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THE TOKORO BELT, A TECTONIC UNIT OF THE CENTRAL AXIAL ZONE OF HOKKAIDO

by

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(with 12 text-figures, 16 tables and 17 plates)

Abstract

The Tokoro Belt, a tectonic unit occupying the eastern side of the Central Axial Zone of Hokkaido, is made up of Jurassic greenstones and Cretaceous clastic sedimentary rocks. The former is called Nikoro Group and the latter Saroma and Yubetsu Groups.

The Nikoro Group is separately distributed forming two masses called the Eastern and the Western masses. The geologic constitutions of the two masses have been studied and the following distinct contrasts between them were revealed: The Western mass is characterized by the presence of abundant hyaloclastites and pillow lavas which are alkalibasalt or trachyte. Limestones associated with chert are rather common in the mass. Strata-bound Mn-oxide ores and massive sulfide ore deposits both in a small scale are found here. On the other hand, the Eastern mass is characterized by the preponderant occurrence of pillow lavas of tholeiitic basalt. It is noteworthy that manganiferous hematite deposits predominate in the Eastern mass, especially in the northern part. Hyaloclastites and limestones are poorer here.

REE abundances of pillow lavas and related rocks from the two masses were examined. The results obtained show that the pillow lavas from the Eastern mass is the solid type whereas those from the Western mass the liquid type. Gabbro and troctolite believed to be of tectonic blocks are found in the northern Tokoro Belt though the quantity is scant.

The above-stated facts suggest that the Nikoro Group of the Tokoro Belt is composed of two masses those are different in origin, both of which are presumed to have been derived from an oceanic crust having ophiolite sequences. The Eastern mass was possibly produced in an abyssal sea floor, while the Western mass represents seamounts (Niida et al., 1983) of Jurassic time.

Introduction

The area of 150 km long and 20-40 km wide extending from Tokoro to Toyokoro occupied by Mesozoic greenstones and turbidites is called the Tokoro Belt. This belt is a tectonic unit occupying the eastern side of the Central Axial Zone of Hokkaido. The Tokoro Belt increases in width toward the north and the constitutions are complicated here, while it decreases in scale toward the south and the greenstones disappear in the southern part of Toyokoro. Thus the Tokoro district occupied by Mesozoic formations is called "Northern Tokoro Belt".

Geologic study of the Northern Tokoro Belt was first carried out by Asahi et al. (1954), then by Suzuki et al. (1956) with the aim of exploration for the volcanogenic sedimentary ore deposits of iron-manganese ores in the terrain. Through these works, mode of occurrence of the ore and its quality were roughly introduced. Afterwards, Geological Survey of Japan advanced the work making Geological Sheet Map (1:50,000) in this terrain, and the sheet maps of "Ikutawara" by Yamada et al. (1963), "Saromako & Sanribanya" by Kuroda et al. (1964), "Rubeshibe" by Sawamura et al.

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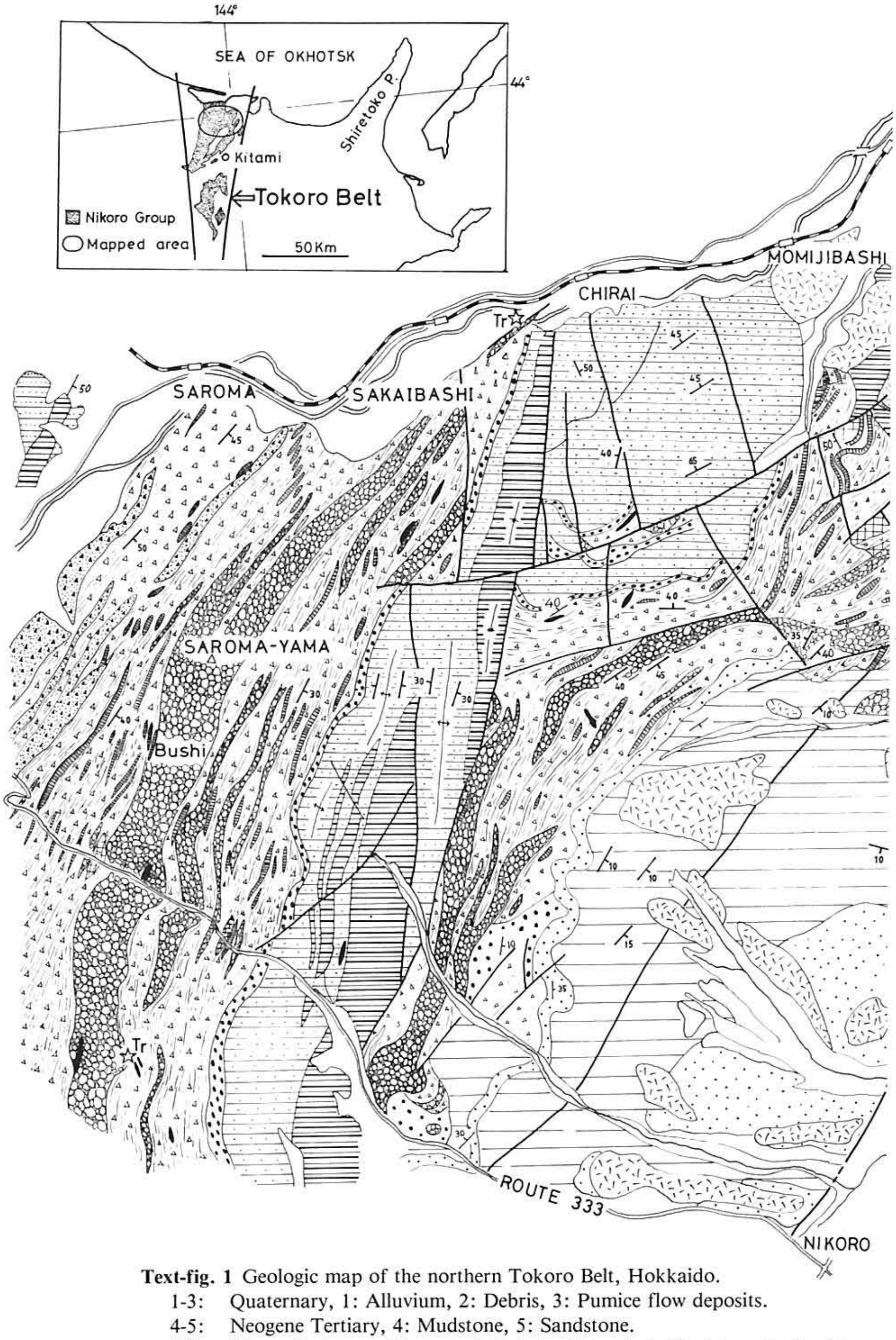


Text-fig. 1 Geologic map of the northern Tokoro Belt, Hokkaido.
1-3: Quaternary, 1: Alluvium, 2: Debris, 3: Pumice flow deposits.
4-5: Neogene Tertiary, 4: Mudstone, 5: Sandstone.
6-8: Upper Cretaceous (Saroma & Yubetsu Group), 6: Mudstone, 7: Sandstone, 8: Conglomerate.

9-17: Jurassic (Nikoro Group), 9: Pillow lava of alkalibasalt, 10: Manganiferous hematite ore, 11: Masive lava of basalt, 12: Pillow lava of tholeiitic basalt, 13: Radiolarian chert, 14: Hyaloclastite, 15: Reworked hyaloclastite, 16: Limestone, 17: Siltstone.

18-20: Dike rock, 18: Quartz-keratophyre, 19: Arfvedsonite-trachyte, 20: Dolerite.

21-22: Tectonic block, 21: Troctolite, 22: Gabbro.

(1965) and "Tanno" by Ishida et al. (1968) have been successively published. The stratigraphy of the Mesozoic pile in the terrain was also studied, i.e. Yamada et al. (1963) concluded that the Jurassic system of this terrain can be divided lithologically into the Yubetsu Group, the Nikoro Group and the Saroma Group in ascending order. These groups have been considered to be conformable with each other.

Subsequent to the preceding works, reinvestigations for the Fe-Mn mineralizations in the northern Tokoro Belt were taken place by Bamba et al. (1967) to reveal the relationship between volcanism and ore genesis. Bamba (1969, 1974) concluded that Fe-Mn mineralizations may be ascribed to subaqueous volcanism of tholeiitic basalt, especially to the subsequent spilitization process.

Since 1975, the second look of the greenstones in the northern Tokoro Belt has been made by Bamba and his many students (Graduation Theses of the Hokkaido University) and more detailed classification of the greenstones have been made, i.e. the greenstones have been divided into 1) pillow lava, 2) massive lava, 3) hyaloclastite, 4) reworked hyaloclastite, 5) radiolarian chert, 6) limestone, 7) siltstone and others. Furthermore, various kinds of dike rock have been found and distinguished as alkalidolerite, trachyte, arfvedsonite-trachyte, keratophyre, and quartz-keratophyre. Besides, some tectonic blocks of troctolite and gabbro have been newly found in the northern Tokoro Belt.

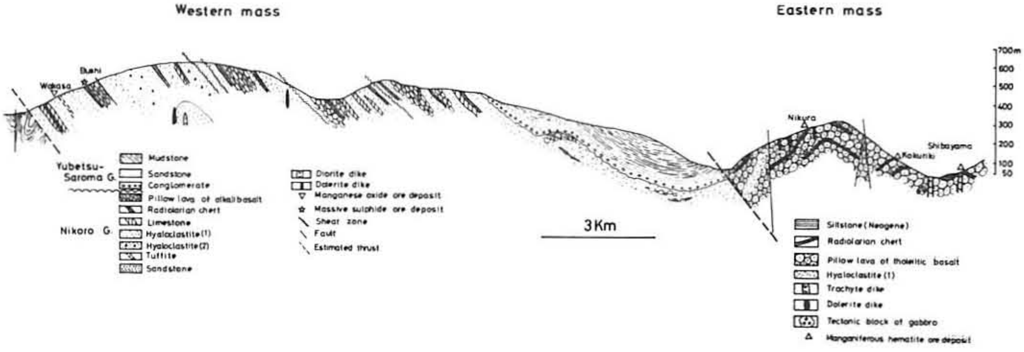
The stratigraphy and geologic structure of this terrain have been also reinvestigated and the presence of anticlinal structure of the Nikoro Group in the Western mass has been disclosed. Thus, the Yubetsu Group can be correlated with the Saroma Group and both two Groups lie on the Nikoro Group. On the other hand, a conglomerate bed indicating the presence of large scale unconformity has been found between the greenstones and clastic sedimentary rocks in the Western mass of the Nikoro Group. Consequently, the basement of the Saroma Group has been redefined by Niida et al. (1982).

