intercalated in the Shimokawa diabase complex were reinvestigated by Mariko et al. (1982), and it was confirmed that the strata were mostly

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overturned and that the pillow lava or diabase previously regarded as a foot-wall was originally the hanging wall of the orebody.

On the other hand, mineralogical study on the Shimokawa ores (Bamba et al., 1985) led to a conclusion that the ores might have been formed by composite mineralizations; The precursory pyrite ore is considered to be of exhalative sedimentary origin, however, the subsequent mineralization induced a geochemical zonation of hexagonal and monoclinic pyrrhotites from southern bottom to northern top ot the orebodies. Co/Ni values of cobaltpentlandites are high in the northern upper part of the orebodies compared with those in the southern lower part.

Geochemical studies on the Shimokawa ores have been carried out. Sulfur isotope ratios of the Shimokawa ores were reported by Nishiyama et al. (1983) and Yamamoto et al. (1984) and show an anomalously wide range from $-5$ to $+20$ of $\delta^{34}S$ (0/00). Lead isotope data suggest that the copper dominant ores of the Shimokawa mine don't originate in the upper mantle but are derived from an island arc system. Thus, in this paper, the geologic setting of the Shimokawa diabase complex and the adjacent Nisama igneous complex of the Hidaka metamorphic belt are comparatively discussed to arrive at an ore genesis model.

## Previous Studies on the Shimokawa Diabase and Ore Genesis

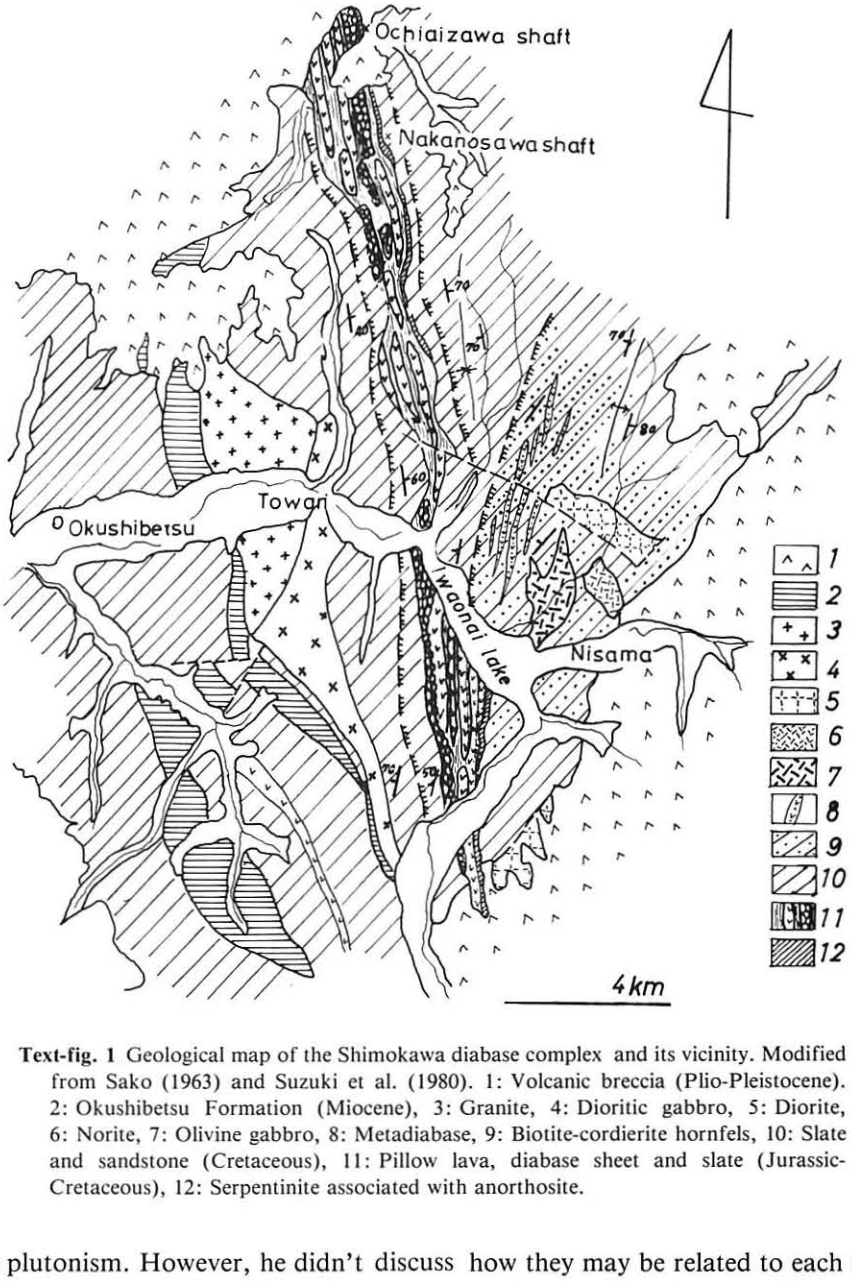
Bamba (1946) introduced the geology of the Shimokawa mine for the first time in his Graduation Thesis from Hokkaido University. In the geologic map, numerous diabases ware interpreted as dike swarms running N-S in strata mainly composed of slate and sandstone. The sedimentary rocks in the diabase swarm are expressed in concordance with the diabase though the strike of the sediments is different on the eastern and western sides of the diabase swarm. He didn't say, however, anything on the tectonic problem in his report. The green rocks in question were first called diabase by him based on the mineral assemblage of augite-plagioclase-ilmenite and its peculiar ophitic texture. Serpentinite, diallage gabbro occurring at the eastern margin of the diabase swarm were interpreted as contemporaneous and the ore deposits were defined as cupriferous pyrite deposits.

Ushizawa (1952, 1956) emphasized that the Shimokawa ores were hydrothermally formed based on the presence of a wall rock alteration halo of about 200m radius surrounding the orebodies.

Because of the complicated mode of occurrence of these rocks, Sako (1952) published the Geological Sheet Map "Okushibetsu" in which he expressed the diabase swarm as diabase-slate complex 20km long and 1.5km wide.

In the eastern area of the Shimokawa diabase swarm, another geologic unit called the Nisama igneous complex appears. Sako (1952) showed that the complex is characterized by the presence of metadiabase, olivine gabbro, norite, diorite and biotite-cordierite hornfels (Text-fig. 1).

Afterward, Sako (1963) investigated a number of sulfide ore deposits in the Hidaka metamorphic belt, then he emphasized that these mineralizations may be closely related




**Text-fig. 1** Geological map of the Shimokawa diabase complex and its vicinity. Modified from Sako (1963) and Suzuki et al. (1980). 1: Volcanic breccia (Plio-Pleistocene). 2: Okushibetsu Formation (Miocene), 3: Granite, 4: Dioritic gabbro, 5: Diorite, 6: Norite, 7: Olivine gabbro, 8: Metadiabase, 9: Biotite-cordierite hornfels, 10: Slate and sandstone (Cretaceous), 11: Pillow lava, diabase sheet and slate (Jurassic-Cretaceous), 12: Serpentinite associated with anorthosite.

to the plutonism. However, he didn't discuss how they may be related to each other. He pointed out that the diabases in the Nisama igneous complex are different rock series than the Shimokawa diabase swarm because prominent amphibolization is recognized in the Nisama diabase. Sako (1963) correlated the Shimokawa diabase to the western zone of the Hidaka metamorphic belt.

Miyake (1964) recognized pillow lava in the Shimokawa diabase complex and he explained it as a product of subaqueous eruptions during the Hidaka geosyncline. From the mode of occurrence of the massive sulfide ores in relation to the pillow lava, he emphasized that the ore deposits should belong to a typical exhalative sedimentary deposit. Miyake (1965) subsequently recognized colloform pyrites in the ores and he inferred a syngenetic origin.

Hunahashi et al. (1966) pointed out that Shimokawa diabase occupy a limited area at the junction of two different geologic units and that both sides of the diabase swarm are characterized by prominent shear zones. Consequently, they concluded that the diabases are wholly intrusive.

Bamba et al. (1970) classified the Shimokawa diabase petrographically into ophitic and variolitic diabases. Both were chemically analysed and it was concluded that these belong to tholeiitic rock series.

Kinzokukogyo-Jigyodan (1970, 1980), a Japanese governmental organization for the exploration of metallic resources, advanced the geologic investigations in the Shimokawa mining area using modern techniques, e.g. geophysical, geochemical methods and deep drillings. They found that the diabases dipping steeply eastward could be observed as deep as 1000m at about ten localities. A more detailed geologic map and profiles of the Shimokawa diabase swarm were drawn, and they confirmed the presence of three prominent mineralized zones in the diabase complex. The mineralized zones were found not only at the boundary between pillow lava and slate but in slate or in diabase itself. It was also found that altered rocks characterized by amphibolization, chloritization, sericitization, and silicification appear in each mineralized zone.

Ikeda et al. (1972) confirmed the mode of occurrence of colloform pyrites at lower levels of the orebodies. They pointed out that the colloform pyrites are restrictedly found in massive pyrite ores.

Suzuki et al. (1980) studied the wall rock alteration of the Shimokawa diabases in relation to the mineralization. They emphasized the presence of an alteration halo around the orebody, i.e. strong amphibolization is observed at the core of the alteration halo, and chloritization is present surrounding the amphibolized rocks. They also recognized that Fe content of chlorite tends to be higher toward the orebody and thus inferred an epigenetic origin for the Shimokawa ores.

Miyake et al. (1981) estimated that the Shimokawa diabase complex is a member of an ophiolite suite which may be composed of serpentinite-peridotite-gabbro-(fine-grained-gabbro)-pillow lava-massive sulfide-slate in ascending order. Thus they proposed a model concerning the generation of an ore solution related to the formation of the Shimokawa ores, i.e. chloritization and amphibolization of the diabase are attributed to the submarine metamorphism characterized by low pressure and high temperature conditions perhaps induced in an oceanic ridge where anhydrous basalt might have been converted to various metamorphic rocks such as amphibolite facies, green-schist facies, zeolite facies and prehnite facies by geothermal activity. Through the process, $Mn^{2+}$ and $Fe^{2+}$ separated from basalt, then at higher temperature Cu may have separated from the rock.

Mariko et al. (1982) investigated the Shimokawa diabase complex from a stratigraphical point of view. They found that the sandy slates in the complex have been overturned in the northern part based on the observations of cross lamina and graded bedding and the downward protrusion of pillow lava. The results led to the conclusion that the pillow lava is the hanging-wall and the slate the footwall of the orebodies.

Nishiyama et al. (1983) and Yamamoto et al. (1984) studied sulfur isotopes of some Kieslager type massive sulfide ore deposits, e.g. Yanahara, Besshi, Hitachi and Shimokawa mines, and obtained values of $\delta^{34}S$ (0/00 ) ranging from 0 to (+)5 in general, whereas the value of the Shimokawa ore is anomalous showing a very wide range from (−)5 to (+)20 in 31 samples. Miyake et al. (1981) reported that sulfur isotope data on some Shimokawa ores are comparatively stable averaging (+)8.71. They interpreted that the ore sulfur may be derived from sulfates in sea water and claimed that this indicates the presence of a geothermal system in an oceanic ridge.

Mariko (1984) classified the metamorphic grade of the Shimokawa diabase complex into amphibolite facies, green-schist facies, prehnite-pumpellyite facies and zeolite facies in ascending order. He concluded that the metamorphic rocks were created as a result of sub-sea metamorphism and the temperature of the metamorphism was assumed to have been 300—500°C.

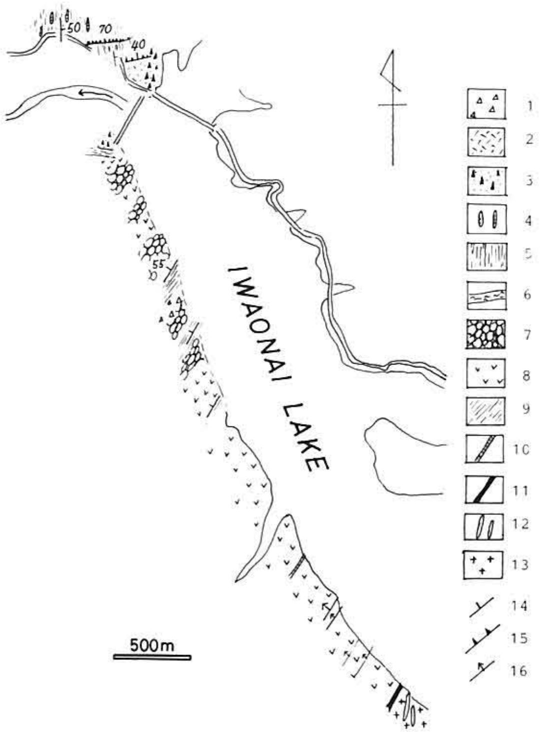
Bamba et al. (1985) studied the Shimokawa ores from the metallogenic point of view. They divided the ore forming process into two phases; The first phase of mineralization is represented by precursory cubic-colloform pyrites, and the later phase is characterized by the presence of a zonal arrangement of hexagonal pyrrhotite, and a hexagonal-monoclinic mixture of pyrrhotite and monoclinic pyrrhotite from the southern toward northern boundaries of the orebodies. Furthermore they pointed out a zonation of Co/Ni values of cobaltpentlandites increasing in the same way. The precursory pyrites were inferred to be of exhalative sedimentary origin at an ocean floor of Mesozoic age whereas the origin of the later phase mineralization was left as a future problem. This problem is discussed in this paper.

## Shimokawa Diabase Complex

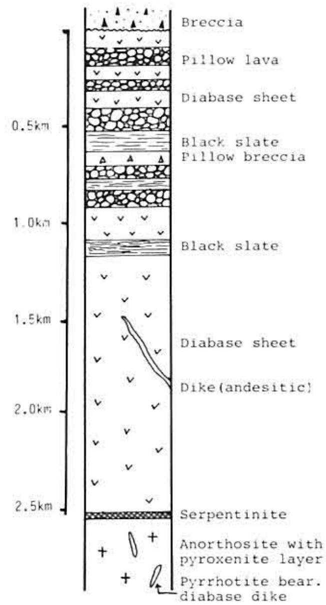
At the southwestern shore of the Iwaonai lake, we can observe excellent, uninterrupted outcrops across the Shimokawa diabase complex with an extent of more than four kilometers. As presented in Text-fig.2, pillow lavas predominate in the northwestern side while massive coarse ophitic-textured diabases are predominant in the southeastern side.

Among these, black slates all dipping westward are observed at several localities. At the southern end of the outcrop, a small scale serpentinite and layered anorthosite of several tens of meters thick associated with thin layers of pyroxenite appear.

The serpentinite and diabase are regarded to be in fault contact. Within the anorthosite mass numerous fine-grained diabase dikes 1—2m thick, in which pyrrhotite spots occur, are observed. The contact between the massive diabase and pillow lava shows a gradual change without any gap between them. This suggests that basaltic




**Text-fig. 2** Geological sketch of the Shimokawa diabase complex along the shore of the Iwaonai lake. 1: Pillow lava cataclasite, 2: Epidotized green rock, 3: Unsorted sandstone (breccia), 4: Sandstone cataclasite, 5: Sheared slate, 6: Slate cataclasite, 7: Pillow lava, 8: Diabase sheet, 9: Slate, 10: Basalt dike, 11: Serpentinite, 12: Pyrrhotite-bearing diabase dike, 13: Anorthosite, 14: Strike and dip, 15: Fault, 16: Joint system.




**Text-fig. 3** A column showing the sequence of the Shimokawa diabase complex. The column was obtained based on Text-fig. 2.

magma intruded into a soft, brine-saturated terrigenous mud and produced pillow lava first. In this case, consolidated pillow lava might have provided a fence against sea water and the remaining magma kept inside of the pillow lava fence produced ophitic diabase. Further evidence is also observed at Nakanosawa where the interpillow black slate is bleached. This leucocratic part is composed mainly of fine-grained quartz and albite. From these, a geologic column of the Shimokawa diabese complex is obtained as given in Text-fig.3.

### Anorthosite

The anorthosite in question has been previously called diallage gabbro because of the homogeneous distribution of diallage in some parts of the mass. The main part of the mass is composed mainly of anorthosite with clinopyroxenite layers (Plate 6a). The anorthosite is cataclastic (Plate 6b), generally coarse-grained and made up of fresh plagioclase and a small amount of sericite after clinopyroxene. The modal ratio of the above two minerals is 9:1. In places, thin layers of clinopyroxenite, 1—2cm thick, occur conformably with the layering of the anorthosite (Plate 3c). Plagioclase laths are euhedral, 2—3mm in size, and show distinct albite-twinning. Based on symmetry extinction angles in terms of (010), the plagioclase is regarded as labradorite ($An_{60}$). The mode of occurrence of anorthosite and the peculiar granoblastic texture of plagioclase suggest that this is a cumulate rock. Bulk rock chemistry of the anorthosite is presented in Table 1.

### Serpentinite and Clinopyroxenite

Serpentinite in the Iwaonai lake is massive and the layering is obscure though bastite after pyroxene is scattered in serpentinite (Plate 7c and d). On the other hand, some of ultramafic rocks from the Nakanosawa are made up of cholorite and a small amount of fresh clinopyroxenes. Relationship between the clinopyroxene and chlorite is shown in Plate 6c and d. Five grains of the clinopyroxene and two grains of chlorite were analysed by EPMA as presented in Tables 2 and 4. From the mode of occurrence of the chlorite, the original rock is probably clinopyroxenite. The Mg/Fe values of the clinopyroxenes and the chlorites are 6.03 and 2.85, respectively. This indicates that the chlorite is a product of hydrothermal alteration.

### Pillow lava and Diabase

The so-called Shimokawa diabase is divided into ophitic diabase and pillow lava (Plates 1 and 2). Studies on the rock properties of the Shimokawa diabase (Ushizawa, 1956; Sako, 1963; Miyake, 1964; Bamba, 1974, 1977), chemistry (Bamba, 1974; Kosaka, 1975) and metamorphism (Suzuki et al., 1980; Mariko, 1984) have been made.

The pillow lavas are made up of numerous lobes with diameters of 10cm—1m. In general these are aphanitic or variolitic (Plate 4a-d). Each pillow has a chilled margin consisting of glass rinds 1—5mm thick (Plate 2a). Cores of the pillows are made up of radial aggregates of acicular plagioclase and fine-grained granular clinopyroxenes (Plate 4b and c). Furthermore, the pillows characteristically show cataclastic structures as shown in Plates 2a and 11b. Bulk rock chemistry is similar to that of the massive ophitic diabase as presented in Table 1.

The ophitic diabase is made up mainly of augite and lath-shape plagioclase (Plate 5c and d). Ilmenite is usaually present as an accessory mineral. These minerals make a typical ophitic to subophitic texture. Coarse-grained ophitic diabase which contains 0.5—1 cm plagioclase laths can be easily distinguished in outcrops. Such coarse diabase contains a considerable amount of glass showing hyaloophitic texture (Plate 3a). In places, peculiar small scale diabase dikes, 1—2m thick, intruding into the preceding ophitic diabase are observed (Plate 2b). This is aphanitic consisting of fine-grained brown hornblende and acicular plagioclase, whereas the chemistry is quite similar to the ophitic ones (Bamba, 1977). The hornblende was identified through X-ray powder diffraction method. Another basaltic dike is known at the shore of Iwaonai lake (Plate 5a and b). This rock is dominant in plagioclase showing intersertal texture. Bulk rock chemistry of this rock (Table 1) indicates that it is the most differentiated one among the Shimokawa diabases.

From bulk rock chemistry, so-called Shimokawa diabases are classified as tholeiitic

**Table 1** Chemical compositions and CIPW norms of pillow lavas, diabases, ultrabasic rocks from the Shimokawa diabase complex

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 48.04 | 49.78 | 49.02 | 45.57 | 47.44 | 49.75 | 48.26 | 48.46 | 56.67 | 39.68 | 43.65 | 39.26 |
| $TiO_2$ | 1.12 | 1.37 | 1.15 | 1.07 | 1.15 | 0.98 | 1.34 | 0.93 | 0.73 | 0.06 | 0.10 | 0.50 |
| $Al_2O_3$ | 16.04 | 16.54 | 15.38 | 16.79 | 18.68 | 16.88 | 17.60 | 16.03 | 17.78 | — | 26.62 | 6.08 |
| $Fe_2O_3$ | 2.52 | 2.28 | 2.56 | 1.88 | 1.32 | 1.50 | 1.69 | 1.71 | 3.40 | 7.37 | 0.55 | 6.46 |
| FeO | 6.14 | 6.43 | 6.03 | 7.34 | 6.72 | 7.45 | 7.50 | 7.15 | 3.13 | 3.14 | 3.06 | 7.36 |
| MnO | 0.19 | 0.13 | 0.16 | 0.10 | 0.12 | 0.08 | 0.10 | 0.17 | 0.10 | 0.12 | 0.07 | 0.24 |
| MgO | 7.91 | 7.97 | 7.80 | 9.13 | 8.44 | 6.03 | 6.63 | 8.51 | 3.46 | 33.65 | 10.75 | 25.71 |
| CaO | 12.20 | 10.06 | 12.16 | 11.74 | 11.26 | 11.62 | 11.14 | 11.95 | 7.08 | 3.08 | 11.40 | 3.38 |
| $Na_2O$ | 1.82 | 2.10 | 1.83 | 2.24 | 1.83 | 2.21 | 2.24 | 2.17 | 2.54 | — | 1.15 | 0.24 |
| $K_2O$ | 0.17 | 0.18 | 0.25 | 0.30 | 0.21 | 0.23 | 0.21 | 0.10 | 1.25 | 0.10 | 0.16 | 0.14 |
| $P_2O_5$ | 0.07 | 0.14 | 0.09 | 0.15 | 0.11 | 0.15 | 0.10 | 0.10 | 0.11 | 0.01 | 0.01 | 0.15 |
| $H_2O(+)$ | 2.48 | 2.29 | 2.32 | 2.22 | 1.76 | 2.13 | 2.40 | 2.29 | 0.85 | 10.86 | 2.28 | 7.87 |
| $H_2O(-)$ | 1.06 | 0.48 | 0.96 | 1.30 | 0.74 | 0.59 | 0.61 | 0.29 | 3.76 | 1.49 | 0.93 | 1.94 |
| Total | 99.76 | 99.75 | 99.71 | 99.83 | 99.78 | 99.60 | 99.82 | 99.86 | 100.86 | 99.56 | 100.73 | 99.33 |
| Q | 1.46 | 3.19 | 2.40 | — | — | 2.10 | 0.03 | — | 16.43 | — | — | — |
| or | 1.00 | 1.06 | 1.48 | 1.77 | 1.24 | 1.36 | 1.24 | 1.36 | 7.38 | — | 0.94 | 0.82 |
| ab | 15.40 | 17.77 | 15.49 | 18.95 | 15.49 | 18.70 | 18.95 | 18.36 | 21.49 | — | 9.73 | 2.03 |
| an | 32.66 | 35.20 | 33.02 | 34.90 | 42.12 | 35.45 | 37.36 | 33.70 | 33.42 | — | 56.49 | 15.09 |
| c | — | — | — | — | — | — | — | — | — | — | 3.85 | — |
| wo | 11.48 | 5.78 | 11.17 | 9.38 | 5.47 | 8.91 | 7.23 | 10.40 | 0.41 | 6.35 | — | 0.28 |
| en | 19.70 | 19.85 | 19.42 | 5.80 | 16.11 | 15.02 | 16.41 | 16.45 | 8.61 | 37.58 | 8.06 | 29.70 |
| fs | 7.69 | 7.90 | 7.36 | 2.61 | 7.35 | 10.98 | 10.32 | 7.14 | 1.91 | — | 1.54 | 3.61 |
| fo | — | — | — | 11.90 | 3.44 | — | — | 3.32 | — | 32.39 | 13.10 | 24.05 |
| fa | — | — | — | 5.79 | 1.73 | — | 0.03 | 1.81 | — | — | 2.76 | 3.22 |
| mt | 3.65 | 3.31 | 3.71 | 2.73 | 1.91 | 2.17 | 2.45 | 2.47 | 4.92 | 10.33 | 0.79 | 9.36 |
| il | 2.13 | 2.60 | 2.18 | 2.03 | 2.18 | 1.86 | 2.54 | 1.76 | 1.38 | 0.11 | 0.18 | 0.94 |
| hm | — | — | — | — | — | — | — | — | — | 0.24 | — | — |
| ap | 0.15 | 0.31 | 0.20 | 0.33 | 0.24 | 0.33 | 0.22 | 0.23 | 0.25 | 0.02 | 0.02 | 0.34 |

1-4: pillow lava (samples for analysis are prepared as a total pillow), Bamba (1974)
5-7: ophitic-textured diabase (Bamba, 1974). 8: diabase dike at L10S50, 9: basalt dike from Iwaonai lake, 10: serpentinite from Iwaonai lake, 11: anorthosite from Iwaonai lake, 12: pyroxenite from Nakanosawa.
Analyst: O. Sawai (8-12)

**Table 2** Chemical compositions of clinopyroxenes from the Shimokawa diabase and pyroxenite

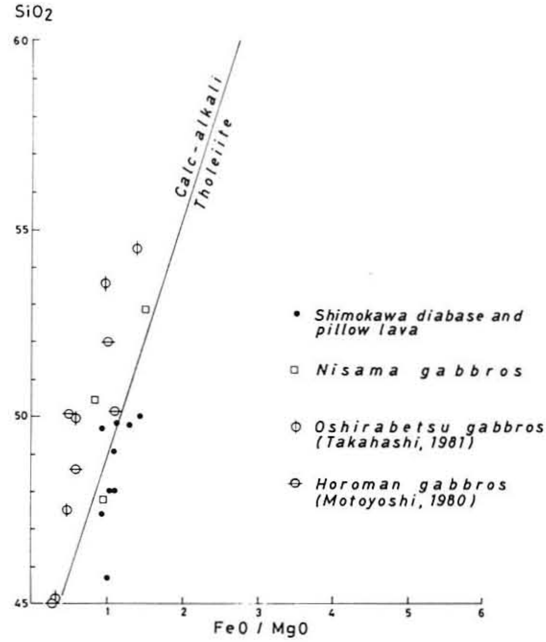
| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| $SiO_2$ | 50.88 | 50.78 | 51.15 | 51.11 | 54.54 |
| $TiO_2$ | 0.59 | 0.66 | 0.62 | 0.00 | 0.00 |
| $Al_2O_3$ | 3.32 | 2.93 | 2.75 | 1.60 | 1.64 |
| $Cr_2O_3$ | 1.81 | 1.27 | 1.40 | — | — |
| FeO | 4.60 | 4.55 | 4.51 | 7.23 | 5.84 |
| MnO | 0.12 | 0.13 | 0.12 | 0.23 | 0.21 |
| MgO | 16.36 | 16.02 | 16.22 | 16.97 | 17.40 |
| CaO | 21.99 | 23.29 | 23.15 | 20.19 | 20.71 |
| $Na_2O$ | 0.27 | 0.25 | 0.23 | 0.00 | 0.00 |
| $K_2O$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 99.96 | 99.92 | 100.19 | 100.33 | 100.34 |
| | | Numbers of ions (0=6) | | | |
| Si | 1.874 | 1.877 | 1.884 | 1.977 | 1.981 |
| $Al^{IV}$ | 0.126 | 0.123 | 0.116 | 0.022 | 0.018 |
| $Al^{VI}$ | 0.018 | 0.004 | 0.003 | 0.045 | 0.051 |
| Cr | 0.052 | 0.037 | 0.040 | — | — |
| Ti | 0.016 | 0.018 | 0.017 | 0.000 | 0.000 |
| Fe | 0.141 | 0.140 | 0.139 | 0.220 | 0.177 |
| Mn | 0.003 | 0.004 | 0.039 | 0.007 | 0.006 |
| Mg | 0.898 | 0.883 | 0.890 | 0.924 | 0.942 |
| Ca | 0.868 | 0.922 | 0.913 | 0.790 | 0.806 |
| Na | 0.019 | 0.017 | 0.016 | 0.000 | 0.000 |
| mg* | 0.868 | 0.863 | 0.864 | 0.807 | 0.841 |

*Mg/(Mg+Fe)
1-3: pyroxenite from Nakanosawa. Analyst: M. Bamba
4-5: diabase from the Shimokawa mine. Analyst: T. Watanabe

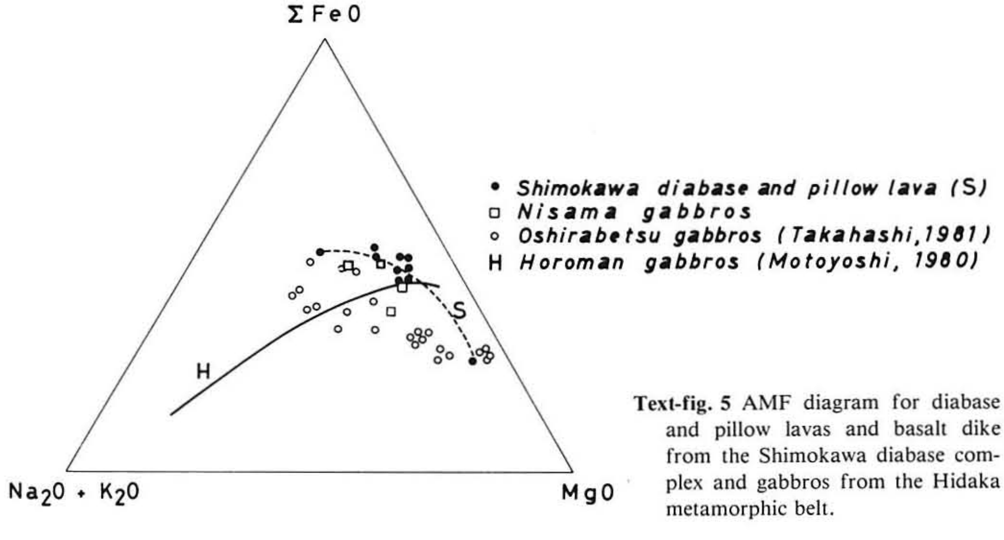
basalt (Bamba, 1974) based on the richness of FeO, MgO and CaO, and poorness of alkalis and $Al_2O_3$, and the silica content of around 45% as presented in Text-figs. 4 and 5. These are considered to belong to abyssal or oceanic ridge basalt based on rare elements analyses (Kosaka, 1975).

## Black Slates

Sandy slate is a main constituent of the Shimokawa diabase complex. It is believed that tholeiitic basaltic magma repeatedly intruded into a brine-saturated sandy mud and the complicated mode of occurrence of pillow lava and sandy slate in the complex has been induced as shown in Plate 11a. Furthermore, a concordant relationship between the above two rocks is observed in places. The slate in question is made up mainly of angular or subangular grains of quartz and plagioclase suggesting that clastic materials are not pelagic but terrigenous in origin. Thus it has been regarded that the




**Text-fig. 4** Compositional variation of pillow lavas, diabases from the Shimokawa diabase complex and gabbros from the Hidaka metamorphic belt. Diagram shows that the former rocks are mostly tholeiitic rock series and the latters of calc-alkalic rock series.




**Text-fig. 5** AMF diagram for diabase and pillow lavas and basalt dike from the Shimokawa diabase complex and gabbros from the Hidaka metamorphic belt.