Pillow lavas of the Eastern mass were distinguished from those of the Western mass, because the former are tholeiitic rocks associated with strata-bound manganiferous hematite deposits whereas the latter are alkalic rocks in which massive sulfide and manganese oxide ores occur. REE abundances in the pillow lavas suggest that the pillow lavas from the Eastern mass are the solid type while those from the Western mass are the liquid type.

The geologic environments where the Tokoro greenstones were produced, and the mineralizations which formed iron-oxide, Mn-silicate, Mn-oxide and massive sulfide ores in this terrain are discussed here on the basis of new data which have been accumulated in recent ten years.

Geological Setting

The geology of the Tokoro Belt is made up of the Nikoro Group of Jurassic system and the Saroma and the Yubetsu Groups of Cretaceous system. The former is unconformably overlain by the latter.



Text-fig. 2 Generalized geologic profile of the northern Tokoro Belt.

As given in Text-fig. 1, the Nikoro Group separately occurs in two masses, and the area between the two masses is occupied by the Cretaceous Saroma Group. On the other hand, the Yubetsu Group occurs in fault contact along the western margin of the Nikoro Group. The separated two masses of the Nikoro Group are called the Eastern and the Western masses. The Eastern mass is composed mainly of pillow lavas of tholeiitic basalt with intercalation of radiolarian chert. Among these layers, manganiferous hematite deposits occur in many places. On the other hand, the Western mass is made up mainly of hyaloclastite associated with pillow lavas of alkalibasalt. Massive sulfide and Mn-oxide ore deposits are present in the Western mass.

The two masses form hilly lands. The Eastern mass includes Mt. Tokoro-yama (480 m) and Mt. Iwakeshi-yama (425 m), and the Western mass embraces Mt. Saroma-yama (480 m) and Mt. Nikoro-yama (829 m). Neogene Tertiary system consisting mainly of mudstone and sandstone is observed at the piedmont area of the above two masses.

Nikoro Group of the Eastern Mass

The Nikoro Group of the Eastern mass is cut by E-W and NW-SE faults and divided into many blocks. The complicated structure makes the interpretation of the stratigraphy difficult. The stratigraphic succession of the Nikoro Group in this mass can be estimated as shown in Text-fig. 3. The geologic columnar section was obtained from the Shibayama mining area. This sequence appears repeatedly in the southern area of the Shibayama mine in terms of an anticlinal axis. Quartz-keratophyre and arfvedsonite-trachyte (Bamba, 1980) showing dike swarm are observed in the western part of this mass. On the other hand, tectonic blocks of gabbro (Bamba, 1981), 10-20 meters in size, are found near by the above dike swarm.

The Jurassic system represented by the Nikoro Group of the Eastern mass is estimated to be about 1,700 meters thick.

Pillow lavas

Pillow lavas of tholeiitic basalt predominate in the Nikoro Group of the Eastern mass. The thickness of a unit of pillow lava bed ranges from ten to several tens meters,

Table 1 Chemical composition and CIPW norm of pillow lavas from the Eastern mass, northern Tokoro Belt

	1	2	3	4	5	6	7	8
SiO_2	48.88	47.40	47.36	52.94	45.20	47.76	45.20	42.44
TiO_2	1.48	1.41	1.10	1.13	2.83	1.39	1.08	0.94
Al_2O_3	14.56	15.35	14.22	14.87	15.15	15.90	15.12	17.92
Fe_2O_3	3.55	3.11	3.88	7.11	6.84	4.67	7.66	5.44
FeO	7.52	6.29	6.78	1.75	4.39	5.13	5.86	6.56
MnO	0.19	0.15	0.19	0.13	0.14	0.20	0.57	0.58
MgO	6.31	8.53	8.07	4.08	7.27	6.87	6.71	6.89
CaO	10.80	11.18	12.05	9.85	7.53	9.81	10.25	9.79
Na_2O	2.82	1.82	2.05	3.30	2.61	3.04	1.13	1.85
K_2O	0.05	0.75	0.13	0.10	0.69	0.37	0.10	0.20
P_2O_5	0.08	0.08	0.08	0.16	0.49	0.12	0.16	0.50
$H_2O(+)$	3.06	3.70	3.52	3.80	5.44	4.16	5.79	6.02
$H_2O(-)$	0.42	0.44	0.40	0.58	1.36	0.52	0.23	0.24
Total	99.72	99.94	99.83	99.80	99.94	99.94	99.86	99.35
Q	1.60	—	0.25	11.45	3.20	0.23	8.04	—
or	0.30	4.43	0.77	0.59	4.08	2.19	0.59	1.18
ab	23.86	15.40	17.35	27.92	22.08	25.72	9.56	15.65
an	26.92	31.50	29.22	25.47	27.59	28.65	35.89	40.00
di	21.22	18.80	24.16	17.40	5.12	15.28	11.06	4.27
hy	14.19	16.75	16.26	2.09	15.73	13.50	15.17	18.56
ol	—	2.06	—	—	—	—	—	3.04
mt	5.15	4.51	5.62	2.79	6.40	6.77	11.10	7.88
il	2.81	2.16	2.09	2.15	5.37	2.64	2.05	1.78
hm	—	—	—	5.19	2.42	—	—	—
ap	0.19	0.19	0.19	0.37	1.13	0.28	0.37	1.16

1-3: pillow lavas from the Kokuriki mine
1: glassy facies, 2: variolitic facies, 3: subophitic facies
4-6: pillow lavas from the Hokko mine
4: glassy facies, 5: variolitic facies, 6: subophitic facies
7: pillow lava from open-pit of the Kokuriki mine, rim of unit pillow
8: pillow lava from open-pit of the Kokuriki mine, core of unit pillow

(Analysts: K. Maeda & M. Kawano)

Explanation of Plate 1

Photographs of pillow lava in the Nikoro Group of the Eastern mass, northern Tokoro Belt.

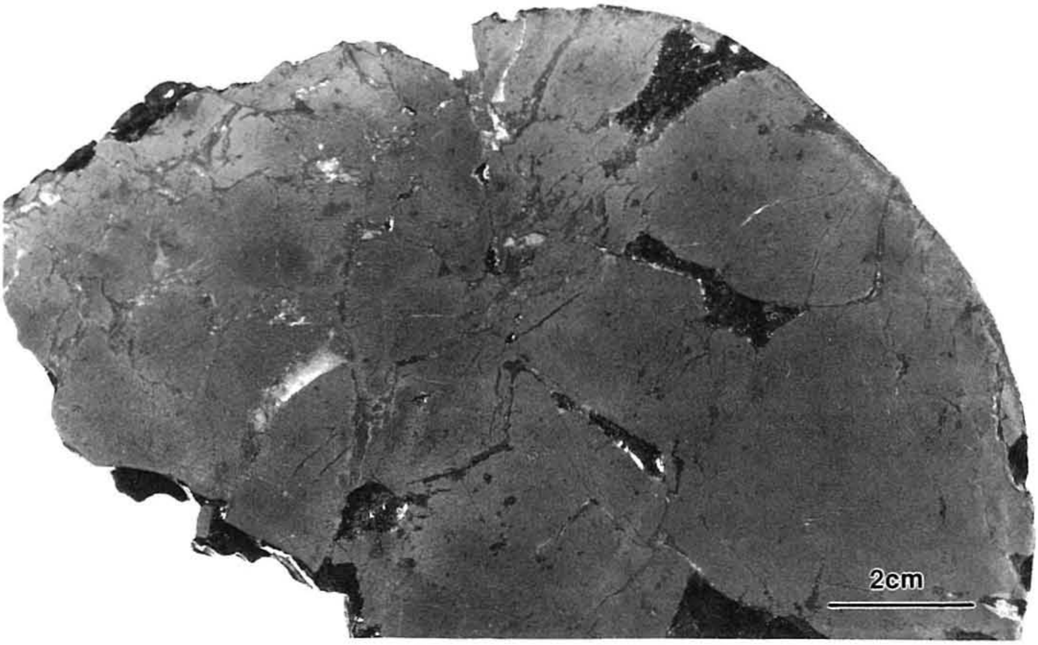
Fig. 1 Mode of occurrence of the pillow lava in the Onokisawa, near Hiyoshi. Radial joint is distinct.

Fig. 2 A slab of a pillow of the pillow basalt.

Glassy rim is 1 mm thick. Fine-grained variolitic facies and coarse-grained variolitic facies are promiscuously distributed from the rim toward the core. Scantiness of amygdule is characteristic feature.

1

2



occasionally attaining several hundred meters. The pillow lavas are intercalated with radiolarian cherts and thin layers of hyaloclastite or some clastic materials. Each pillow generally shows spheroidal, ellipsoidal or bowl-like forms, about 0.3-2 meters in size. Frequently pillows showing several kinds of form occur together in an outcrop. The margin of a pillow is generally aphanitic, but toward interior of the pillow, variolitic and subophitic textures made up of plagioclase and augite are observed. In general, ilmenite is present as an accessory mineral. Presence of chlorite, epidote, sphene, pumpellyite and calcite in the pillow lava is considered to have been formed as the products of low grade metamorphism.

The chemistry of the pillow lavas in the Eastern mass shows mostly tholeiitic as presented in Table 1. The pillow lavas can be petrographically classified into glassy, variolitic and subophitic parts with a continuous gradation (Bamba, 1969). The crystallinity varies from glassy to holocrystalline. The variolitic facies having a considerable amount of glass is predominant, and characterized by the presence of numerous varioles composed of radial aggregates of fibrous plagioclase.

Glassy facies. This is made up of brownish glass with irregular cracks. Occasionally, tortoise-shell structure caused by the development of hexagonal cracks is observed. The areas bounded by the cracks are about 0.3 mm across. In places, a small amount of fibrous crystallites of plagioclase can be seen.

Variolitic facies. The varioles are composed of plagioclase and clinopyroxene, with or without a small amount of glass, showing a variolitic texture. The varioles are commonly about 0.1 mm across, rarely up to 0.3 mm. Clinopyroxene is very fine-grained and usually forms ceder-leaf aggregates. Plagioclase is fibrous or acicular. Amygdules, 0.1-0.2 mm across filled up by pumpellyite, attain about 1-5 vol.% in general.

Subophitic facies. Clinopyroxene and plagioclase are the main components associated with a small amount of ilmenite. Clinopyroxene and ilmenite are granular, about 0.1 mm in size, and the plagioclase is prismatic, 0.2 mm in length, forming a subophitic texture.

The three rock facies described above are commonly recognized in an individual pillow. Their distribution therein, however, is irregular without concentric arrangement. Network veins, 1-3 mm in width, consisting of pumpellyite-calcite-quartz, are

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Explanation of Plate 2

Photomicrographs illustrating the texture of the pillow lava and dolerite dike from the Kokuriki mining area, Eastern mass of the northern Tokoro Belt.

Fig. 1 Outermost rim of a pillow. Gel-textured glass is observed. Parts of colorless and brown in color are distinguishable.

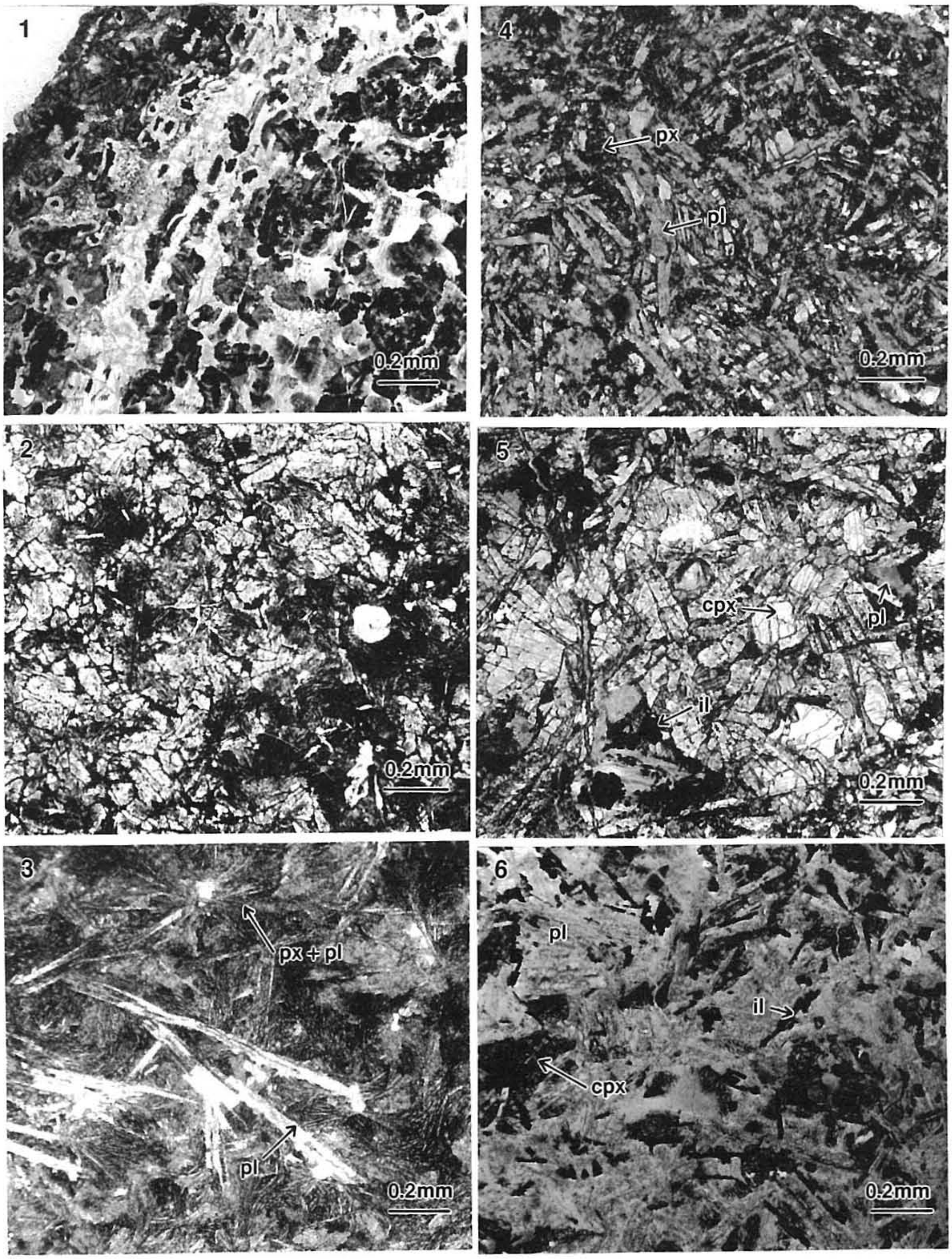
Fig. 2 Glassy rim. Skeletal plagioclase and tortoise-shaped glass are observed.

Fig. 3 Core of a pillow. Skeletal pyroxene-plagioclase intergrowth forms variolitic texture. pl: plagioclase, px: pyroxene.

Fig. 4 Fine-grained subophitic facies. Granular clinopyroxene and lath of plagioclase are present. cpx: clinopyroxene, pl: plagioclase.

Fig. 5 Coarse-grained subophitic facies. Granular clinopyroxene and lath-shaped plagioclase are present. cpx: clinopyroxene, pl: plagioclase, il: ilmenite.

Fig. 6 Dolerite dike from the Kokuriki mine. Ophitic texture is distinct. pl: plagioclase, il: ilmenite, cpx: brownish purple clinopyroxene.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common in the pillow lavas from the mineralized zone running from the Hokko mine to the Shibayama mine. In the hyaloclastite from the Hokko mine at the northern end of the mineralized zone, veins of epidote-pumpellyite association are found.

Pillow lavas from the Eastern mass of the northern Tokoro Belt are tholeiitic basalt. Chemically they contain 45-52 wt% of silica and are poor in Al_2O_3 and K_2O and rich in CaO and total Fe. Normative quartz is generally present in the pillow lavas as presented in Table 1. Consequently, the primary magma from which the pillow lavas of the Eastern mass were derived is regarded as tholeiitic.

Radiolarian chert

Bedded radiolarian cherts are present in the sequence of pillow lavas and hyaloclastites with various thickness. The chert that plays a role of hanging wall on the strata-bound manganiferous hematite deposits shows more than 100 meters thick. Some of the chert are massive while mostly they show bedded structure. In both bedded and massive cherts, abundant fossils of radiolaria are observed, but most of them have been replaced by calcedonic quartz and become to be unidentified. Matrix of the chert is composed of fine-grained ferruginous quartz and fibrous or dusty hematite. The fibrous hematite bearing chert occurs at the very contact with the bedded hematite ore. Hence, the Fe and Mn contents of the chert hanging above the ore have been examined. The results are presented in Table 2.

Table 2 Fe, Mn contents of the hanging wall (radiolarian chert) of the Kokuriki mine, Tokoro Belt

	Fe wt%	Mn wt%
Chert collected from several meters above the contact with the ore bed	2.91	0.8
Chert collected from the very contact with the manganiferous hematite ore	3.60	0.20
Manganiferous hematite ore	30.00	10.00

Manganiferous hematite ore deposits

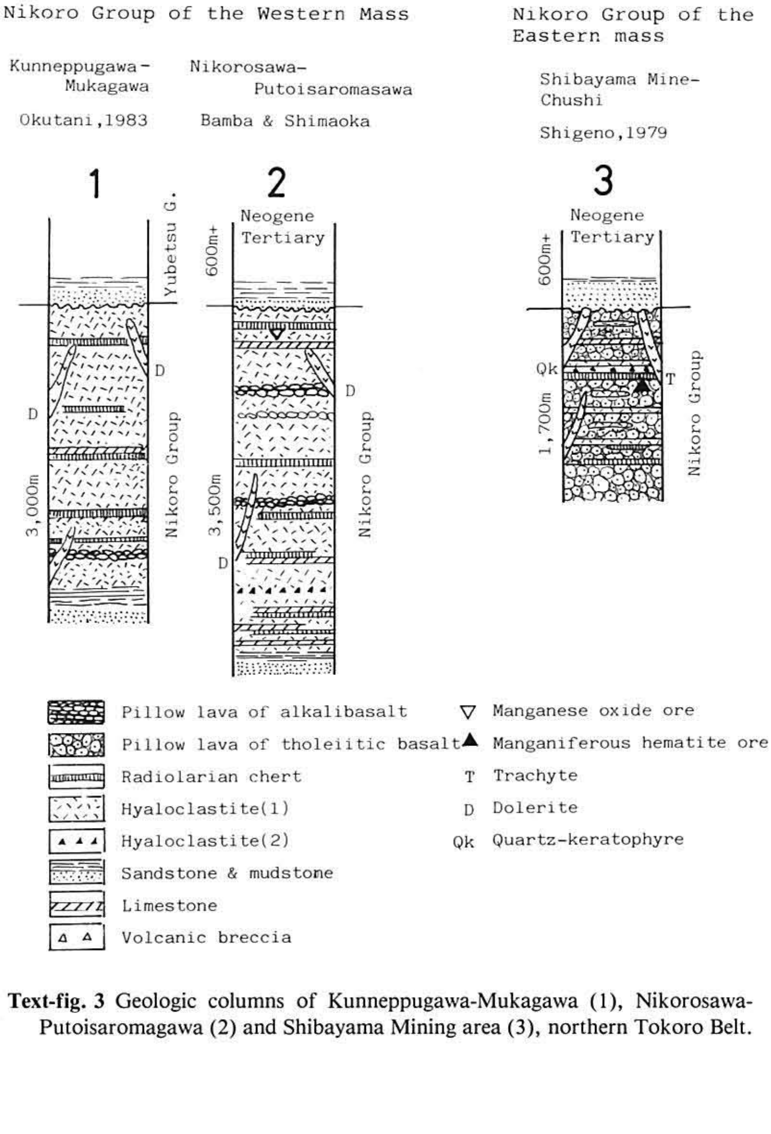
The Nikoro Group in the Eastern mass is characterized by the presence of abundant strata-bound manganiferous hematite deposits. These deposits had been mined at the Hokko, Nikura, Kokuriki and Shibayama mines (Text-fig. 1). 500,000 metric tons of massive ores with 30%Fe and 10%Mn in average were producted during the years 1930-1964. In general, the ores occur at or near the boundary between pillow lava and radiolarian chert. The former plays a role of foot wall and the latter hanging wall. The ore bed in the Kokuriki mine, extending 600 meters long with 10 meters thick in average, is the biggest in scale in this mining region.

The ore is made up of very fine-grained or dusty hematite. The grade of ore is generally unstable due to irregular concomitance of ferruginous quartz. The hematite has been chemically examined by Togari (1983). The trace element analysis revealed that impurity in the hematite is scarce. Network veins of manganese minerals in the ores are 1-5 mm in width and in places the concentration grade attains to 50%. Penwithite and piedmontite are common manganese minerals in the vein.

It is noteworthy that considerable amounts of Mn-dominant pumpellyite have been discerned as a new mineral by Togari (1983) through EPMA analysis and X-ray powder diffraction methods. Consequently, penwithite, piedmontite and Mn-pumpellyite are regarded to be more important source minerals for manganese of the ore.