Shimokawa diabases are extrusive and/or sheet intruded into brine-saturated muds.

## Metamorphism

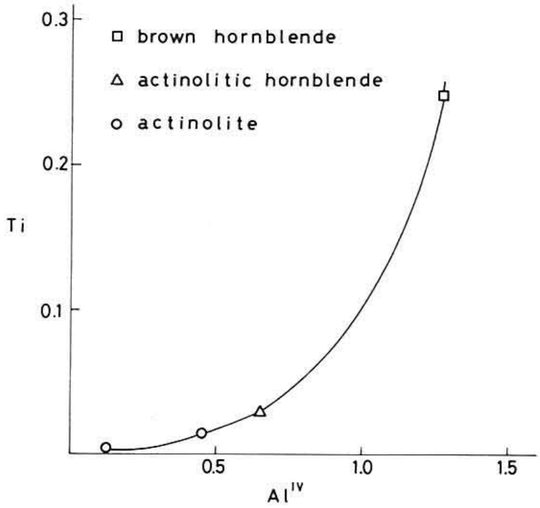
Alteration or metamorphism of the Shimokawa diabase has been studied by Suzuki et al. (1980) and Mariko (1984). They have recognized that a zonation of metamorphic rock facies is present; the highest grade metamorphic rock appears in the eastern side of the diabase complex and becomes lower toward the west. Mariko (1984) has claimed that the highest metamorphic grade is amphibolite facies at the eastern side of the complex and greenschist facies, pumpellyite facies and zeolite facies have been distinguished westward.

Metamorphic amphiboles of the Shimokawa diabase are classified into brown hornblende, actinolitic hornblende and actinolite. It is distinct that brown hornblende is precursory because actinolitic hornblende replaced the brown hornblende as shown in Plate 8a and b. Following the work of Helz (1973), Ti and $Al^{IV}$ of the Shimokawa hornblendes were plotted in Text-fig.6. The plot indicates that Ti and $Al^{IV}$ of brown hornblende are both high compared with those of actinolitic hornblende and actinolite. Consequently it is concluded that amphibolization of the Shimokawa diabase is

**Table 3** Chemical compositions of amphiboles from the Shimokawa diabase

| | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| $SiO_2$ | 46.53 | 50.94 | 55.29 | 53.71 |
| $TiO_2$ | 2.35 | 0.25 | 0.03 | 0.15 |
| $Al_2O_3$ | 8.98 | 4.60 | 1.58 | 4.48 |
| FeO* | 9.42 | 15.56 | 8.70 | 10.52 |
| MnO | 0.11 | 0.27 | 0.29 | 0.28 |
| MgO | 15.89 | 13.01 | 19.01 | 16.55 |
| CaO | 10.76 | 12.43 | 12.82 | 13.12 |
| $Na_2O$ | 3.03 | 0.43 | 0.48 | 0.27 |
| $K_2O$ | 0.34 | 0.06 | 0.02 | 0.08 |
| Total | 97.41 | 97.55 | 98.22 | 99.26 |
| | Numbers of ions (0=23) | | | |
| Si | 6.735 | 7.470 | 7.771 | 7.536 |
| Al | 1.265 | 0.530 | 0.229 | 0.464 |
| total | 8.000 | 8.000 | 8.000 | 8.000 |
| Al | 0.264 | 0.264 | 0.032 | 0.292 |
| Ti | 0.255 | 0.028 | 0.003 | 0.292 |
| Fe | 1.136 | 1.901 | 1.019 | 1.230 |
| Mn | 0.013 | 0.033 | 0.034 | 0.033 |
| Mg | 3.450 | 2.862 | 4.008 | 3.483 |
| total | 5.118 | 5.088 | 5.096 | 5.054 |
| Na | 0.849 | 0.122 | 0.131 | 0.041 |
| Ca | 1.669 | 1.953 | 1.931 | 2.010 |
| K | 0.063 | 0.011 | 0.004 | 0.007 |
| total | 2.581 | 2.086 | 2.066 | 2.058 |

1: brown hornblende, 2: actinolitic hornblende,
3: colorless actionolite, 4: actinolite
Analyst: T. Watanabe (Suzuki et al., 1980). All iron as FeO*




**Text-fig. 6** Ti-Al$^{IV}$ relation of amphiboles from the Shimokawa diabase complex. According to Helz (1973), brown hornblende is estimated to be of high temperature type.

**Table 4** Chemical compositions of chlorites from the Nakanosawa pyroxenite near the Shimokawa mine

| | 1 | 2 |
|---|---|---|
| $SiO_2$ | 33.35 | 34.39 |
| $TiO_2$ | 0.00 | 0.04 |
| $Al_2O_3$ | 14.20 | 11.04 |
| $Cr_2O_3$ | 0.00 | 0.04 |
| FeO | 10.68 | 10.73 |
| MnO | 0.15 | 0.12 |
| MgO | 26.82 | 28.56 |
| CaO | 0.13 | 0.19 |
| $Na_2O$ | 0.00 | 0.05 |
| $K_2O$ | 0.00 | 0.00 |
| Total | 85.35 | 85.20 |
| | Numbers of ions (0 = 14) | |
| Si | 3.310 | 3.430 |
| $Al^{IV}$ | 0.690 | 0.570 |
| $Al^{VI}$ | 0.972 | 0.728 |
| Ti | 0.000 | 0.000 |
| Cr | 0.000 | 0.000 |
| Fe | 0.886 | 0.899 |
| Mn | 0.013 | 0.010 |
| Mg | 3.969 | 4.247 |
| Ca | 0.010 | 0.020 |
| Na | 0.000 | 0.000 |
| K | 0.000 | 0.000 |

Analyst: M. Nakagawa

retrogressive. Chemical compositions of amphiboles in question and chlorites are given in Tables 3 and 4, respectively.

## Nisama Igneous Complex

The eastern area near the Shimokawa diabase complex is occupied by olivine gabbro, norite and diorite arranged from east to west occurring in cordierite or garnet bearing hornfels (Plate 9b and c). Though these igneous rocks occur separately, it is thought that the former two are closely related to each other, because they have common characteristic rock properties, e.g. the intercumulus phase of the olivine cumulate gabbro is the same as the adjacent norite mass. Furthermore, disseminated pyrrhotites with pentlandite and chalcopyrite are present in both olivine gabbro and norite masses. The olivine gabbro shows distinct flow layers though the other two masses are massive. The highest grade of concentration of sulfide is shown in norite mass in the Nisama igneous complex, i.e. the modal ratio of sulfide minerals reaches 10% in the norite. These sulfide-rich gabbros were studied by Kim (1964a, 1964b) and Sako (1963) in detail. They concluded that these can be divided into two rock series; olivine gabbro series and diorite series. The former is represented by troctolite and olivine gabbro and the latter norite and diorite, and the norite has been considered as a marginal facies of the diorite mass.

From peculiar phenomena indicating interaction between crustal materials and magma in both norite and diorite, they have used the term "metasomatic gabbro" for the norite and diorite. The presence of the two rock series of gabbros in the Hidaka metamorphic belt has been recognized by Motoyoshi (1980) and Takahashi (1983) in the Horoman and Oshirabetsu areas, respectively. Takahashi et al. (1983) reported $\delta^{34}S$ (0/00) values ranging from $-1.6$ to $-8.7$ in the Oshirabetsu gabbroic mass suggesting the presence of interaction between crustal materials and magma, because the sulfur isotopic data on the hornfels and migmatite in the region are around $-10$ (Takahashi et al., 1983).

### Olivine Gabbro

The olivine gabbro mass is composed of melanocratic and leucocratic layers. The former is made up of olivine, clinopyroxene, orthopyroxene, plagioclase and pyrrhotite essentially as presented in Plate 10a, while the latter lacks olivine. In both rock facies brown hornblende occurs around clinopyroxenes and is regarded as secondary mineral because clinopyroxene is always observed in the core of the hornblende.

Olivine is mostly euhedral, 1—2mm in size. Plagioclase of lath shape is 0.3—1.5mm, and rarely attains 2mm. Plagioclase is the most abundant mineral in the rock and generally forms ophitic textures with clinopyroxenes, but sometimes granoblastic textures. Pyrrhotite occurs forming ophitic textures with silicate minerals.

The modal ratio of the minerals is given as follows: plagioclse, 68%; clinopyroxene, 20%; olivine, 9%; orthopyroxene, 1%; and pyrrhotie, 2%. Kim (1964b) measured

**Table 5** Chemical compositions and CIPW norms of olivine gabbro, norite, diorite and metadiabase from the Nisama igneons complex

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| $SiO_2$ | 46.62 | 49.85 | 47.05 | 52.09 | 50.78 |
| $TiO_2$ | 1.28 | 0.53 | 0.61 | 1.84 | 1.48 |
| $Al_2O_3$ | 21.03 | 21.17 | 21.31 | 15.42 | 13.76 |
| $Fe_2O_3$ | 0.69 | 1.01 | 1.11 | 1.38 | 0.99 |
| FeO | 5.91 | 4.30 | 6.10 | 7.21 | 9.27 |
| MnO | 0.11 | 0.10 | 0.12 | 0.17 | 0.30 |
| MgO | 8.87 | 6.94 | 8.25 | 6.18 | 6.77 |
| CaO | 11.06 | 11.42 | 10.60 | 8.53 | 11.19 |
| $Na_2O$ | 2.40 | 2.52 | 2.11 | 3.31 | 2.70 |
| $K_2O$ | 0.27 | 0.35 | 0.41 | 1.13 | 0.29 |
| $P_2O_5$ | 0.08 | 0.11 | 0.04 | 0.27 | 0.13 |
| $H_2O(+)$ | 0.62 | 0.98 | 1.29 | 1.04 | 1.21 |
| $H_2O(-)$ | 1.44 | 1.59 | 2.09 | 0.16 | 0.48 |
| Total | 100.38 | 100.87 | 101.09 | 98.73 | 99.35 |
| Q | — | — | — | 1.11 | 0.23 |
| or | 1.59 | 2.06 | 2.42 | 6.67 | 1.71 |
| ab | 20.30 | 21.32 | 17.85 | 28.00 | 22.84 |
| an | 45.81 | 45.41 | 47.46 | 23.87 | 24.56 |
| c | — | — | — | — | — |
| wo | 3.56 | 4.39 | 2.02 | 6.96 | 12.56 |
| en | 3.83 | 13.92 | 8.25 | 15.39 | 16.85 |
| fs | 1.44 | 5.13 | 3.81 | 9.37 | 14.31 |
| fo | 12.79 | 2.35 | 8.60 | — | — |
| fa | 5.34 | 0.95 | 4.38 | — | — |
| mt | 1.00 | 1.46 | 1.60 | 2.00 | 1.43 |
| il | 2.43 | 1.00 | 1.15 | 3.49 | 2.81 |
| hm | — | — | — | — | — |
| ap | 0.18 | 0.25 | 0.09 | 0.62 | 0.30 |

1: olivine gabbro (melanocratic layer), 2: olivine gabbro (leucocratic layer), 3: norite, 4: diorite, 5: metadiabase.
Analyst: O. Sawai

183 grains of plagioclase optically and found a wide range of An contents from $An_{50\%}$ to $An_{95\%}$, averaging $An_{78\%}$. In this study an intrusion temperature of 961°C has been measured from paired ortho-clinopyroxenes using Wood & Banno's (1973) method. EPMA analyses of the olivines and pyroxenes in the olivine gabbro are presented in Table 6, and Text-figs. 7 and 8. Bulk rock chemical analyses are given in Table 5.

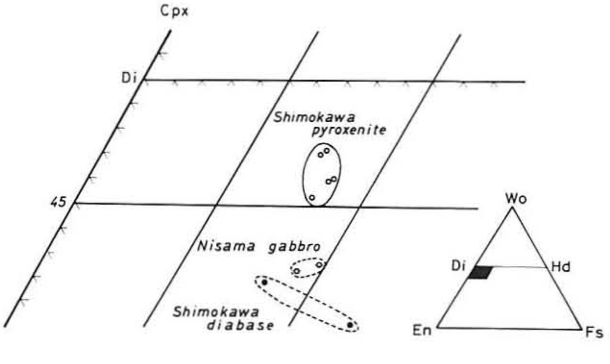
**Table 6** Chemical compositions of olivine and pyroxene in the olivine gabbro and norite from the Nisama igneous complex

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| $SiO_2$ | 35.93 | 38.17 | 49.92 | 52.90 | 52.20 | 55.57 |
| $TiO_2$ | 0.00 | 0.00 | 0.57 | 0.41 | 0.38 | 0.16 |
| $Al_2O_3$ | 0.00 | 0.00 | 3.99 | 1.40 | 1.72 | 0.78 |
| $Cr_2O_3$ | 0.00 | 0.00 | 1.30 | 0.00 | 0.04 | 0.00 |
| FeO | 26.21 | 25.78 | 57.52 | 16.26 | 6.12 | 14.95 |
| MnO | 0.36 | 0.34 | 0.13 | 0.37 | 0.12 | 0.42 |
| MgO | 38.74 | 34.84 | 16.66 | 27.47 | 16.69 | 26.36 |
| CaO | 0.00 | 0.04 | 20.95 | 0.65 | 22.13 | 1.16 |
| $Na_2O$ | 0.02 | 0.07 | 0.75 | 0.00 | 0.89 | 0.00 |
| $K_2O$ | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| NiO | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Total | 101.33 | 99.28 | 100.05 | 99.49 | 100.34 | 99.43 |
| | Numbers of ions (0=4) | | Numbers of ions (0=6) | | | |
| Si | 0.945 | 1.016 | 1.845 | 1.929 | 1.923 | 2.000 |
| Al | 0.000 | 0.000 | 0.147 | 0.060 | 0.074 | 0.033 |
| Ti | 0.000 | 0.000 | 0.015 | 0.011 | 0.010 | 0.004 |
| Cr | 0.000 | 0.000 | 0.038 | 0.000 | 0.001 | 0.000 |
| Fe | 0.577 | 0.573 | 0.177 | 0.496 | 0.188 | 0.451 |
| Mn | 0.008 | 0.007 | 0.004 | 0.011 | 0.004 | 0.012 |
| Mg | 1.520 | 1.382 | 0.918 | 1.493 | 0.917 | 1.418 |
| Ca | 0.000 | 0.001 | 0.830 | 0.025 | 0.874 | 0.045 |
| Na | 0.001 | 0.003 | 0.054 | 0.000 | 0.063 | 0.000 |
| K | 0.001 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Ni | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

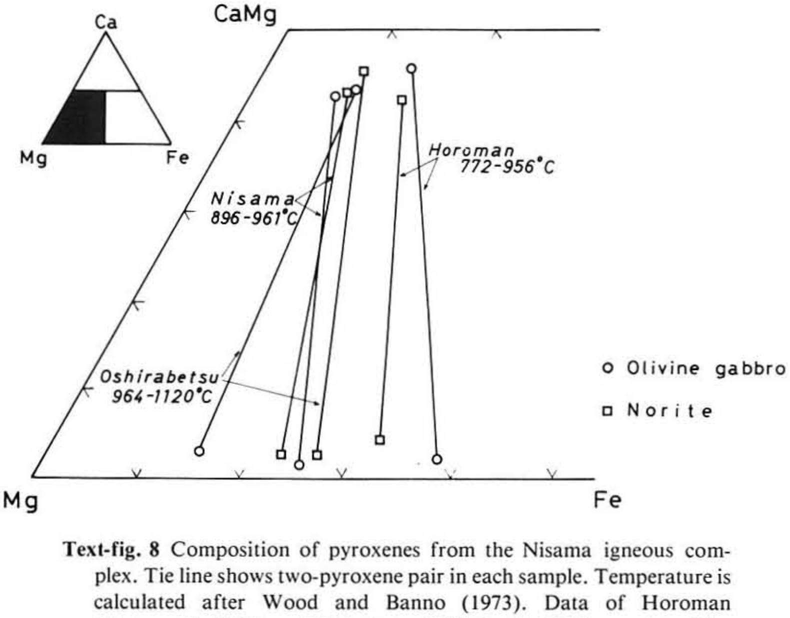
1-2: olivine, 3: clinopyroxene in norite, 4: rhombic pyroxene in norite, 5: clinopyroxene in olivine gabbro, 6: rhombic pyroxene in olivine gabbro.
Analyst: M. Bamba

## Norite

This rock is massive and is characterized by absence of olivine, but resembles the olivine gabbro in both grain size and texture as shown in Plate 10b. Norite is made up mainly of plagioclase, clinopyroxene and pyrrhotite. Hornblende and orthopyroxene are less abundant than in the olivine gabbro. Kim (1964b) measured 150 plagioclase grains and reported An contents ranging from 30% to 80%, averaging 50%. Orthopyroxene and clinopyroxene were chemically analysed by EPMA as presented in Table 6, and Text-figs. 7 and 8. The formation temperature of the norite was estimated to be 896°C from the paired ortho-clinopyroxenes. Disseminated spots of sulfides up to 1 cm across are composed of hexagonal pyrrhotite, pentlandite and chalcopyrite as shown in Plate 10d. Pentlandite is intimately grown with pyrrhotite showing exsolution intergrowth. Chemical compositions of these sulfide minerals are given in Table 7.