Hyaloclastite

Hyaloclastite in the Eastern mass is rather scant in quantity compared with that in



Text-fig. 3 Geologic columns of Kunneppugawa-Mukagawa (1), Nikorosawa-Putoisaromagawa (2) and Shibayama Mining area (3), northern Tokoro Belt.

the Western mass. Hyaloclastite is a subordinate constitution of the greenstones in this mass. Volcanogenic sandstone showing laminated structure is common. This rock is composed mainly of fragments of basalt and trachyte in which network veins of pumpellyite-epidote-prehnite predominate. In the northern part of this mass, near by the Hokko mine, fragments of hornblende-plagioclase-quartz schist are frequently found in the hyaloclastites.

Nikoro Group in the Western Mass

The geologic sequence and structure of the Nikoro Group of the Western mass in the mapped area have been investigated by Niida et al. (1981) and Narui (1982). The thickness of the pile is estimated to be 3,000-3,700 meters. On the other hand, the geologic column and thickness of the Nikoro Group in southern area was checked in Nishiainonai (Text-fig. 12) area by Okutani (1983), Yoshida (1983) and Bamba et al. The results obtained are presented in Text-fig. 3. The Nikoro Group in the area is composed of siltstone, hyaloclastite(1) and (2), alternation of limestone-chert-hyaloclastite-pillow lava, bedded Mn-oxide ore deposit (Hokkaido mine), alternation of chert-limestone, and pillow lava in ascending order. The siltstone bed strikes NS to N45°E and dips 45°W and 30°-70°SE, and is unconformably covered by siltstone of Neogene Tertiary on the eastern side of the Nikoro Group.

The lower stratum of the Nikoro Group consisting of siltstone associated with volcanogenic sandstone shows anticlinal structure as noted above. Therefore, the presence of concealed anticlinal axis is conceivable in the Western mass of the Nikoro Group in the mapped area. Symmetrical distribution of Mn-oxide ore deposits represented by the Wakasa (Text-fig. 12) at the western wing and the Hokkaido mine (Text-fig. 12) on the eastern wing suggests that there exist an anticlinal axis dipping eastward.

From the above-stated view point, the Yubetsu Group occupying the western side of the Nikoro Group is correlative with the Saroma Group covering the Nikoro Group on the eastern side. Text-fig. 2 was obtained from the above-stated concept.

Explanation of Plate 3

Photographs of a slab of hyaloclastite and photomicrographs illustrating the rock properties of the hyaloclastites in the Nikoro Group, northern Tokoro Belt.

Fig. 1 Coarse hyaloclastite from the Eastern mass. Angular fragments of basalt, chert and many other volcanogenic materials are observed. ba: basalt, ch: chert.

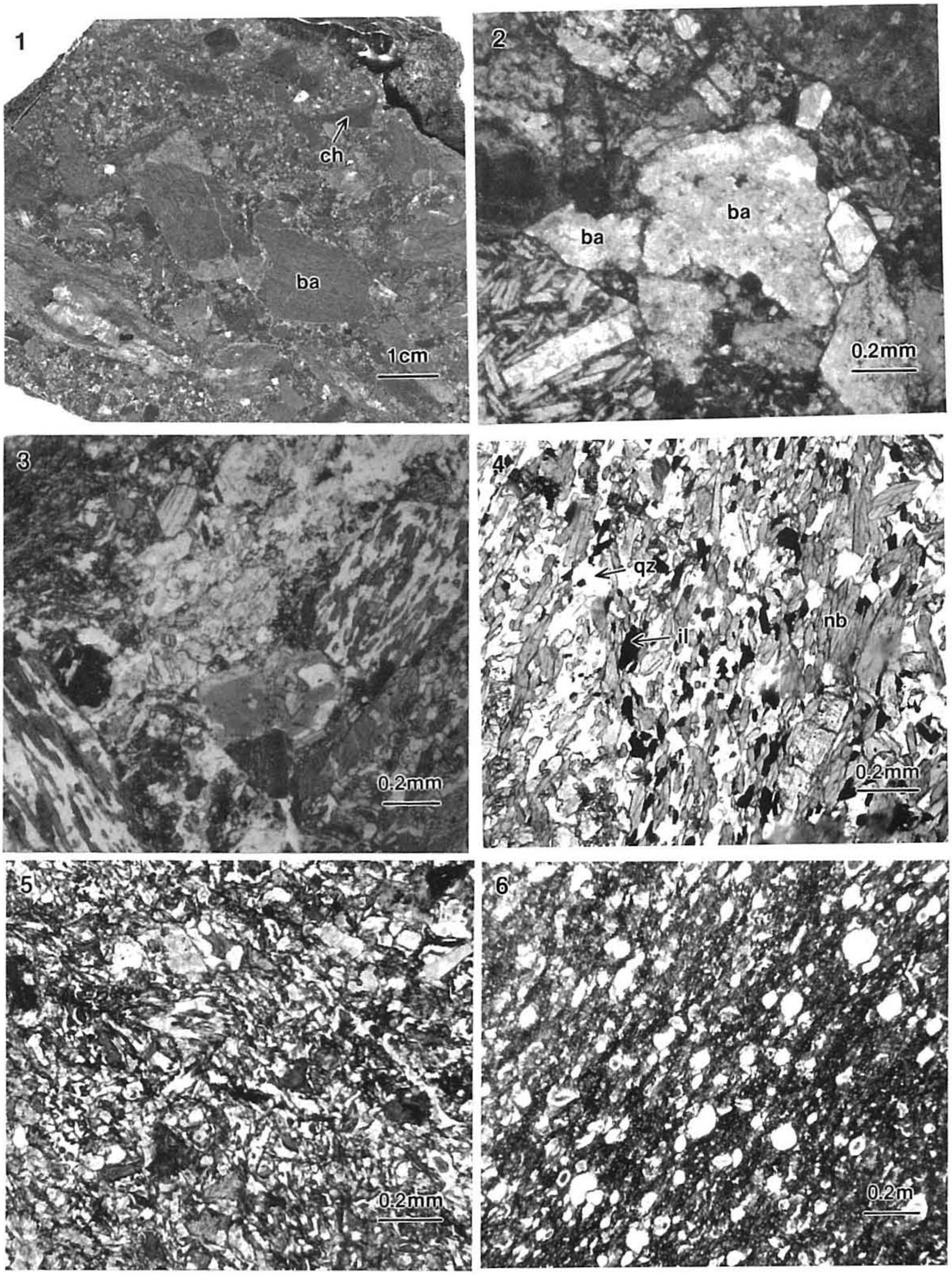
Fig. 2 Photomicrograph of hyaloclastite (1) from the Western mass. Angular fragments of basalt, plagioclase and glassy shards are observed. ba: basalt.

Fig. 3 Hyaloclastite (2). Rock fragments of green schist are recognized. Subangular or well rounded shape of the fragment suggests that they might have been reworked.

Fig. 4 Green schist fragment in the preceding rock. il: ilmenite, hb: hornblende, q: quartz.

Fig. 5 Tuffite from the Route 333, Western mass. This rock occurs well stratified and is made up of fine-grained volcanogenic glass shards.

Fig. 6 Hyaloclastite at the contact with radiolarian chert. Gradational change from chert to green hyaloclastite is observed. Right bottom of the picture is hyaloclastite.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Hyaloclastite (1)

Subaqueous volcanogenic sedimentary rocks which compose a large part of the green sandstone in the Western mass are called hyaloclastite (1). Fine- to coarse-grained sandy hyaloclastite is composed of angular or somewhat rounded fragments of basalt, trachyte and tuffaceous materials, 1-2 mm in grain size. Fragments of radiolarian chert, ferruginous quartz, isolated clinopyroxene, tabular plagioclase are occasionally contained. The matrix of this kind of hyaloclastite is generally made up of calcite, dusty hematite or fine-grained tuffaceous materials.

The above-stated rocks are usually invaded by numerous network veins consisting of calcite-quartz-prehnite-pumpellyite association. Sometimes, the hyaloclastite is wholly altered by sericitization. Besides, slumping structure of the hyaloclastite is frequently observed.

Hyaloclastite (2)

Though the rock properties are similar to the preceding hyaloclastite (1), this rock contains accidental materials which are well eroded fragments of epidote-hornblende-plagioclase-ilmenite schist or tonalitic granite. The size of the fragments varies from 2-3 cm to 10-20 cm. These fragments are distinguished as accidental materials though the origin has not yet been clarified.

Tonalitic granite. This rock is made up of quartz, plagioclase and minor amount of hornblende being altered to chlorite. Plagioclase and quartz, 0.5-2 mm in size, are the essential minerals of this rock. Zonal structure of plagioclase is distinct though the plagioclase is turbid by sericitization. The alteration makes the measurement for An% of the plagioclase difficult. It is notable that this rock shows cataclastic structure. Chemical composition of the tonalitic granite in question is presented in Table 9.

Epidote-actinolite-ilmenite-quartz schist. This rock is pale green and characterized by scantiness of plagioclase and richness of ilmenite. A large block of the rock, 10-20 meters in size, is found along the shear zone developing at the upper stream of the Nikorosawa, southern piedmont of the Nikoro-yama (Text-fig. 12).

Pillow lavas

The Nikoro Group of the Western mass is composed mainly of hyaloclastite. Consequently, pillow lava is subordinate in this mass. Several of pillow lavas occur in the hyaloclastites. Well pillowed basalt is observed at the middle stream of the Nikorosawa. A pillow, 200 cm in diameter, has been examined petrographically as well as chemically from the rim to the core. The results are presented in Table 3 and Text-fig. 4. As shown in Text-fig. 4, SiO_2, CaO and Al_2O_3 increase from the rim toward the core.

Rim. The rim of the pillow is 2 mm thick and shows greasy luster and aphanitic structure. Chemistry of this part is shown in Table 3 and Text-figs. 5, 6 and 7.

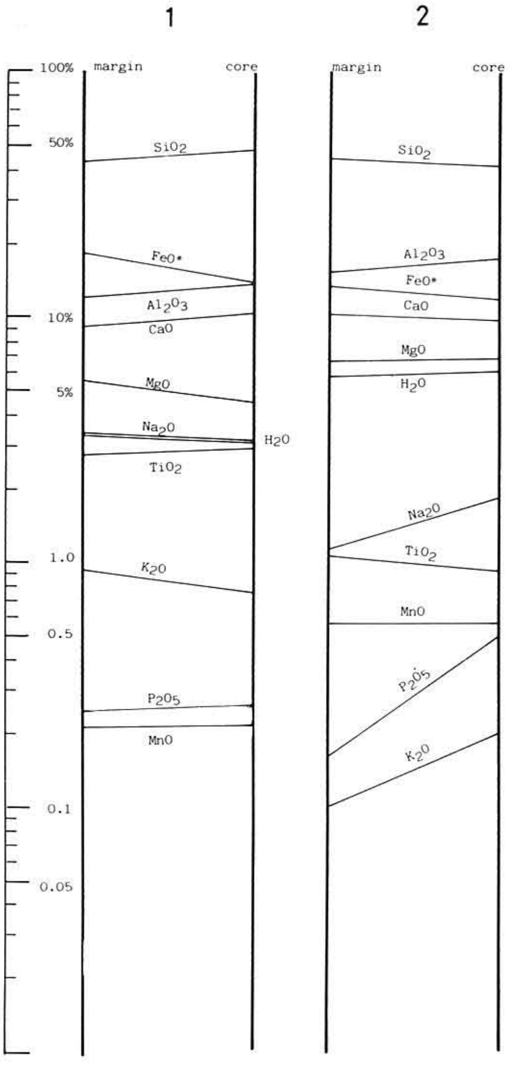
Mantle. The mantle of the pillow shows variolitic texture including moderate amount of amygdules filled by chlorite and calcite. The varioles are composed of radiating crystals of acicular plagioclase and clinopyroxene. Chemistry of this part is presented in Table 3.

Core. The core is coarse-grained and shows subophitic texture made up of plagioclase and clinopyroxene. The core has a few amygdules filled by calcite. Rarely porphyritic structure by the presence of plagioclase and olivine phenocrysts is observed. The plagioclase phenocryst is tabular and shows 2 mm in size. Chloritization and montmorillonitization along the twinning lamella of the plagioclase make the crystal turbid. Olivine phenocrysts, 2 mm in size, are distinguishable by the characteristic crystal form though they are wholly serpentinized.

Table 3 Chemical composition and CIPW norm of pillow lavas from the Western mass, northern Tokoro Belt

	1	2	3	4
SiO_2	43.01	45.90	46.54	52.06
TiO_2	2.77	2.91	2.93	2.04
Al_2O_3	12.00	13.06	13.17	15.59
Fe_2O_3	9.61	6.71	5.45	5.22
FeO	9.10	7.90	8.68	2.08
MnO	0.22	0.17	0.22	0.10
MgO	5.63	5.03	4.64	3.12
CaO	9.61	9.05	10.15	7.51
Na_2O	3.42	4.72	3.25	6.02
K_2O	0.94	0.23	0.76	0.54
P_2O_5	0.25	0.24	0.26	2.38
$H_2O(+)$	3.42	3.02	3.37	0.76
$H_2O(-)$	1.10	0.64	0.96	1.90
Total	101.08	99.58	100.08	99.32
q	—	—	—	2.63
or	5.55	1.36	4.49	3.19
ab	24.09	33.98	27.50	50.94
an	14.62	13.77	19.10	13.92
ne	2.63	3.23	—	—
di	25.17	23.72	24.06	6.07
hy	—	—	6.78	4.96
ol	4.72	4.04	0.05	—
mt	13.93	9.73	7.90	1.12
il	5.26	5.53	5.56	3.87
ap	0.58	0.56	0.60	5.51
hm	—	—	—	4.45

1-3: pillow lava from upper stream of Nikorosawa, Tomisato
1: outer rim of unit pillow
2: inner rim of unit pillow
3: core of unit pillow
4: pillow lava from Rubeshibe
Analysts: 1-3: H. Shimaoka, 4: Tokyo Coal & Miner. Inst.



Text-fig. 4 Semilogarithmic plots of the chemical variations between the core and the rim of unit pillows of the pillow basalts from the northern Tokoro Belt.
1: Unit pillow from Tomisato, Western mass.
2: Unit pillow from the Kokuriki mine, Eastern mass.

Scattering pyrites, 1-1.5 mm in size, are observed from the mantle to the core. Though they show strong anisotropism, it has been identified as pyrite with the values of reflectivity of 52-55% under 547 nm and hardness (VHN) of 1265.

Pillow lavas of trachytic basalt are also found at several localities of the Western

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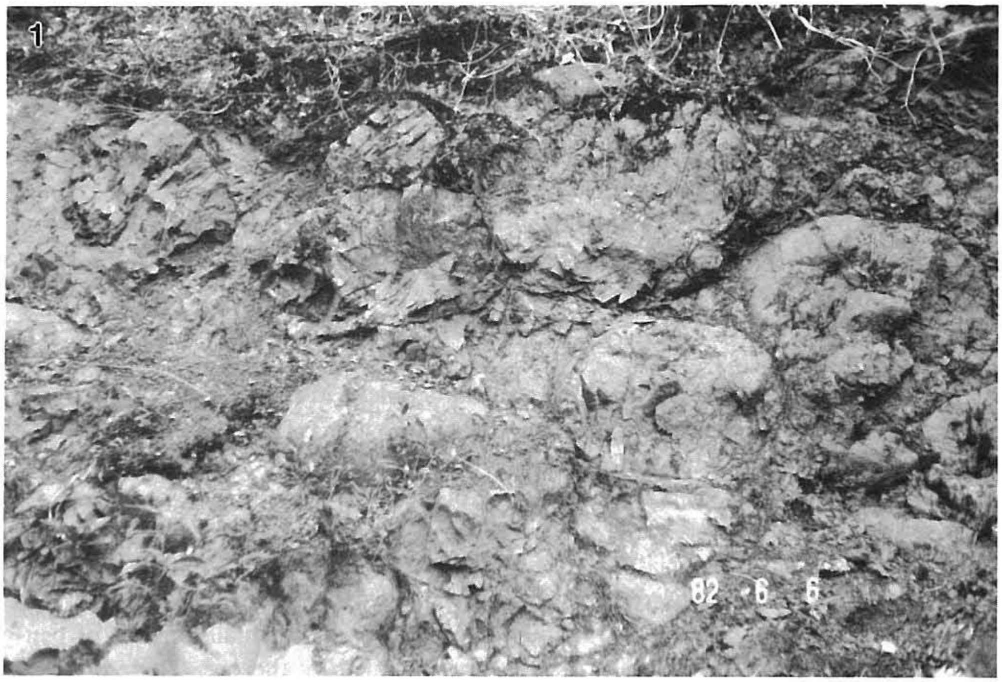
Explanation of Plate 4

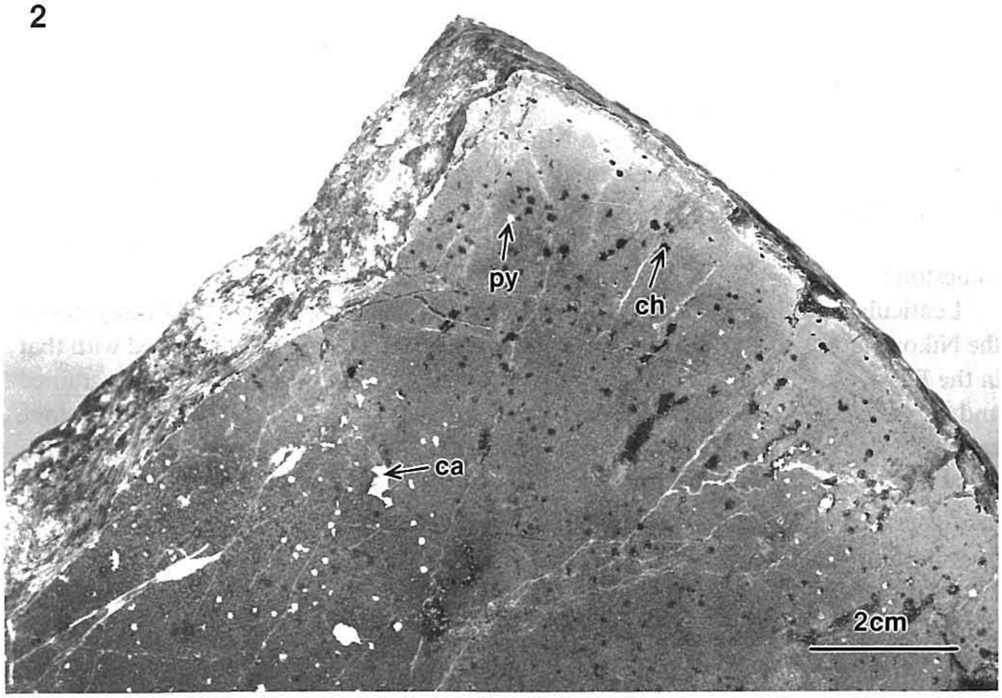
Photographs of pillow lava in the Nikoro Group of the Western mass of the northern Tokoro Belt.

Fig. 1 Mode of occurrence of pillow lava in the upper stream of the Nikorosawa.

Fig. 2 A slab of a pillow of the pillow basalt. Rim, 2 mm thick, is composed of glass. Abundant amygdules and scattering pyrite are characteristic features of the pillow lava from the Western mass. Amygdules filled with chlorite are predominant in the mantle of the pillow and those filled with calcite are abundant in the core. ch: chlorite, ca: calcite, py: pyrite.



2



mass. Mineralogy and chemistry suggest that the pillow lavas in the Western mass are alkalic, while the pillow lavas in the Eastern mass are tholeiitic.

Radiolarian chert

In general, chert shows reddish brown in color, and we can easily distinguish the boundary between chert and greenstones. Chert is composed mainly of fine-grained ferruginous quartz in which abundant fossils of radiolaria are observed. The shell of radiolaria has been wholly replaced by aggregates of fine-grained calcedonic quartz. In places, coarse-grained mosaic quartz has replaced the fossil.

Mn-oxide ore deposits

Strata-bound Mn-oxide ore deposits are characteristic in the Nikoro Group of the Western mass. Mn-oxide ore deposits are associated with tuffite running parallel to pillow lava in which massive sulfide ores occur.

Wakasa mine (Text-fig. 12) which had exploited Mn-oxide ore is situated at the tributary of the Bushi river, western wing of the Nikoro Group in the Western mass. The ore deposits occur associated with tuffite (Plate 3), striking NE-N30°E, dipping 20-40°SE. The ore bed varies from 50-250 cm in thickness showing a irregular lenticular form. The ore is composed mainly of pyrolusite and a small amount of penwithite. Jasper, brown in color, is usually accompanied by the ore. Therefore, the grade of the ore varies from 25% to 40% Mn.

On the other hand, Hokkaido mine which had mined the same type Mn-oxide ores is situated on the eastern wing of the Nikoro Group near by Rubeshibe-cho. The Hokkaido mine producted 500 metric tons of ore with 40% Mn in average. The geologic positions of the above two Mn-oxide ore deposits can be interpreted from Text-fig. 12 where they show a symmetrical distribution in the Nikoro Group of the Western mass.