**Text-fig. 7** Chemical composition of clinopyroxenes from the Shimokawa diabases and the Nisama gabbros. The latter has an intermediate composition between those from the Shimokawa clinopyroxenite and diabase.




**Text-fig. 8** Composition of pyroxenes from the Nisama igneous complex. Tie line shows two-pyroxene pair in each sample. Temperature is calculated after Wood and Banno (1973). Data of Horoman (Motoyoshi, 1980) and Oshirabetsu (Takahashi, 1981) are plotted for reference.

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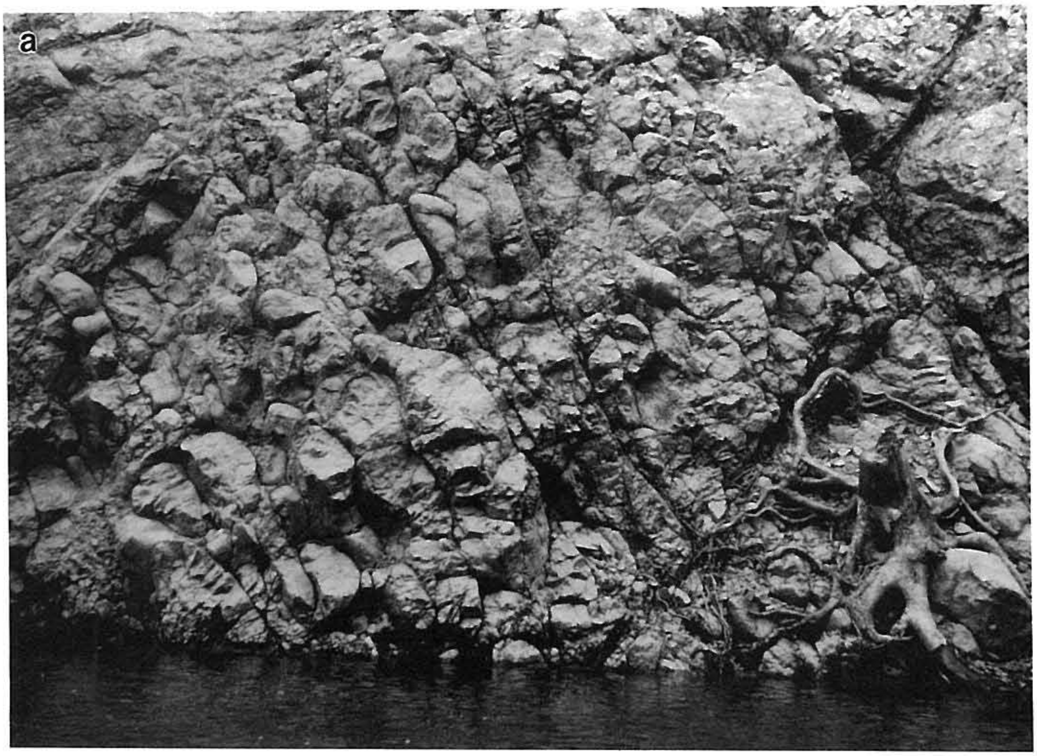
**Explanation of Plate 1**

Photographs showing the outcrops of typical pillow lava and massive diabase in the vicinity of the Shimokawa mine.

**a)** Mode of occurrence of the closed packed Shimokawa pillow lava, looking from north at the southern shore of the Iwaonai lake. The top of the lava is estimated to be right side of the picture based on the downward protrusion of the pillow.

**b)** Mode of occurrence of the massive Shimokawa diabase, looking from north at the southern shore of the Iwaonai lake. Development of joint is clearly observed.


a


b

**Table 7** Chemical compositions of pyrrhotite, pentlandite and chalcopyrite from the Okushibetsu mine, Nisama, northern Hokkaido

| | 1 | 2 | 3 |
|---|---|---|---|
| Fe | 61.52 | 28.98 | 31.13 |
| Ni | 0.53 | 30.51 | 0.00 |
| Cu | 0.08 | 1.32 | 34.94 |
| Co | 0.00 | 2.90 | 0.08 |
| S | 39.47 | 33.73 | 35.03 |
| Total | 101.60 | 97.44 | 101.18 |

1: pyrrhotite, 2: pentlandite, 3: chalcopyrite.
Analyst: Y. Motoyoshi

## Diorite

The Nisama diorite is massive showing variations from coarse- to fine-grained though the mineral assemblage is constant. The diorite is generally composed of plagioclase (60%), green hornblende (25%) and biotite (15%). In places, a small amount of sphene and apatite are observed. An% of plagioclases measured by Kim (1964b) varies from 20% to 45% and is estimated to be 30% in average. Fine-grained facies show granoblastic to nematoblastic textures. A chemical analysis is presented in Table 5.

## Metadiabase

This rock is characterized by prominent amphibolization. Actinolite 0.1—0.2mm, and fine-grained epidote are the main constituent minerals and pyroxene is not observed. In places, aggregates of coarse-grained actinolite 0.5—1mm in size form irregular pools with considerable amounts of quartz (Plate 9a). Such rock properties cannot be found in the Shimokawa diabase complex. Hence, this rock should not be consanguineous with the diabase swarm in the Shimokawa diabase complex.

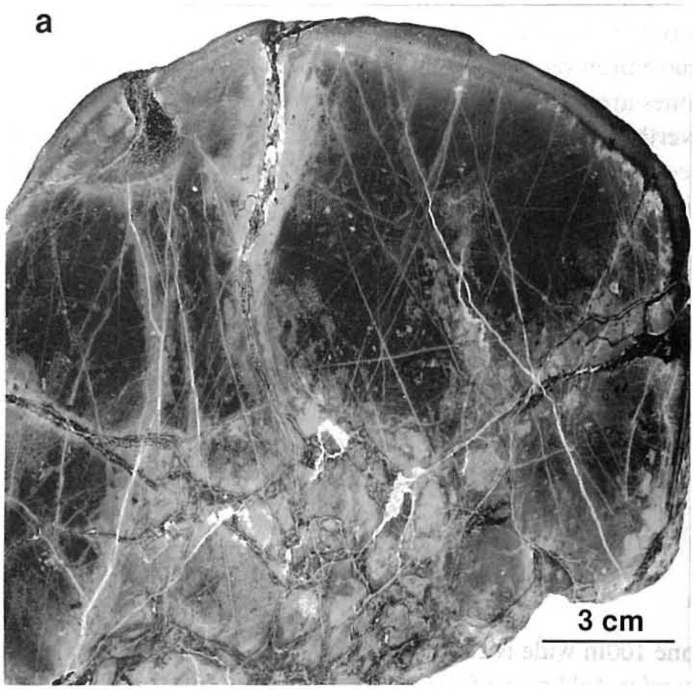
Its chemical composition of metadiabase is given in Table 5.

**Explanation of Plate 2**

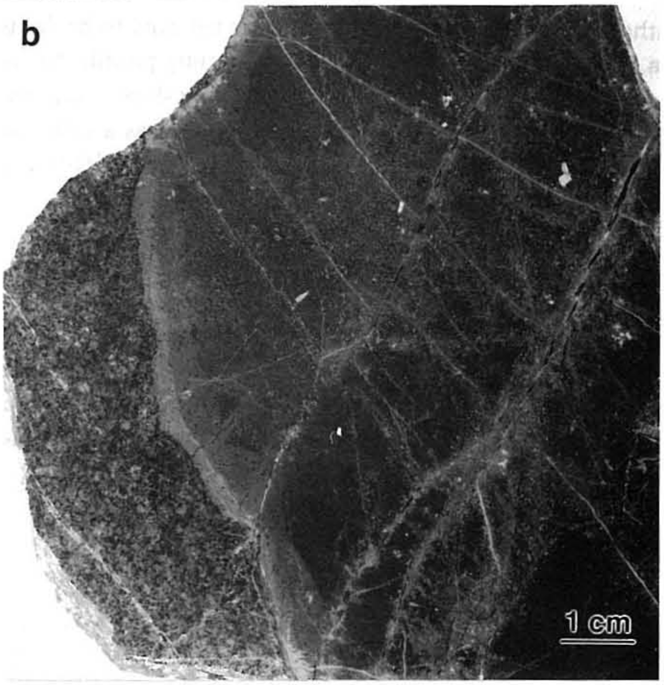
**a)** Photographs of a slab of pillow from the gallery of the Shimokawa mine. Rim of a few millimeters is glassy and the interior is made up of acicular plagioclase and very fine-grained augite showing variolitic texture. Fine streeks consist of albite-quartz assemblage. Fracture is distinct. Fractured or sheared structure is one of the prominent features of the Shimokawa pillow lava and diabase.

**b)** Photograph showing the contact relation between the ophitic diabase (coarse-grained) and the later phase aphanitic diabase dike, 1 m thick (fine-grained) from the Shimokawa gallery (L10S50). Chilled margin shows a selvage consisting of glass (Bamba, 1977).

a




b



## Tectonic Features of the Shimokawa Diabase Complex

As pointed out by many geologists, two parallel shear zones running N-S and dipping eastward have been recognized on both sides of the Shimokawa diabase complex. These shear zones are called A and B from west to east in this paper. Furthermore, a NE striking overthrust that dips southeast toward the Shimokawa diabase complex is oberved between two masses of the Nisama igneous complex and the Shimokawa diabase complex as shown in Text-fig.1.

The presence of the above tectonic features were first recognized by Hunahashi et al. (1966) and they emphasized that two masses consisting of the Hidaka Super Group on both sides of the Shimokawa diabase complex show different structure from one another; sandy slate strata of the eastern mass show bedding planes striking NE, while the western mass strikes NW. From the above fact, Hunahashi et al. (1966) concluded that the diabases might have intruded as dike swarms along the tectonic junction of the two different geologic units. However, since the pillow lavas have been recognized in the complex, the above model has become unacceptable as discussed in the previous chapter.

### Shear Zone-A

A shear zone 100m wide is characterized by the presence of crushed turbidite beds in which many microfold axes of the kink band type are observed as presented in Text-fig.9. From a lithological point of view, this strata is believed to be Santonian to Campanian (Kimura, 1985). Several small scale faults running parallel to each other striking N70°E and dipping 70°NW are recognized within the shear zone. Such folding and shear patterns of right lateral offset have been recognized as a characteristic tectonic feature of Oligocene to late Miocene age representing the older tectonic movement of the northern Hidaka belt (Kimura, 1985).

### Shear Zone-B

This shear zone is characterized by the presence of amphibolization in the green rocks and chloritization in the phyllites. Chloritized phyllite seems to be a semi-chlorite schist but retains relicts of phyllite everywhere. In the Nakanosawa Shaft area (Text-fig.1) pools of quartz aggregates and a number of seams of pyrrhotite-dominant

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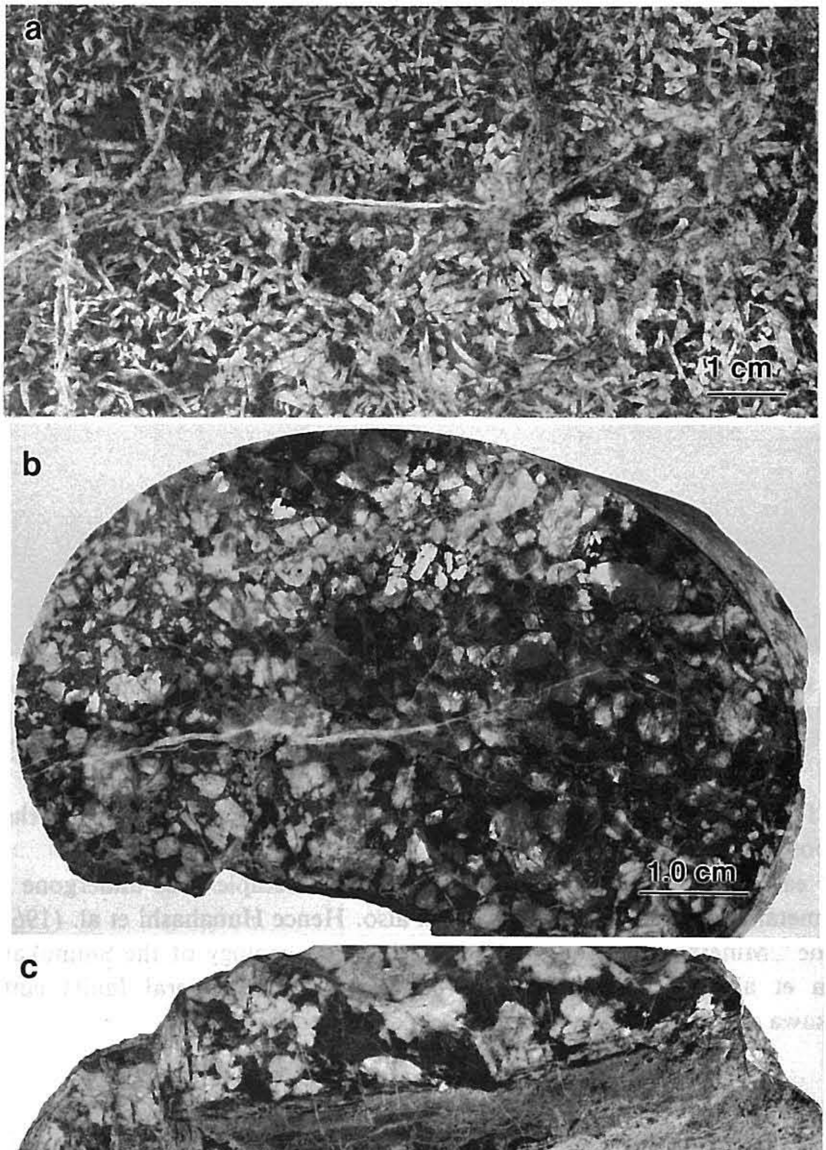
**Explanation of Plate 3**

Photographs of slabs showing the texture of the Shimokawa diabases and anorthosite.

a) The most coarse-grained hyaloophitic diabase consisting of lath of plagioclase, augite and ilmenite. Some pools of dark color are made up of glass in which variolite texture is observed (see Plate 5d).

b) Porphyritic diabase from the core of drilling (Towari-No. 2, depth: 244 m). Coarse-grained tabular plagioclase is prominent. Dark colored part is composed mainly of augite and chlorite.

c) Anorthosite and the associated diallage gabbro from Nakanosawa, Shimokawa mine. The layering indicates that the anorthosite is a cumulate rock. Clinopyroxenite, a variety of the diallage gabbro, is observed in places.


a
1 cm
b
1.0 cm
c
1 cm

Text-fig. 9 Photograph of "Shear zone-A" at the northern side of the Iwaonai damsite. The folded strata are regarded as Cretaceous turbidite cataclasite from the lithological feature. Microfolding axes run N70°E. This photograph was taken in 1966 during the construction of the dam. On the right side, out of sight, "Zone of breccia" appears.

sulfide forming banded ore are present in the semi-chlorite schist. This is the geotectonic position of the massive sulfide ore of the Shimokawa mine.