Limestone

Lenticular limestone masses, rather small in scale, are common in hyaloclastites of the Nikoro Group in the Western mass. The limestone is abundant compared with that in the Eastern mass. The limestone can be called micrite because it is very fine-grained and contains abundant coccoliths (identified by Dr. N. Minoura), thus the limestone can be recognized as a kind of pelagic sediments. The limestone masses are generally accompanied by radiolarian chert or silicastone. In places, banded structure being

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Explanation of Plate 5

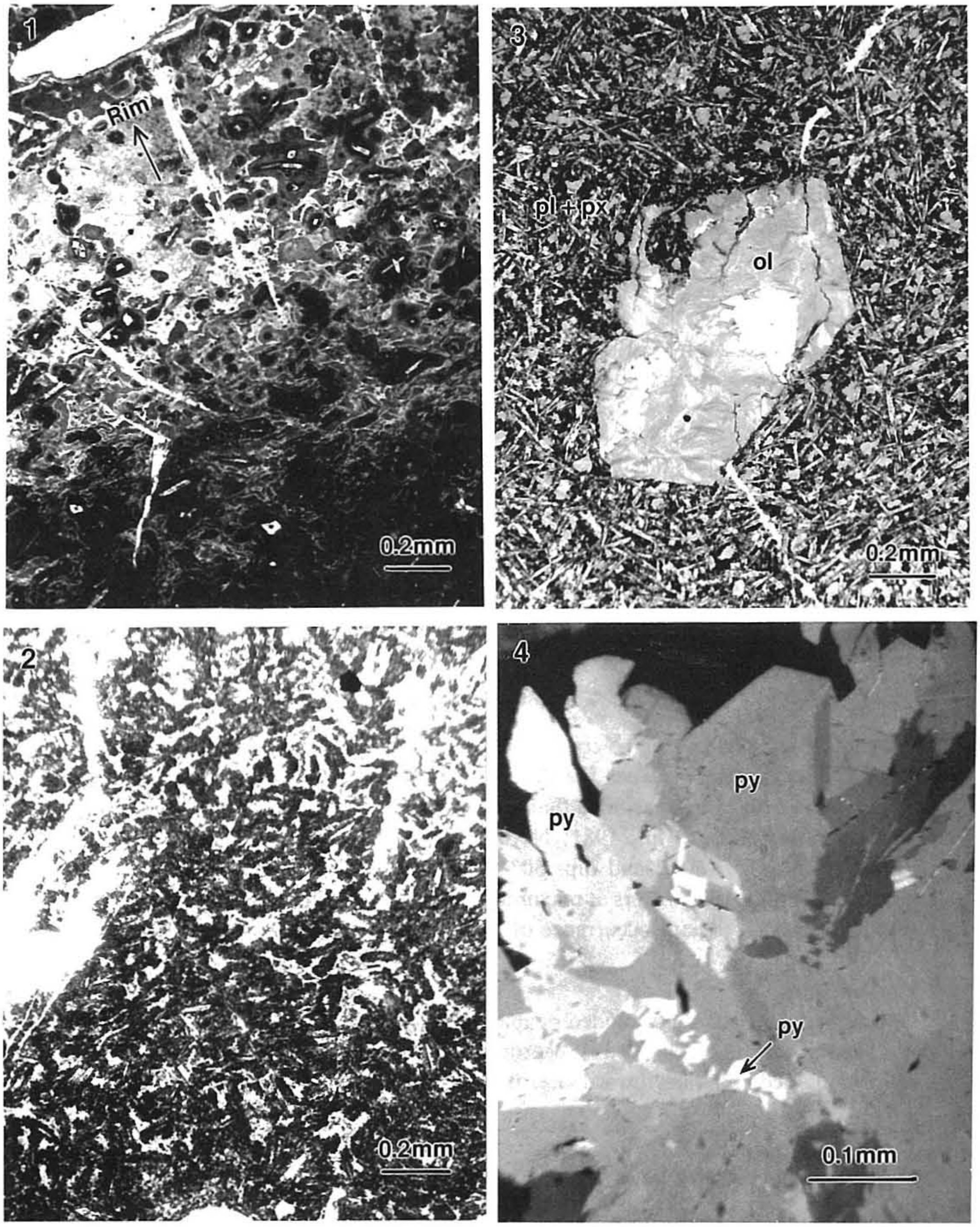
Photomicrographs of thin sections and a polished section of pillow lava from the Western mass.

Fig. 1 Interpillow materials. Gel-textured glass is observed.

Fig. 2 Rim of a pillow. Worm-shaped colored glass with embryonic plagioclase is observed.

Fig. 3 Core of the pillow. Intersertal texture made up of acicular and lath-shaped plagioclase and clinopyroxen is prominent. Phenocryst is serpentinized euhedral hollow olivine. ol: serpentine after olivine, pl: plagioclase, px: pyroxene.

Fig. 4 Photomicrograph of polished section illustrating the texture of scattering pyrite. Mosaic aggregates of pyrite is distinguished by strong anisotropism. Oil immersion, Crosed nicols.


1
Rim
0.2mm
3
pl + px
ol
0.2mm
2
0.2mm
4
py
py
py
0.1mm

made up of silica rich part and calcite rich part is observed (Plate 15).

Massive sulfide ore deposits

Cupriferous pyrite ore deposits in small scale are known in the Bushi and some other mines. These deposits show a linear distribution in the central part of the Nikoro Group in the Western mass. Along this copper zone, we can find plagioclase-olivine cumulate pillow lavas in which pyrite-chalcopyrite association is observed (Plate 6).

Chemical Characteristics of the Two Masses

The above-stated geologic features of the Eastern and the Western masses are summarized and compared in Table 4. A notable difference in petrochemical features of pillow lavas is recognized between the two masses. Analytical results of bulk rock chemistry for the Eastern mass pillow lavas, the Western mass pillow lavas, dolerite dikes, keratophyre, quartz-keratophyre are presented in Tables 1, 3 and 9. Alkali-silica diagram (Text-fig. 5) shows that the Eastern mass pillow lava is tholeiitic and the Western one is alkalic. When CIPW norm is recalculated on the basis of $Fe_2O_3/(FeO+Fe_2O_3)=0.1$, normative nepheline is calculated in the Western mass pillow lavas though it does not in the Eastern ones.

An-Ab-Or diagram (Text-fig. 6) makes the difference between the Eastern mass pillow lavas and the Western mass ones more clear.

Saroma Group

Saroma Group consisting of conglomerate, sandstone and mudstone in ascending order occupies the area between the Eastern and the Western masses in the northern Tokoro Belt. It has been concluded that the Saroma Group overlies the Nikoro Group unconformably (Niida et al., 1981; Narui, 1982; Kiminami et al., 1983). The bed strikes NE and N10°-60°E and dips 30°-45°NE. The total thickness of the beds is regarded to be about 600 meters at maximum. There is no doubt that it is Cretaceous in age based on the abundant occurrence of *Inoceramus* sp. (Sakakibara, 1982).

Conglomerates

More than 50% of well rounded pebbles are contained in the conglomerate. From the mode of occurrence, this bed is regarded to be a basal conglomerate of the Saroma Group. This bed thins northward, i.e. it is about 20 meters in the north though it

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Explanation of Plate 6

Photographs of plagioclase-olivine cumulate pillow basalt from Chirai, Western mass, northern Tokoro Belt.

Fig. 1 Photograph of a slab of subophitic textured basalt. pl: plagioclase, ol: serpentine after olivine, mx: matrix.

Fig. 2 Photomicrograph of thin section of the preceding rock. pl: turbid plagioclase, cpx: clinopyroxene, plf: unturbid plagioclase.

Fig. 3 Photomicrograph of thin section of olivine-picotite cumulate basalt. ol: serpentine after olivine, pc: picotite, mx: matrix made up of plagioclase and clinopyroxene.

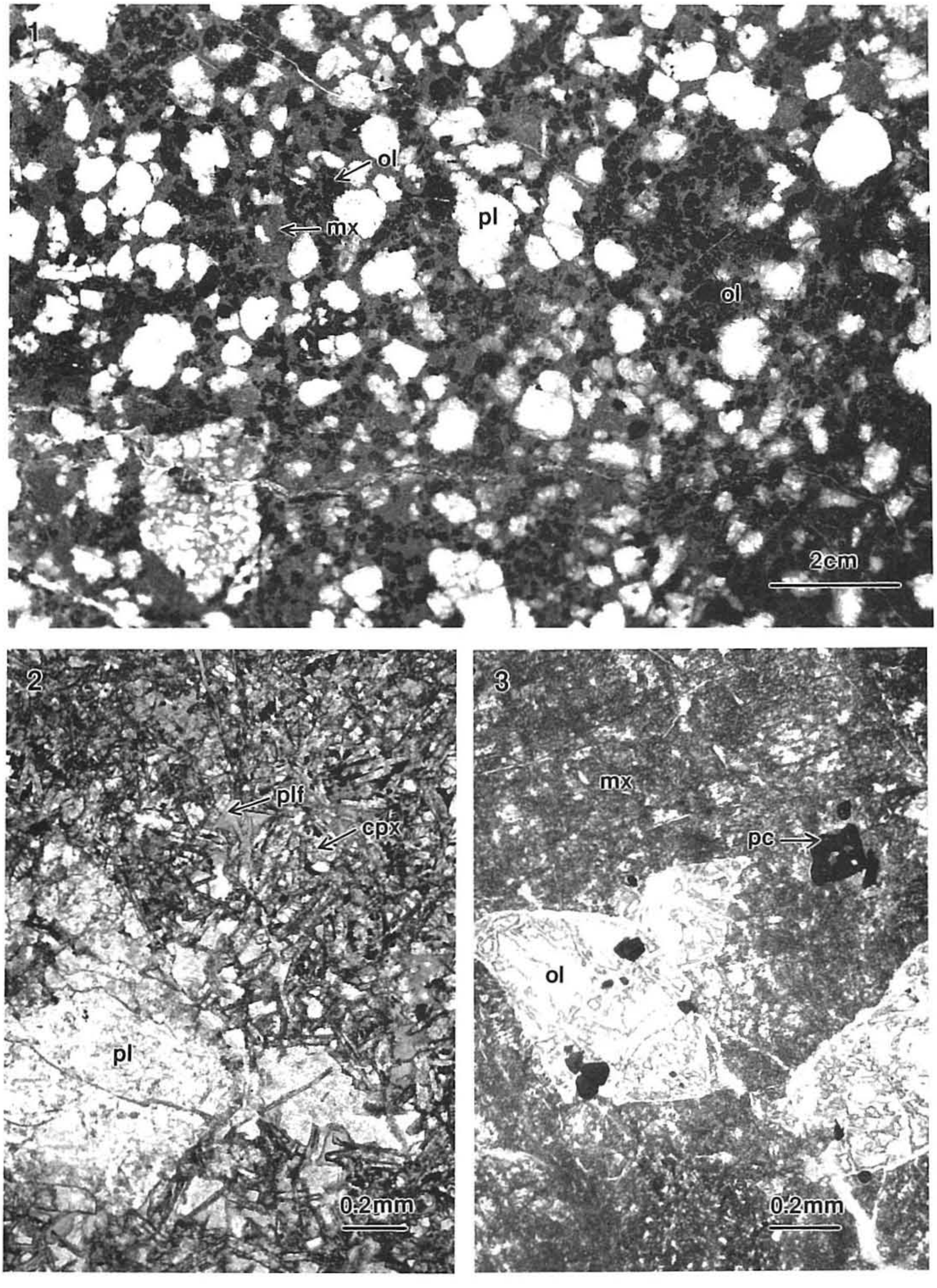
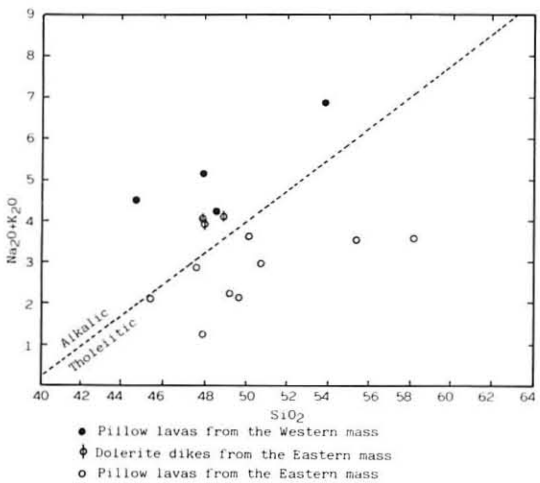

1
ol
mx
pl
ol
2cm
2
plf
cpx
pl
0.2mm
3
mx
pc
ol
0.2mm

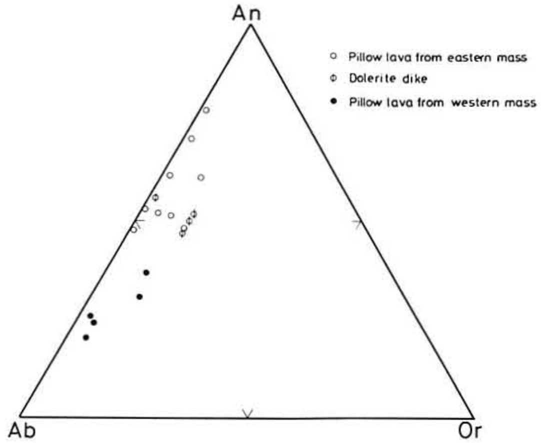
Table 4 Comparison between the Eastern mass and the Western mass of the Nikoro Group in the nothern Tokoro Belt

A. Western mass	B. Eastern mass
Hyaloclastite predominates. Pillow lavas of alkalibasalt and trachyte are present.	Pillow lavas of tholeiitic basalt predominate. Dolerite, keratophyre, arfvedsonite-trachyte and quartz-keratophyre occur as dike.
Limestones associated with radiolarian chert or silicastone are common.	Limestone is scant.
Strata-bound Mn-oxide ore deposits associated with tuffite are aligned linear parallel to massive sulfide ore deposits.	Strata-bound manganiferous hematite deposits are abundant.
The bad strikes NS-N45°E dipping eastward. Shear zone or faults are parallel to the strike and dip of the bed.	Structure of the Nikoro Group is characterized by N-S and E-W faults. These faults make the geology of this mass complicated.
REE pattern shows that pillow lavas are liquid type.	REE pattern shows that pillow lavas are solid type.

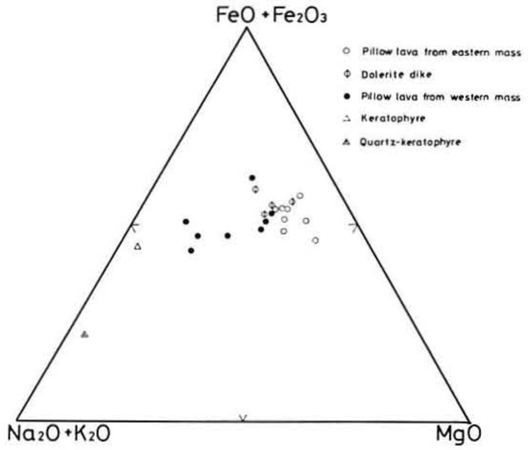


Text-fig. 5 Alkali-silica variations of pillow basalts and related rocks from the northern Tokoro Belt. All plotted in weight percent after subtracting total water and normalizing.

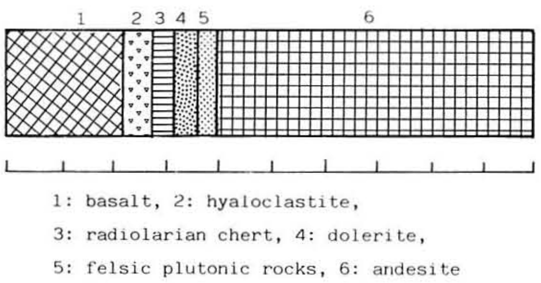
attains more than 100 meters in the south. Modal proportion and grain size of the constituent pebbles increase southward. Well rounded pebbles, 50-100 cm in size predominate in the south. Pebbles of hyaloclastite, basalt, radiolarian chert, andesite and some plutonic rocks are observed. Among them, andesite pebbles containing plagioclase and clinopyroxene phenocrysts are the most predominant. Variation in modal proportion of the constituent pebbles is shown in Text-fig. 8.



Text-fig. 6 An-Ab-Or diagram of the pillow basalts from the northern Tokoro Belt.



Text-fig. 7 AFM diagram of pillow basalts and related rocks from the northern Tokoro Belt.



Text-fig. 8 Modal proportions of the constituent pebbles of the basal conglomerate of the Saroma Group in the northern Tokoro Belt (Narui, 1982).

Sandstone

Sandstone bed with 300 meters thick overlies the above conglomerate. In general, the sandstone is massive and compact. The bed, however, sometimes shows alternation of coarse- and fine-grained facies. Occasionally the sandstone bed intercalates thin mudstone beds. In the sandstone which occurs along the Nikuragawa, *Inoceramus* sp.

has been found at several localities (Sakakibara, 1982).

Mudstone

Mudstone bed overlies the preceding sandstone bed. It shows dark green to grayish black in color. The mudstone grades to the sandstone. The thickness of the mudstone is estimated to be more than 150 meters.

Yubetsu Group

The Yubetsu Group which occupies an area of 450 km^2 from southwestern flank of the Saroma lake toward Rubeshibe-cho had been considered to be correlative with the Saroma Group (Hashimoto, 1952; Hashimoto et al., 1958) inferred from the common features of constituent materials. While, Yamada et al. (1963) proposed a different view that the Yubetsu Group conformably underlies the Nikoro Group. From the time onward today, stratigraphic sequence of the Yubetsu, Nikoro and Saroma Groups in ascending order has been applied. Recently, Kiminami et al. (1983b) have come to a conclusion that the Yubetsu Group can be partly correlated with the Saroma Group based on the fossil evidence which indicates that the Yubetsu Group is late Cretaceous in age. The outcrop of the Yubetsu Group at Nakazono, eastern contact with the Nikoro Group, shows that the bed dips westward showing overturned structure though the Yubetsu Group on the western wing shows wholly normal dipping toward east. Therefore, a concealed complicated structure having synclinal axes dipping steeply westward as shown in Text-fig. 2 is presumable on the eastern wing of the Yubetsu Group.

The Yubetsu Group is composed mainly of well graded turbidites characterized by alternation of sandstone and mudstone. It tends that sandstone predominates in the lower sequence and mudstone predominates in the upper half. Conglomerate is rarely found associated with sandstone. Total thickness of the Yubetsu Group is estimated to be more than 10,000 meters by Yamada et al. (1963).

Conglomerate

Coarse sandstone and conglomerate from the Asahi pass between Yasukuni and Sakae have been examined for the constituent materials. The pebbles in the conglomerate are sandstone, chert, mudstone, basalt, andesite, quartz-diorite, granite and gabbro. The matrix consists of fragments of feldspar, quartz, clinopyroxene, chlorite, calcite and very fine volcanogenic materials. Feldspar is 1 mm in size and zonal struc-

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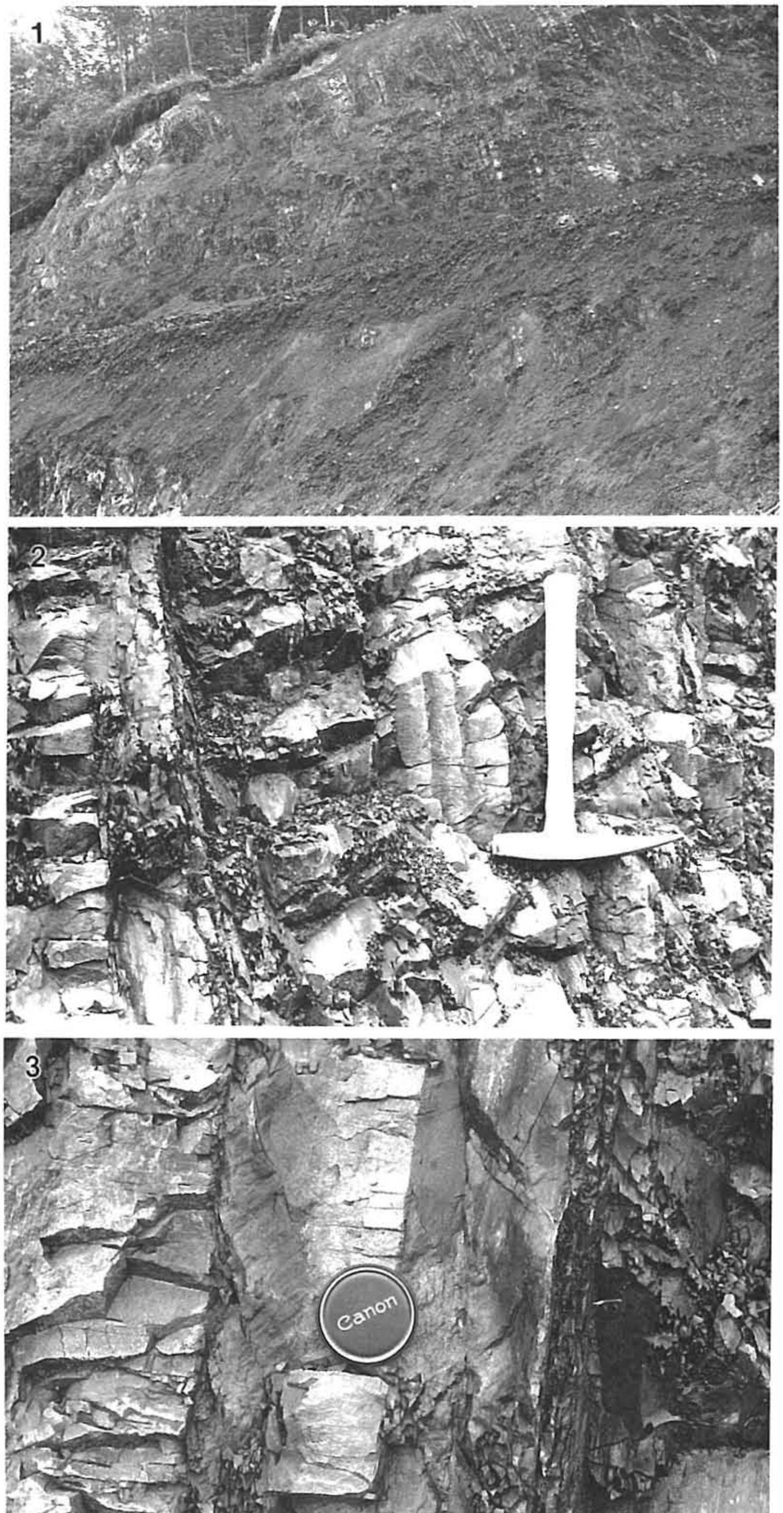
Explanation of Plate 7