The eastern margin of the Shimokawa diabase complex has undergone not only strong metamorphism, but mineralization also. Hence Hunahashi et al. (1966) called this zone "Mineralized shear zone". Underground geology of the Shimokawa mine (Bamba et al., 1970) disclosed the presence of right lateral faults cutting the Shimokawa diabase complex and the orebodies in this zone.

## Thrust

A steeply dipping thrust striking NNE-SSW is observed between the 126Ma

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**Explanation of Plate 4**

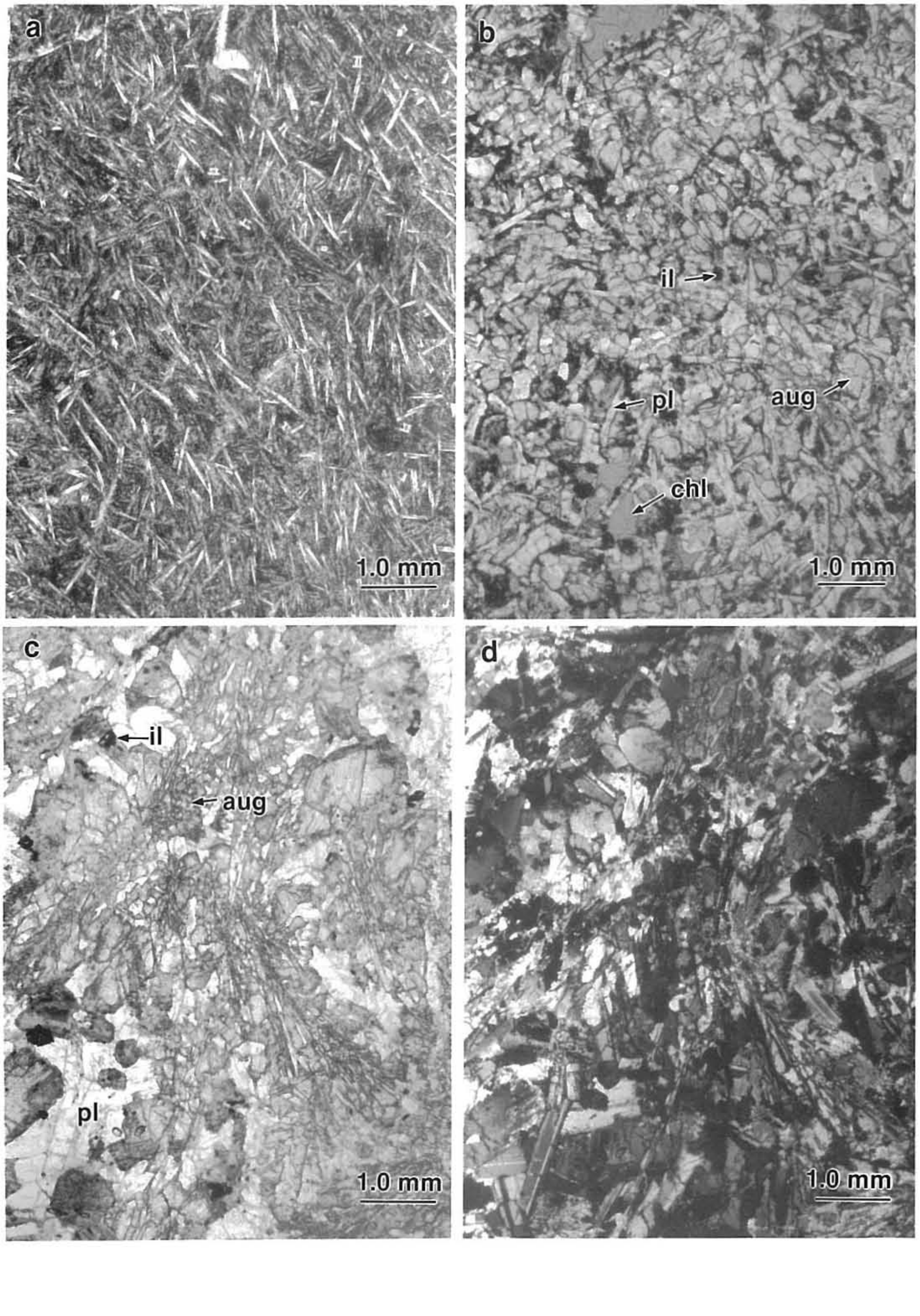
Photomicrographs illustrating the variation in texture of the Shimokawa pillow lavas.

**a)** Variolitic-intersertal texture. Fibrous plagioclase and very fine-grained clinopyroxene associated with glass are the main constituent. Such a texture is common in almost all pillows in the Shimokawa area.

**b)** Subophitic-intersertal texture. This rock is made up of lath of plagioclase, augite and accessory ilmenite. In the northern part of the Iwaonai lake pillow lavas which are characterized by this texture are exposed. pl: plagioclase, aug: augite, chl: chlorite and il: ilmenite.

**c)** Coarse variolitic texture. This rock facies is rarely observed in the Shimokawa pillow lava. The sample was obtained from the Shimokawa gallery (AD, S111). aug: augite, pl: plagioclase and il: ilmenite.

**d)** ditto. Crossed nicols.


a
1.0 mm
b
il
pl
aug
chl
1.0 mm
c
il
aug
pl
1.0 mm
d
1.0 mm

Shimokawa diabase complex (Miyake et al., 1981) and the Neogene Nisama igneous complex. The boundary between these two different masses implies that these are different in origin from one another, i.e. the Shimokawa diabase complex is allochthonic and the Nisama mass, including the igneous complex, is autochthonic because the Nisama igneous complex and the surrounding biotie hornfels can be correlated to the 17-31Ma Main Zone of the Hidaka metamorphic belt (Nozawa, 1975; Kimura, 1985) which represents a typical island arc. It is possible that the mass including the Nisama igneous complex has made a diapiric upward movement contemporaneously with the emplacement of the Shimokawa diabase complex from the west.

### Zone of Breccia

A peculiar clastic sediment, possibly breccia (Plate 12b), found along the western margin of the Shimokawa diabase complex contains various but limited kinds of rock fragments. The fragments are believed to be derived from the Shimokawa diabase complex. It is notable that the modal ratio of slate to green rocks in the breccia is about 1:3 which is nearly equal to that of the Shimokawa diabase complex itself. From this, it is concluded that the breccia might have been produced as a result of abrupt fall after obduction of the Shimokawa diabase complex slab.

The same type of breccia showing a similar mode of occurrence is known along the Tomuraushi diabese-slate complex lying to the south, 100km from the Shimokawa mine. Therefore, the implication of the breccia is important in considering the origin of the Shimokawa and Nisama masses.

## Lead Isotopes

Analyses for the concentration of lead and the ratio of lead isotopes were made with the purpose of obtaining a geochemical correlation between copper dominant massive sulfide ores from the Shimokawa mine and rock types occurring in the Shimokawa diabase complex and gabbros associated with nickel bearing pyrrhotite ore of the Oshirabetsu igneous complex. Measurements were performed by Mr. Tanaka under the instruction of Prof. Murozumi at the Department of Applied Chemistry,

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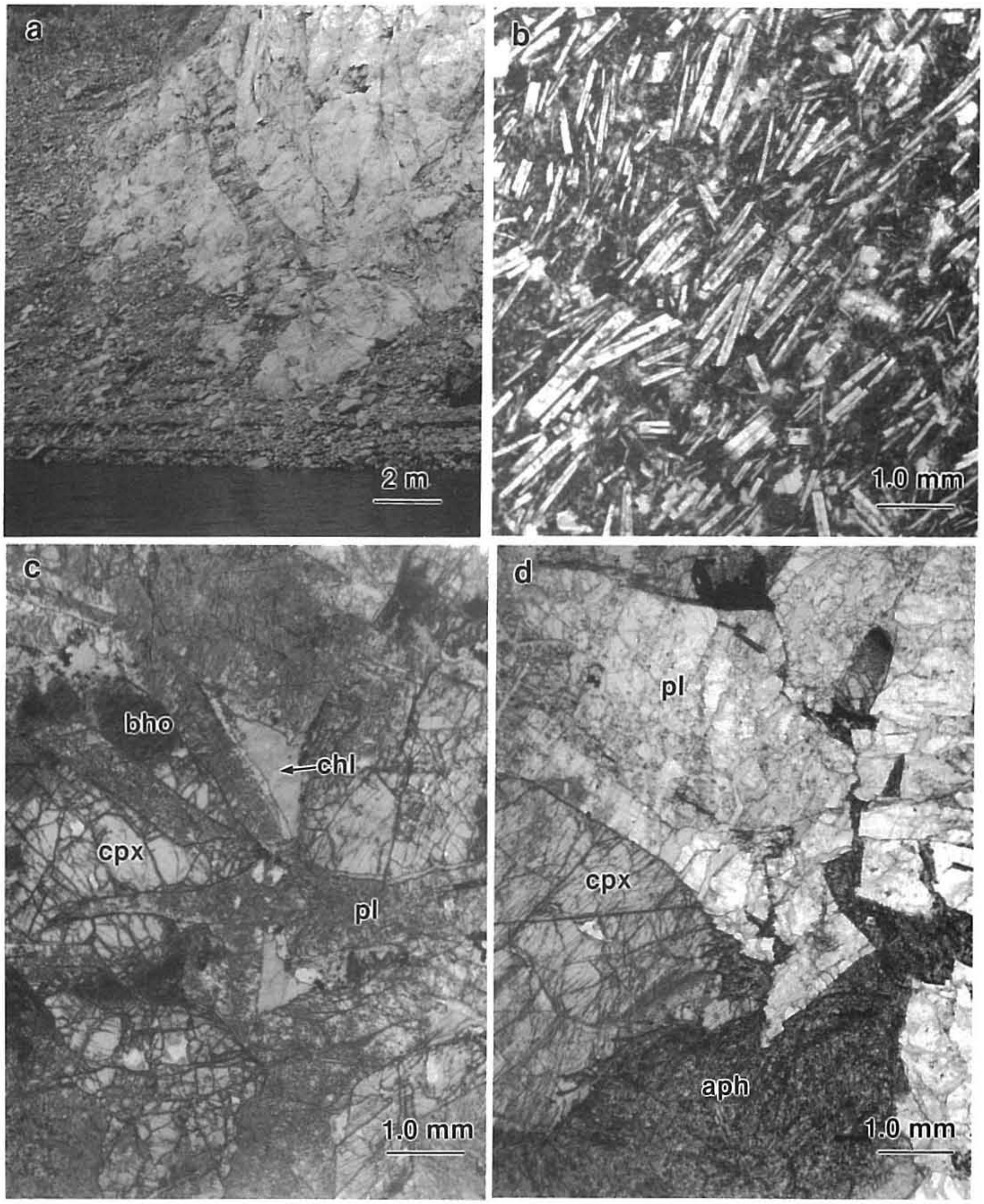
**Explanation of Plate 5**

a) Photograph showing the mode of occurrence of basalt dike, 1 m width in the massive diabase at the southern coast of the Iwaonai lake.

b) Photomicrograph of the above basalt. Laths of plagioclase show faint flow structure. Groundmass is made up of fine-grained augite and glass.

c) Photomicrograph showing a typical rock of the Shimokawa diabase. Ophitic texture is prominent. Plagioclase is turbid and clinopyroxene is partly altered to brown hornblende. Sample locality: AD, S111, Shimokawa gallery. pl: plagioclase, cpx: clinopyroxene, bho: brown hornblende and chl: chlorite.

d) The most coarse-grained hyaloophitic diabase. Plagioclase is chloritized, while augite remains fresh. Aphanitic part is composed mainly of glass where embryonic ilmenite and pyroxene are present. pl: plagioclase, cpx: clinopyroxene and aph: aphanitic part.


a
2 m
b
1.0 mm
c
bho
chl
cpx
pl
1.0 mm
d
pl
cpx
aph
1.0 mm

Muroran Institute of Technology. The instrument used is a Surface Ionization Mass Spectrometer of the Hitachi RMU-6-Type. All the analytical procedures followed the method established by Murozumi et al. (1977, 1981). The analyses were made at Murozumi's ultraclean laboratory using a single filament of rhenium as an ion source as well as phosphoric acid and silica gel as an ionization stabilizer. Lead was extracted by the dithizone-chloroform method. The concentration of lead was determined by an isotope dilution analysis using a spike solution of $^{206}Pb$. The effects of overall contamination were estimated to be less than 2ng of Pb. The results of isotope ratios were normalized by NBS-SRM 981 standard sample.

The results are presented in Table 8. The measured data on the Oshirabetsu gabbros show high ratios of $^{206}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$, and low ratios of $^{207}Pb/^{206}Pb$ respectively compared with those on the Shimokawa pillow lava and diabase. The copper dominant sulfide ore from the Shimokawa mine shows nearly the same value as those of the Oshirabetsu gabbros. The copper dominant ore of the Shimokawa mine occupies a domain together with the Oshirabetsu gabbros as shown in Test-fig.10.

Doe et al. (1974) established that conformable ore leads don't originate in the upper mantle. Their uniform lead-growth pattern may be the result of extensive mixing of

**Table 8** Lead concentrations and isotope ratios

| Shimokawa diabase complex | $^{207}Pb/^{206}Pb$ | $^{208}Pb/^{206}Pb$ | $^{206}Pb/^{204}Pb$ | $^{207}Pb/^{204}Pb$ | $^{208}Pb/^{204}Pb$ | Pb concentration (ppm) |
|---|---|---|---|---|---|---|
| 1. pillow lava | 0.8542(0.1) | 2.097(0.1) | 18.11(0.2) | 15.43(0.2) | 37.88(0.2) | 0.77 |
| 2. diabase sheet | 0.8514(0.2) | 2.112(0.3) | 18.14(0.2) | 15.40(0.2) | 38.25(0.3) | 1.66 |
| 3. diabase dike | 0.8495(0.2) | 2.094(0.2) | 18.31(0.2) | 15.52(0.3) | 38.26(0.2) | 1.89 |
| 4. Cu-dominant ore | 0.8422(0.1) | 2.085(0.1) | 18.46(0.2) | 15.52(0.2) | 38.41(0.2) | 10.65 |
| 5. amphibolized diabase | 0.8449(0.1) | 2.087(0.2) | 18.44(0.2) | 15.55(0.2) | 38.41(0.1) | 2.41 |
| 6. coarse ophitic diabase | 0.8557(0.1) | 2.099(0.1) | 18.12(0.3) | 15.47(0.3) | 37.93(0.3) | 0.37 |
| Oshirabetsu gabbro complex (=Oshirabetsu igneous complex) | | | | | | |
| 7. olivine gabbro | 0.8459(0.1) | 2.086(0.1) | 18.38(0.3) | 15.51(0.2) | 38.24(0.3) | 2.52 |
| 8. norite | 0.8457(0.1) | 2.086(0.1) | 18.44(0.1) | 15.56(0.2) | 38.38(0.2) | 7.63 |
| 9. sulfide-bear. norite | 0.8474(0.1) | 2.089(0.1) | 18.33(0.1) | 15.50(0.1) | 38.21(0.1) | 18.57 |
| 10. diorite | 0.8434(0.1) | 2.081(0.1) | 18.40(0.1) | 15.49(0.1) | 38.20(0.1) | 5.86 |
| 11. graphite | 0.8485(0.1) | 2.097(0.1) | 18.36(0.2) | 15.54(0.2) | 38.41(0.2) | 10.51 |

( ): uncertainty (%)
Analyst: H. Tanaka

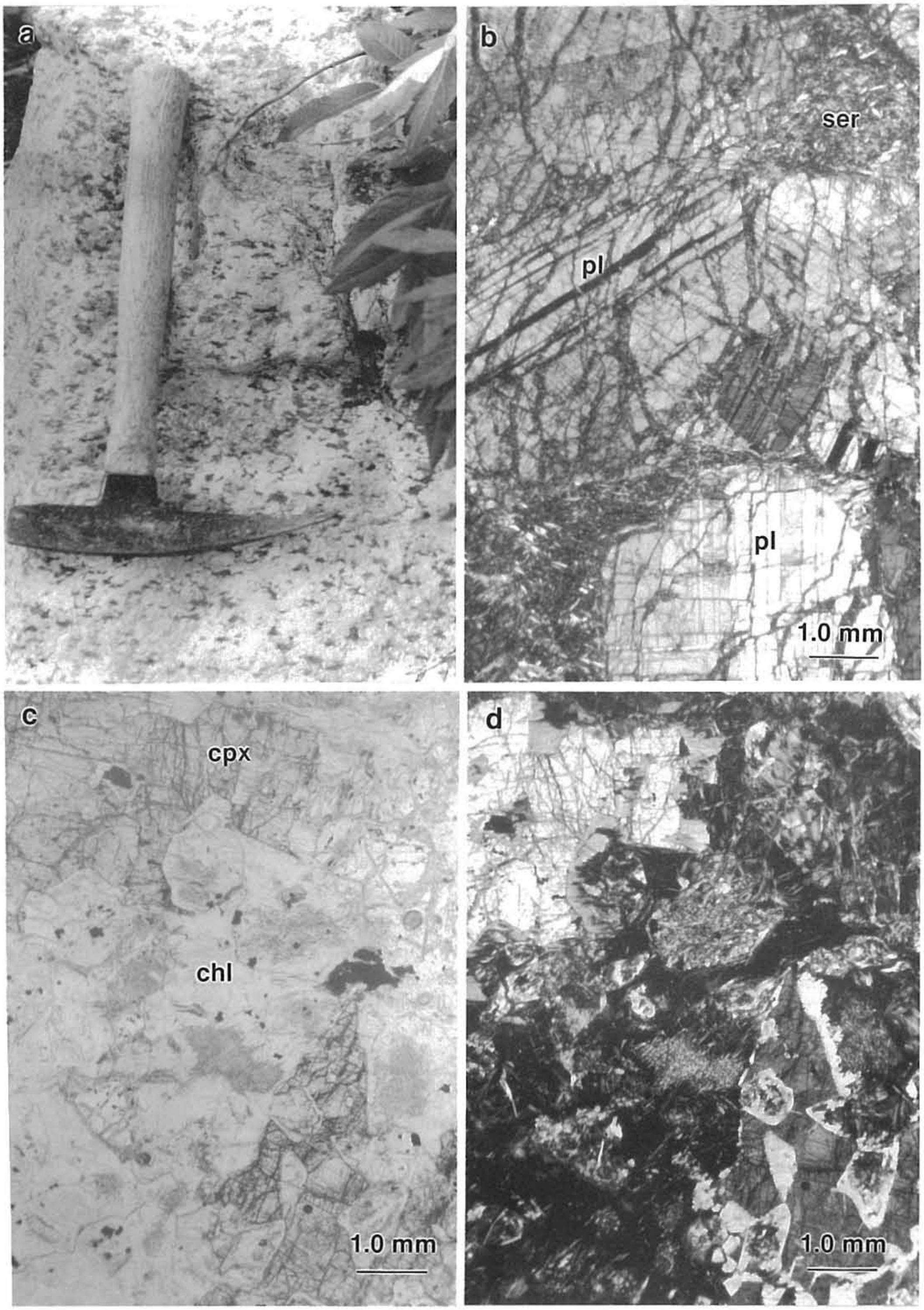
**Explanation of Plate 6**

**a)** Photograph showing an outcrop of the cumulate anorthosite at Nakanosawa, Shimokawa mine. Clots of clinopyroxenes show layering structure. Pyroxenes vanish in places.

**b)** Photomicrograph of a thin section of the anorthosite. Coarse-grained plagioclase is major constituent. Small amounts of sericitized clinopyroxene are observed as an intercumulus phase. ser: sericite after clinopyroxene, pl: plagioclase.

**c)** Photomicrograph of a thin section of chloritized clinopyroxenite. This rock occurs closely related with the anorthosite. Sample locality: Nakanosawa. cpx: clinopyroxene, chl: chlorite.

**d)** ditto, Crossed nicols.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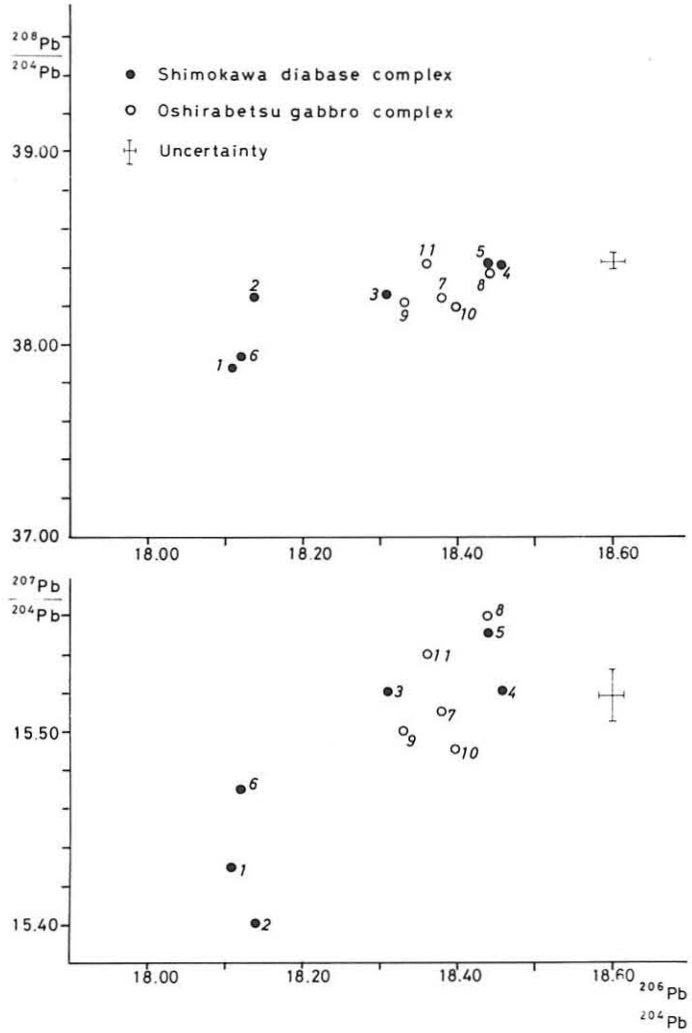



**Text-fig. 10** Diagrams showing $^{207}Pb/^{204}Pb$ (lower) and $^{208}Pb/^{204}Pb$ (upper) vs. $^{206}Pb/^{204}Pb$. The values are obtained from whole rock sample. Sample numbers refer to those in Table 8.

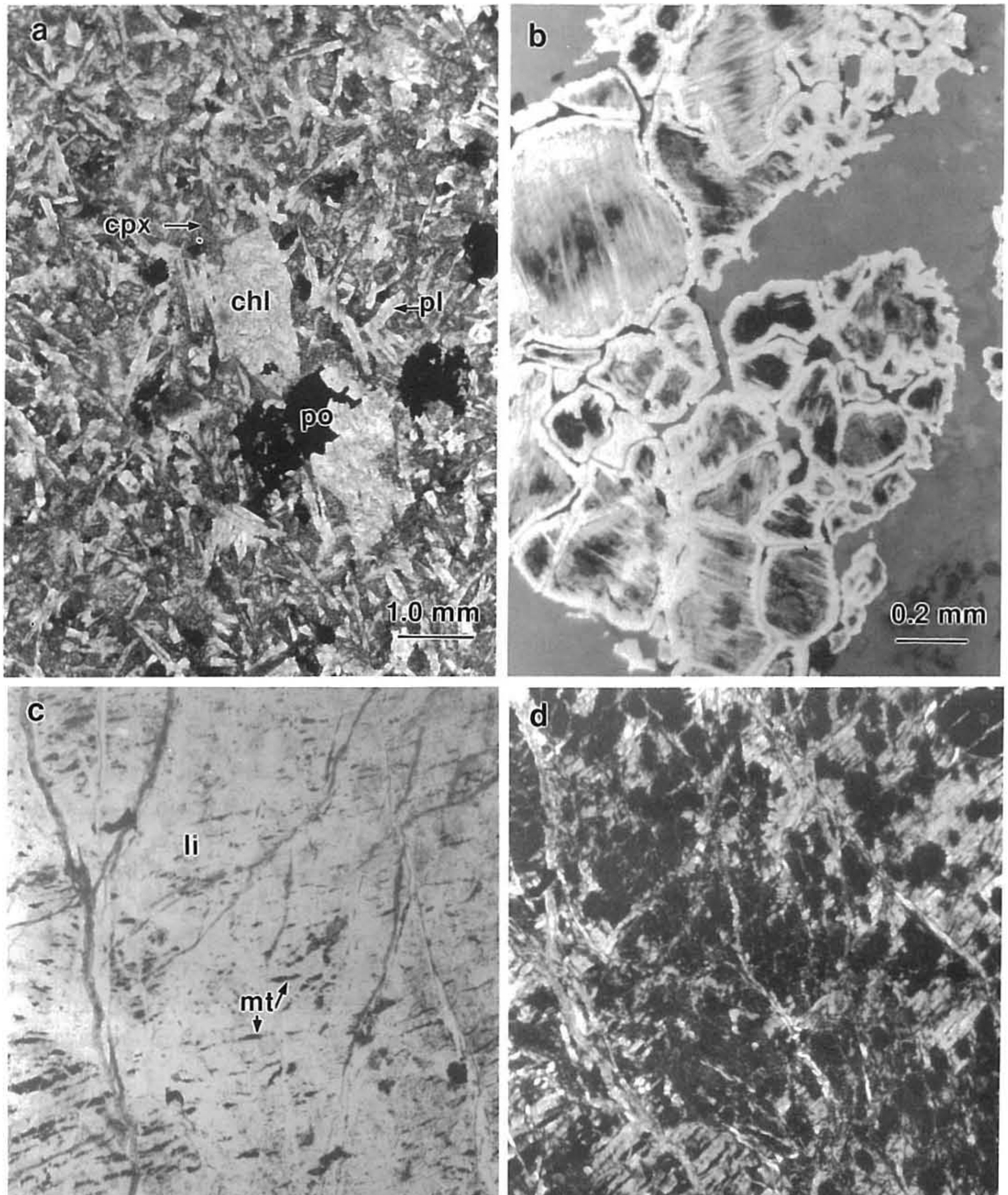
**Explanation of Plate 7**

**a)** Photomicrograph of a thin section of pyrrhotite bearing diabase dike in anorthosite. Sample locality: Iwaonai lake. pl: plagioclase, cpx: clinopyroxene, po: pyrrhotite, and chl: chloritized plagioclase phenocryst.

**b)** Photomicrograph of a polished section of the preceding pyrrhotite. Peculiar aggregates of pyrrhotite form a domain. Interior of the pyrrhotite is decayed.

**c)** Photomicrograph of a thin section of the Shimokawa serpentinite. Presence of bastite suggests that the original rock is harzburgite. Dusty magnetite occurs along the mesh. mt: magnetite, li: lizardite.

**d)** ditto, Crossed nicols.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lead derived from pelagic sediments subducted under volcanic island arc systems. Lead concentrations show a distinct variation between the Shimokawa diabases and the Oshirabetsu gabbros, i.e. these are 0.77—1.89 ppm in the Shimokawa pillow lava and diabase sheet, and 2.25—7.63 ppm in the Oshirabetsu gabbros. Copper-dominant massive sulfide ore of the Shimokawa mine and Ni-pyrrhotite bearing norite in the Oshirabetsu mine show high values; the former contains 10.65 ppm and the latter 18.57 ppm.

## Discussions

The Shimokawa diabase complex is regarded as a dismembered ophiolite slab 20km long with the thickness of 1.5km consisting of ultrabasic rocks, massive diabase, and pillow lavas with intercalations of sandy slates in ascending order. Petrographical and petrochemical features of the Shimokawa green rocks led to the conclusion that the green rocks belong to an abyssal tholeiite which have been generated at an oceanic ridge of late Jurassic to Cretaceous age (Bamba, 1974, Kosaka, 1975; Miyake, 1981). Colloform or euhedral cubic pyrites of the Shimokawa ores might have been contemporaneously formed with the magmatic activity that created the pillow lava (Bamba et al., 1985)

On the other hand, the Nisama igneous complex occupying the adjacent eastern area of the Shimokawa diabase complex is characterized by biotite-cordierite hornfels and intrusions of gabbroic masses showing variations from olivine gabbro to diorite belonging to the calc-alkaline rock series of Oligocene-Miocene age. This geologic unit can be regarded as a mass possessing the characteristics of an island arc. A K-Ar age of the Hidaka metamorphics (migmatite) has been reported (Nozawa, 1975) as 17-31Ma which should also apply to the Nisama hornfels. Therefore, the Nisama igneous complex is estimated to be of Oligocene-Miocene age.

From the mode of occurrence, the Shimokawa diabase complex is regarded as an upper sequence of the Shimokawa ophiolite which was obducted at the accretionary boundary with the western margin of the island arc as illustrated in Text-fig. 12. In this sense, Shimokawa diabase complex can be called an "obduction zone ophiolite" proposed by Miyashiro (1977). However, from the lithological features of the sandy slates intercalated with the Shimokawa pillow lavas or diabases, the Shimokawa pillow lavas

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**Explanation of Plate 8**

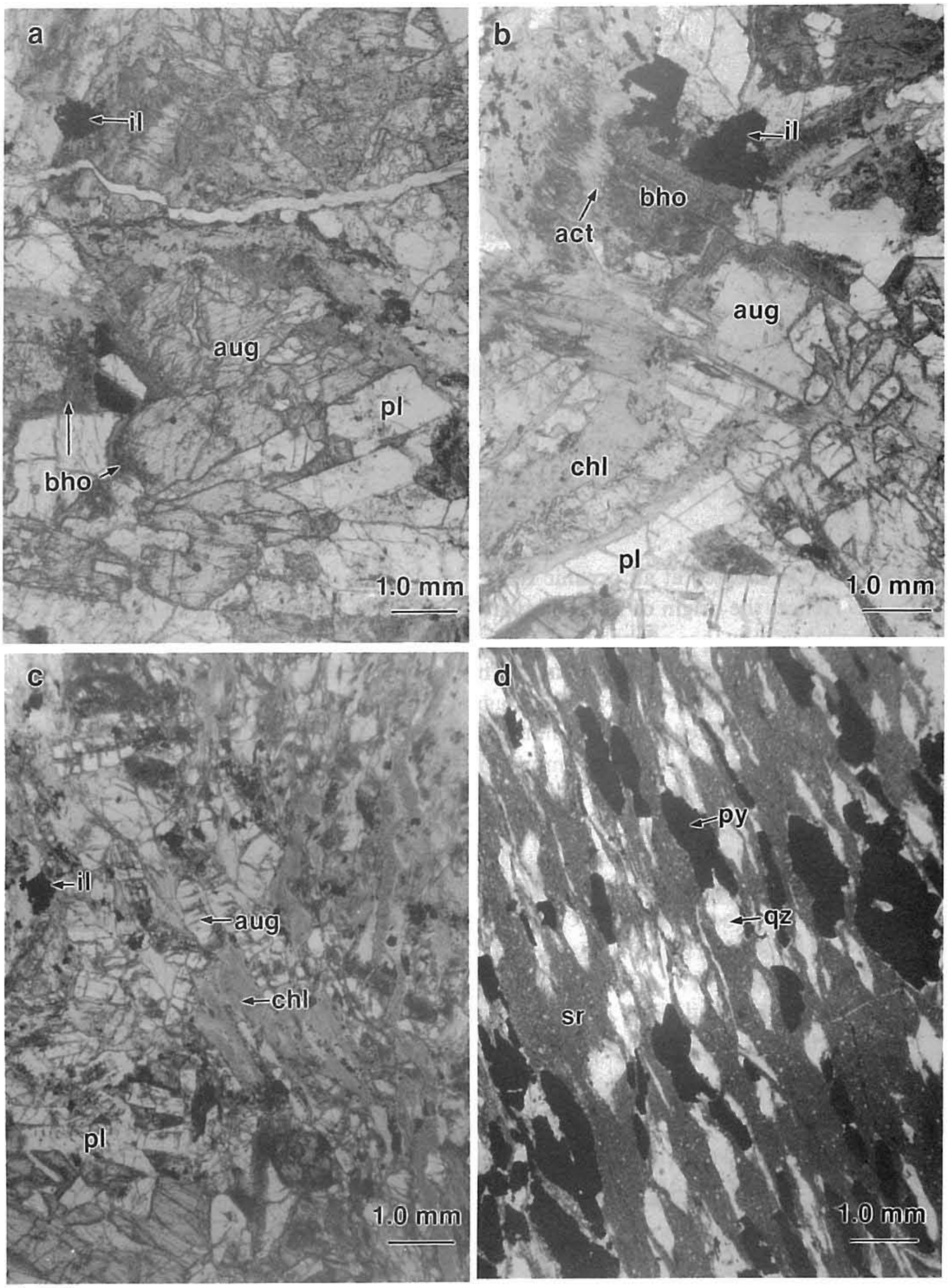
Photomicrographs of thin sections of altered rocks from the Shimokawa diabase complex.

**a)** Medium-grained ophitic diabase from the Shimokawa gallery (AD,S111). Brown hornblende occurs at the rim of augite. bho: brown hornblende, aug: augite, pl: plagioclase, and il: ilmenite.

**b)** Medium-grained ophitic diabase from the Shimokawa gallery (AD,S111). Fibrous actinolite replacing brown hornblende is observed. bho: brown hornblende, act: actinolite, il: ilmenite, aug: augite, pl: plagioclase, and chl: chlorite.

**c)** Chloritized diabase from the Shimokawa mine. chl: chlorite, aug: augite, pl: plagioclase, and il: ilmenite.

**d)** Sericite-quartz-pyrite rock from Chisawa, Iwaonaigawa. sr: sericite-rich part, py: pyrite (aggregates of cubic pyrite), and qz: aggregates of quartz.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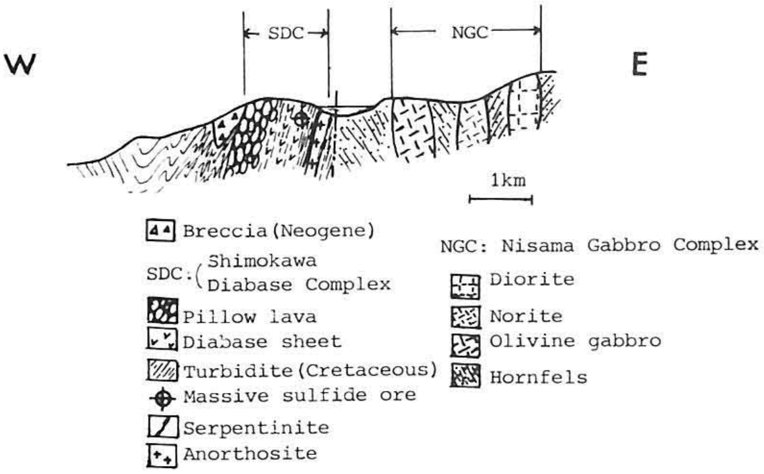


**Text-fig. 11** A profile showing the geologic positions of the Shimokawa diabase complex and the Nisama igneous complex (= Nisama gabbro complex) near the Iwaonai lake area, northern Hokkaido.

should not be created at an oceanic ridge but at fore-arc basin as illustrated in Text-fig.12. Hence, the origin of the Shimokawa diabase complex is quite complex.

The lower sequence of the Shimokawa ophiolite might have subducted and created a sulfide bearing calc-alkaline magma at the Benioff Zone as a result of partial melting (Ringwood and Green, 1966). The magama might have contaminated the crustal materials and separated into two immiscible liguids silicate and sulfide melts in a gabbroic mass. Coexisting states of immiscible liquids in gabbroic magma has been explained by Naldrett (1969) and Naldrett et al. (1976); main sulfide melt is at the bottom of the magma reservoir but is interstitial with silicate melt at the middle part of the magma reservoir. The sulfide melt has yielded an hexagonal pyrrhotite-pentlandite (Ni 30%)-chalcopyrite assemblage in olivine gabbro and norite.

The sulfide concentration reaches 10 modal percent in the norite. During this process, Ni in the sulfide melt was consumed, thus it is assumed that the remaining sulfide melt became rich in Fe, Cu and Co. The remaining melt has ascended as far as the level of the Shimokawa diabase complex slab. Thereby impregnations of pyrrhotite-chalcopyrite in which pyrite is free are observed at the eastern margin of the

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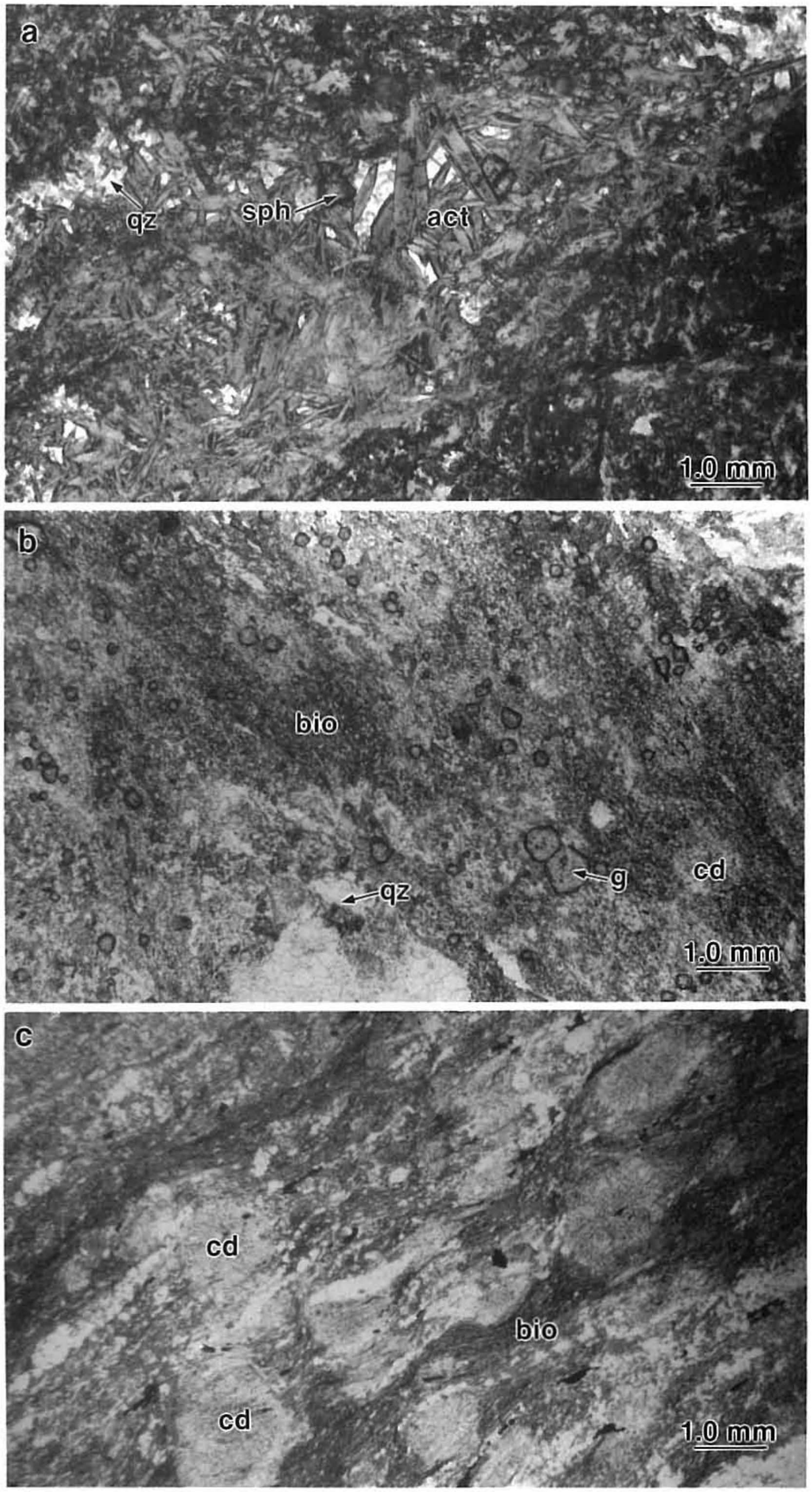
**Explanation of Plate 9**

Photomicrographs of thin sections of metamorphic rocks from the mass of the Nisama igneous complex.

**a)** Amphibolized diabase. Actinolite-quartz veins occur widely in the fine-grained diabase. act: actinolite, qz: quartz, and sph: sphene.

**b)** Garnet and cordierite-bearing schistose hornfels. This rock occurs nearby the olivine gabbro mass. g: -garnet, cd: cordierite, bio: biotite, and qz: quartz.

**c)** Cordierite-bearing schistose hornfels nearby the olivine gabbro mass. Cordierite porphyroblasts are replaced by fine-grained quartz. bio: biotite-rich part, and cd: cordierite porphyroblast.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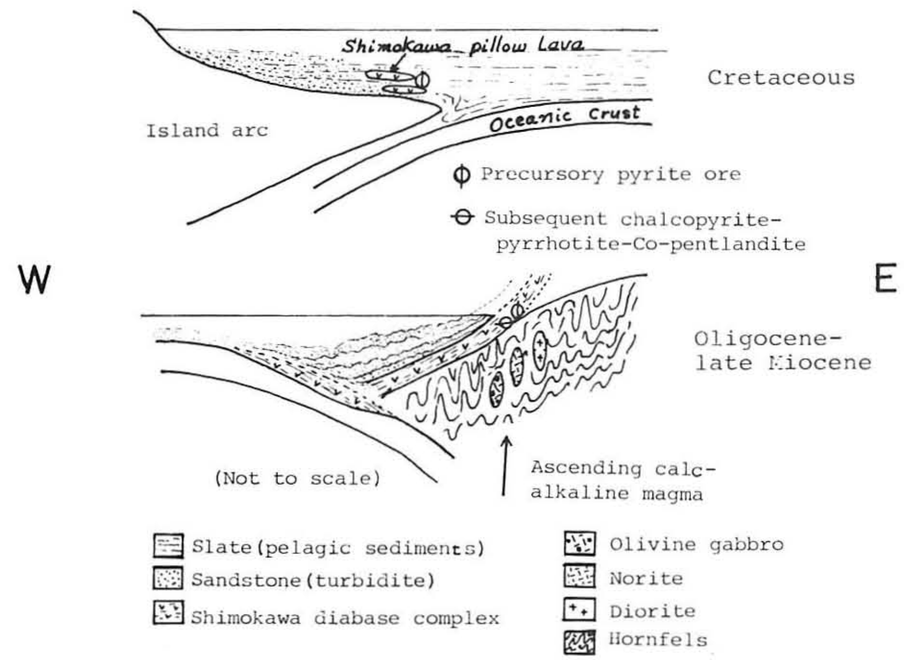


**Text-fig. 12** Diagrams illustrating the development and emplacement of the Shimokawa diabase complex and the Nisama igneous complex in an island arc and its adjacent regions.

Shimokawa diabase complex, e.g. in phyllite at Nakanosawa Shaft area and in anorthosite at Iwaonai lake. On the other hand, pre-existing colloform pyrite or cubic pyrite masses of exhalative sedimentary origin were combined with the ascending sulfide melt. Consequently so-called Shimokawa ores consisting of pyrrhotite-chalcopyrite-cobaltpentlandite-cubanite-mackinawite-pyrite (py(I))-pyrite (py(II)) were formed at the Shimokawa mine.

From the above model, the anomalous values of $\delta^{34}S$ (0/00) of the Shimokawa ores ranging from $-5$ to $+15$ (Yamamoto et al., 1984) can be explained as follows:

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**Explanation of Plate 10**

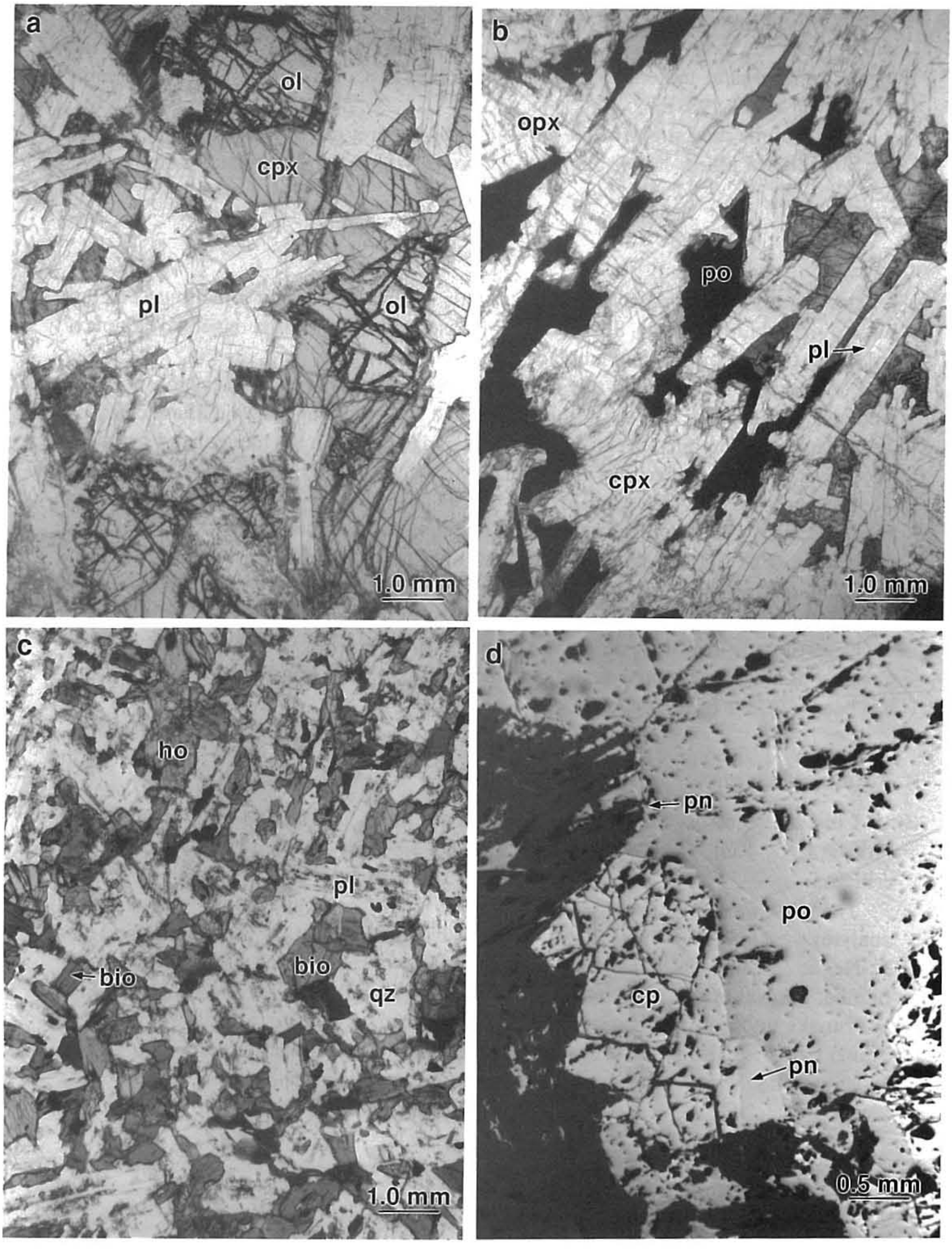
Photomicrographs of thin sections and a polished section of plutonic rocks from the Nisama igneous complex.

**a)** Olivine gabbro. Olivine is euhedral indicating orthocumulus phase. Intercumulus phase is made up of clinopyroxene and plagioclase showing ophitic texture. ol: olivine, cpx: clinopyroxene, and pl: plagioclase.

**b)** Norite. Pyrrhotites make up ophitic texture with silicate minerals, indicating that pyrrhotite is orthomagmatic origin. po: pyrrhotite containing pentlandite, pl: plagioclase, cpx: clinopyroxene, and opx: orthopyroxene.

**c)** Diorite. ho: brown hornblende, bio: biotite, pl: plagioclase, and qz: quartz.

**d)** Photomicrograph of a polished section of Ni-pyrrhotite ore from the Okushibetsu mine. Paragenetic relationship between pyrrhotite, chalcopyrite and pentlandite is observed. po: pyrrhotite (hexagonal), cp: chalcopyrite, and pn: pentlandite.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sulfur isotope ratios of precursory pyrite are high because they represent sea water sulfate, and the low values of pyrrhotite may be ascribed to the interaction between magma and crustal materials, evidence of which is found in the Oshirabetsu mine (Takshashi et al., 1983).

Lead isotope data suggest that the Cu-dominant ores are not consanguineous with the Shimokawa pillow lavas, but with gabbros in the adjacent Hidaka metamorphic belt.

## Conclusions

Ore genesis on the massive sulfide depostis of the Shimokawa mine must be considered in relation to the Shimokawa diabase and the Nisama igneous complex, especially to their origins and emplacement processes.

Petrographic features and the present status of these two complexes have been introduced in this paper and the author concluded that the Shimokawa diabase complex was created in a fore-arc sea floor of Cretaceous age based on the intercalated sedimentary rocks showing terrigenous characteristics.

The anomalously wide range of $\delta^{34}S$ values, from $-5$ to $+15$ of the Shimokawa ores, and the similarity of lead isotope ratios of copper-dominant Shimokawa ores with gabbros from the Hidaka metamorphic belt, but not with Shimokawa pillow lava leads to the conclusion that the later phase mineralization is closely related to the magmatic activity forming the Nisama igneous complex of Oligocene to late Miocene age.

Nevertheless, the way of access between the Shimokawa diabase complex of Cretaceous and the Nisama igneous complex of Oligo-Miocene has not been solved and has been left as a future problem.

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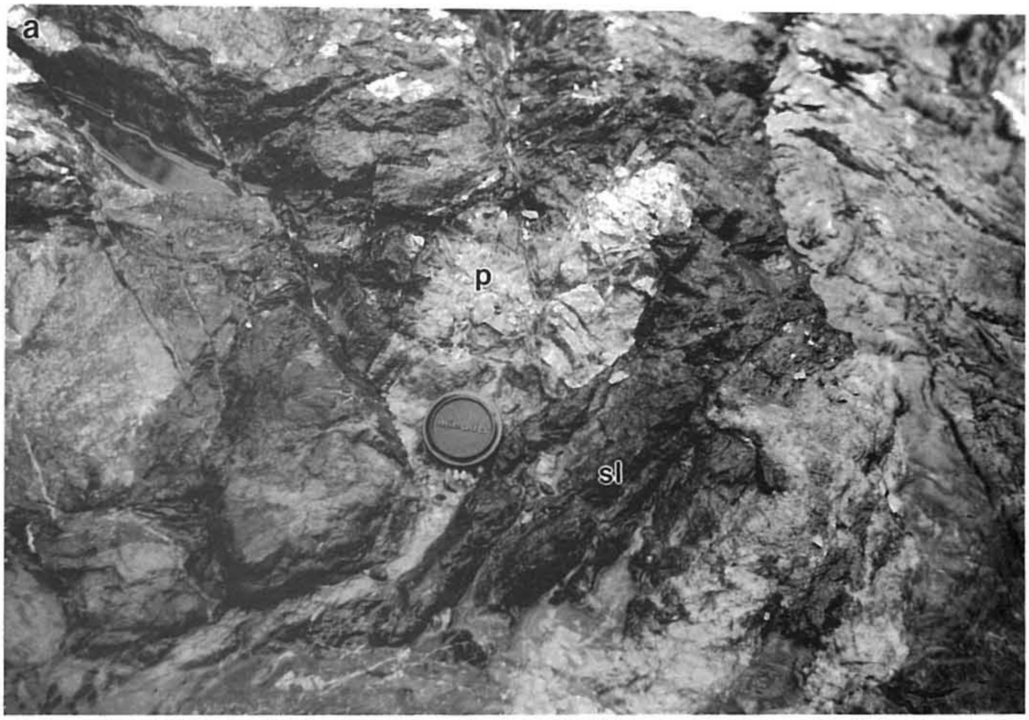
**Explanation of Plate 11**

**a)** Photograph showing the relation between black slate and pillow lava at Nakanosawa. Interpillows are made up of slate. In places slate is included in a pillow and vice versa. p: pillow lava, and sl: black slate.

**b)** Outcrop of the foliated pillow lava cataclasite at the southern shore of the Iwaonai lake looking from the north. The foliation plane is almost vertical.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Johnson. I would like to express my sincere thanks to above persons.

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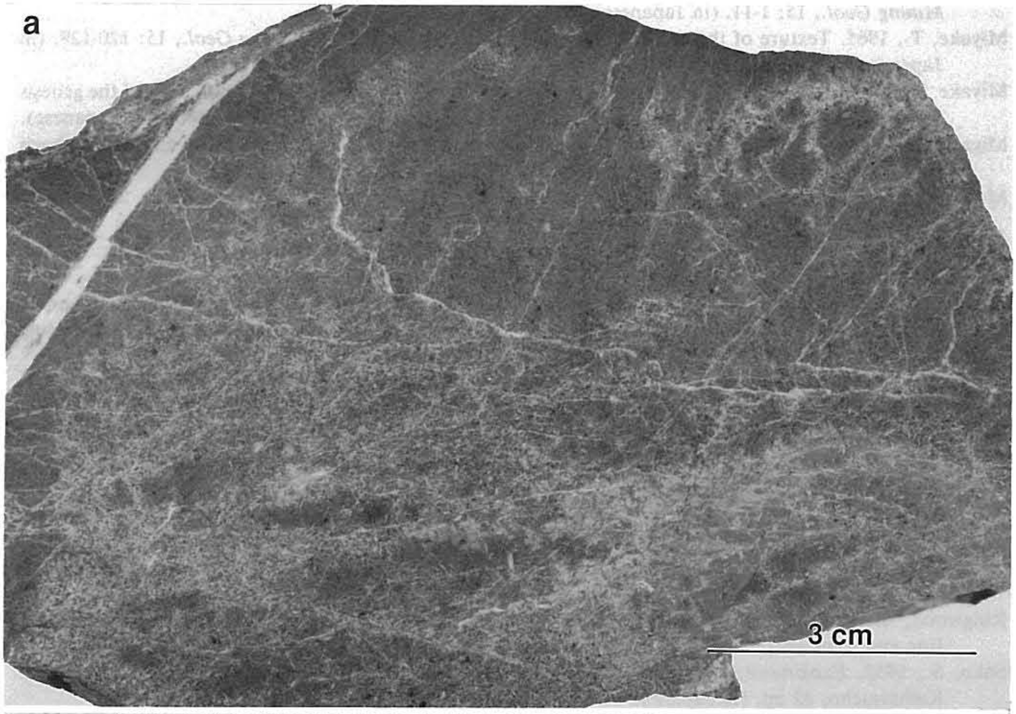
**Explanation of Plate 12**

**a)** Photograph of a sheared pillow specimen from the Spiral Tunnel, Towari inclined gallery, Shimokawa mine. Chilled margin is observed at the top of the picture. Shearing effect is seen in the middle to bottom of the pillow. The pillows from the Shimokawa diabase complex are characterized by cataclastic structure as shown in the picture.

**b)** Photograph of a slab of peculiar unsorted sandstone (breccia) from the Iwaonai damsite, southern part of the Shimokawa mine. The sandstone is made up of angular fragments of variolitic — ophitic diabases, sandstone and mudstone. Metamorphic rock fragments of amphibolite facies and prehnite-pumpellyite facies are also contained in the sandstone.

a

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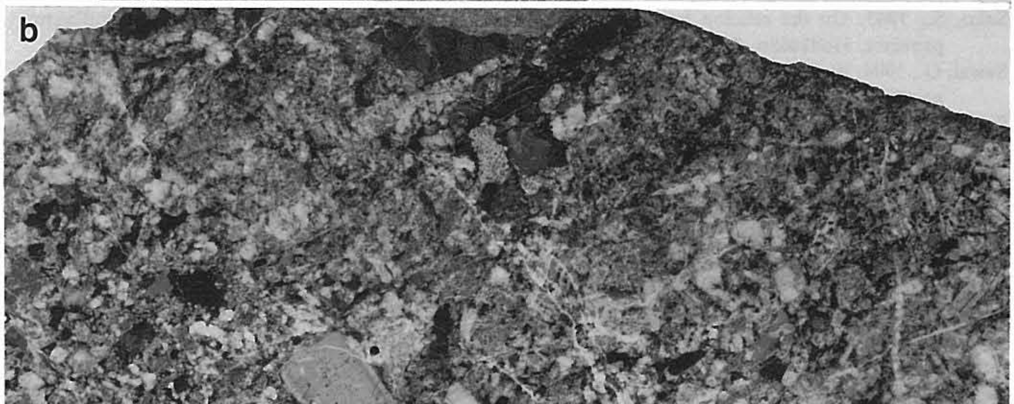

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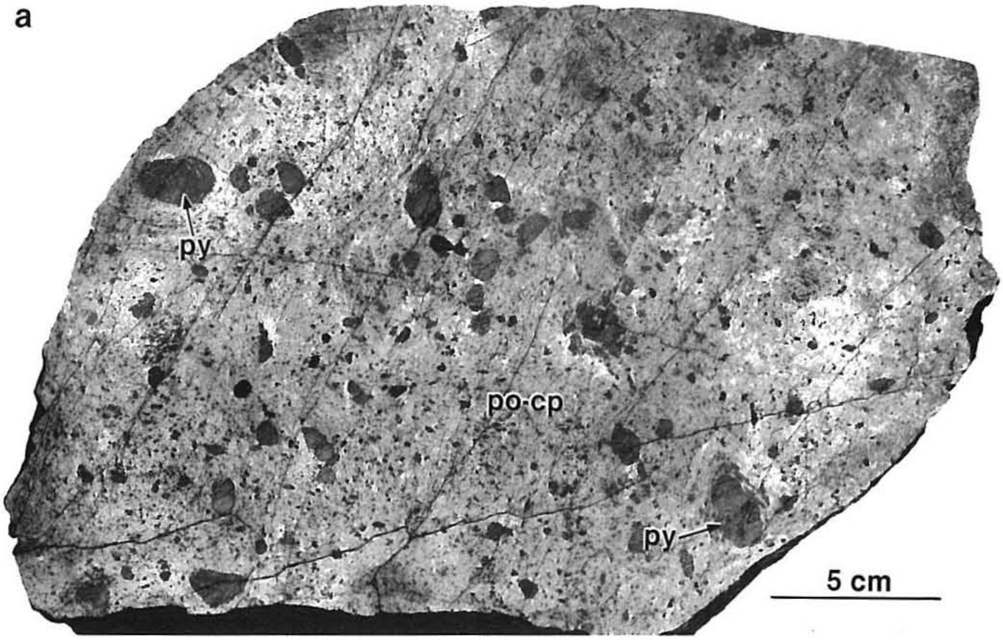
**Explanation of Plate 13**

**a)** Photograph of a polished specimen of the typical massive sulfide ore from L13S16 (No. 17-OREBODY), Shimokawa mine. Fragments of pyrite mass (py) are scattered in pyrrhotite-chalcopyrite-rich ore. Such precursory pyrite is called pyrite (I). The pyrrhotite-chalcopyrite-rich part (po-cp) shows faint flow structure around the precursory pyrite mass.

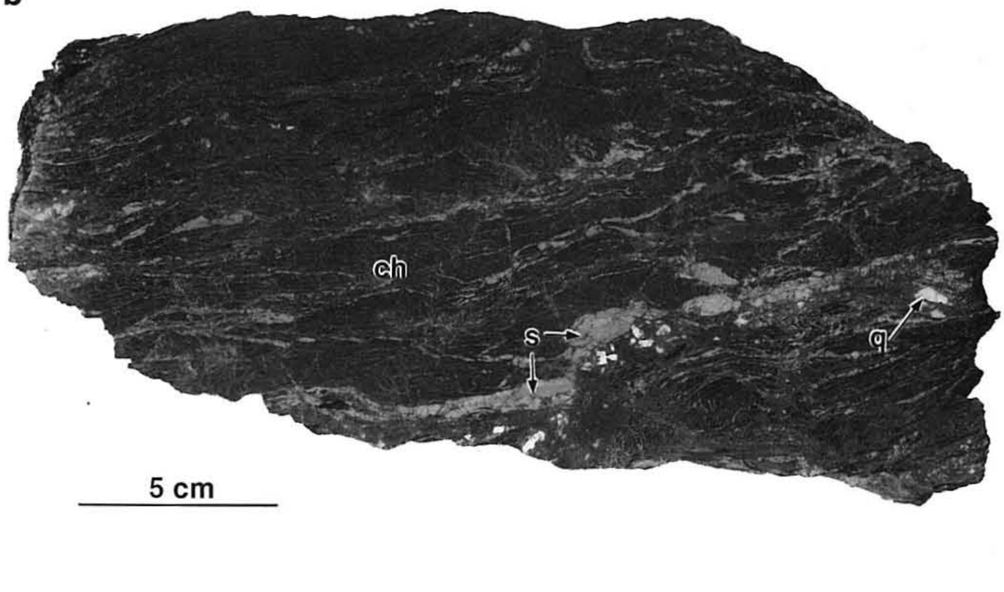
**b)** Photograph of a polished specimen of the typical banded ore from L18N6 (SHIN-OREBODY), Shimokawa mine. The ore is made up of chlorite-rich part (ch) and sulfide-rich part (s). The former is composed of chloritized black phyllite. Chlorite is fibrous showing a linear arrangement parallel with the banded structure. Leucocratic pools consisting of quartz-albite-sericite-sphene-apatite assemblage (q) are produced in both chlorite-rich and sulfide-rich parts. Sulfide consists mainly of pyrrhotite and chalcopyrite.

The banded ore formed in the black phyllite is regarded as a product of subsequent phase of mineralization.

a




b



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