Photographs showing the mode of occurrence of turbidite which forms the Yubetsu Group at Nakazono, Saromacho.

Fig. 1 View of outcrop of the Yubetsu Group. Alternation of sandstone and mudstone is distinct.

Fig. 2 ditto, close up photograph.

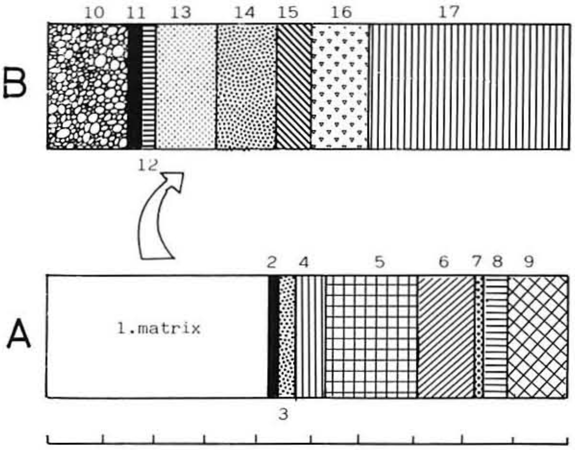
Fig. 3 ditto, more close up photograph. The grading suggests that the left hand side is upper. Consequently, the Yubetsu Group shows overturned folding at this outcrop.


1
2
3
Canon

ture is not clear but shows perthite structure. The modal proportion of the conglomerate is given in Text-fig. 9.

Sandstone

Sandstone is the most abundant in the Yubetsu Group. Eight samples of the sandstone from the bottom to the top of the Yubetsu Group were collected by Kainuma (1982) for modal analysis. The sandstone specimens are composed of fragments of feldspar, quartz, clinopyroxene and rock fragments of plutonic rocks. Fragments of radiolarian chert and granitic rock increase toward the top with decrease in volcanic rock fragments. Variation in the modal proportion of the sandstone is shown in Table 5.



1: matrix, 2: granite, 3: gabbro, 4: andesite, 5: trachyte, 6: basalt, 7: radiolarian chert, 8: mudstone, 9: sandstone, 10: unidentified, 11: clay-minerals, 12: calcite, 13: basalt, 14: chlorite, 15: clinopyroxene, 16: quartz, 17: feldspar

Text-fig. 9 Modal proportions in average of the constituent materials of conglomerates of the Yubetsu Group from Sakae-Ikutawara area (Kainuma, 1982).
A: Modal proportion of constituent grains
B: Modal proportion of matrix materials

Table 5 Modal compositions of sandstones from the Yubetsu Group in the Ikutawara district, Hokkaido

	F	Q	cpx	ss-ms	ch	ba	an	gb	gr	others
U. Mizuho F.	17.3%	3.0%	3.2%	16.6%	9.0%	11.5%	5.2%	5.7%	5.1%	23.4%
M. Mizuho F.	3.1	1.2	0	31.9	18.2	9.5	6.9	5.7	3.4	20.1
L. Mizuho F.	3.9	0.9	0	30.7	17.3	15.4	4.0	5.1	4.6	18.0
Onari F.	8.7	1.1	0	18.1	12.5	19.9	5.6	2.1	0.5	31.5
Nisen F.	35.2	8.9	3.2	7.9	5.5	14.9	0	3.0	0.3	11.1
Asahitoge F.	37.6	4.4	5.6	7.1	4.4	18.0	—	1.0	1.5	20.4
Asahino F.	37.1	5.6	4.1	10.3	3.8	14.9	1.7	2.6	1.8	18.9
Yasukuni F.	34.8	6.9	4.0	8.9	2.4	17.6	—	2.5	1.5	21.4

F: feldspar, Q: quartz, cpx: clinopyroxene, ss: sandstone, ms: mudstone, ch: chert, ba: basalt, an: andesite, gb: gabbro, gr: granite, others: matrix etc.

Analyst: H. Kainuma

Tectonic Blocks

Tonalitic granite, hornblende quartz schist, troctolite and gabbro, believed to be of tectonic blocks have been found in the northern Tokoro Belt. As the first two rocks have been described in the preceding chapter, troctolite and gabbro are introduced.

Troctolite

Troctolite looks like serpentinite in outcrop by its meranocratic greasy feeling. The troctolite is composed mainly of olivine, plagioclase and clinopyroxene. Ilmenite and chromite and accessory minerals.

Olivine is coarse-grained, 2×4 mm in size, and is euhedral suggesting cumulus crystal. Olivine shows mesh structure by the presence of network veins of crysotile. 2Vz of olivine varies from 88° to 96° with an average of 92°. Fine-grained euhedral chromite is frequently confined in olivine.

Clinopyroxene-plagioclase-chromite-ilmenite assemblage indicating intercumulus liquid is observed in the interspaces of olivine crystals. This intercumulus phase shows intersertal structure. Clinopyroxene showing hourglass structure is light brown in color and 0.8×2 mm in size. Cleavage of clinopyroxene is distinct and $c \wedge Z$ varies from 39° to 44° with an average of 42°. 2Vz is 51° in average. Plagioclase is euhedral, tabular to lath shape, 0.8×1.6 mm in size and An_{55} in average composition. This mineral is wholly turbid by sericitization.

Opaque minerals in the troctolite were identified as ilmenite and chromite with rim of maghemite. The chromite in the intercumulus phase is always rimmed by maghemite though the chromite included in olivine has no rim. Such different occurrence of the chromite is very interesting consideration of the formation of the orthocumulus and intercumulus phases of the troctolite. Chemical composition of the troctolite is listed in Table 6.

Gabbro

Gabbro is made up of clinopyroxene, plagioclase and ilmenite showing equigranular texture. Modal proportion of these three minerals is 43.1:47.5:9.3.

Clinopyroxene is euhedral. Some of the crystals are coarse-grained, 1.5×4 mm in size, but the others are fine-grained, 0.8-1 mm in size. Clinopyroxenes of two sizes are both light brown in color and have distinct cleavage. The coarse-grained one shows zonal structure. 2Vz of the pyroxene is 52° in average, and slightly smaller at the core than at the margin (Table 8). $c \wedge Z$ of the coarse-grained clinopyroxene ranges from 38° to 49° with an average of 47°. While that of the fine-grained one ranges from 43° to 52° with an average value of 47°. Coarse-grained clinopyroxene was chemically analysed by EPMA as presented in Table 7.

Ilmenite is abundant in the gabbro attaining to 9.3%. Ilmenite is euhedral showing lath shape, 1×4 mm in size. Rounded ilmenite, 1 mm in diameter, is rarely observed. The ilmenite commonly shows intergrowth with magnetite which occurs as a rim of ilmenite or exsolution intergrowth. The contact between the two minerals is sometimes

Table 6 Chemical composition and CIPW norms of troctolite, gabbro from the Tokoro Belt

	Troctolite	Gabbro
SiO_2	38.16	42.52
TiO_2	0.61	6.84
Al_2O_3	5.41	12.95
Fe_2O_3	5.99	4.45
FeO	8.47	7.75
MnO	0.16	0.30
MgO	26.82	7.72
CaO	3.13	9.84
Na_2O	0.22	3.35
K_2O	0.04	0.53
P_2O_5	0.25	0.31
H_2O (+)	8.77	2.24
H_2O (−)	1.53	0.64
Total	99.56	99.44
or	—	3.34
ab	2.10	24.12
an	13.63	18.08
ne	—	2.27
di (wo)	—	11.96
(en)	—	10.34
(fs)	—	—
hy (en)	25.30	—
(fa)	4.09	—
ol (fo)	29.05	6.19
(fa)	5.20	—
mt	8.80	6.02
il	1.21	13.05
ap	0.67	0.67

Analyst: H. Shimaoka

Table 7 Chemical composition and chemical formula of clinopyroxene and ilmenite in gabbro from the Tokoro Belt

	Clinopyroxene	Ilmenite
SiO_2	51.64	0.06
TiO_2	1.68	50.96
Al_2O_3	3.13	0.38
Cr_2O_3	0.11	0.30
FeO*	5.92	44.80
MnO	0.13	0.43
MgO	13.58	2.10
CaO	23.33	0.13
Na_2O	0.38	0.01
K_2O	0.04	0.02
Total	99.94	99.29
Si	1.911	Ti 1.01
Al^{IV}	0.089	
		Al 0.01
Ti	0.047	Cr 0.01
Al^{VI}	0.047	Fe* 0.88
Cr	0.003	Mn 0.01
Fe*	0.183	Mg 0.04
Mn	0.004	(0=3)
Mg	0.749	
Ca	0.925	
Na	0.027	
K	0.002	
(0=6)		

All iron as FeO* or Fe*
Analyst: T. Katoh

Explanation of Plate 8

Photographs illustrating the tectonic blocks of gabbro and tonalitic granite from the northern Tokoro Belt.

Fig. 1 Mode of occurrence of gabbro block in quartz-keratophyre near Hiyoshi, Eastern mass. Dimension of the block may be more than 5 meters.

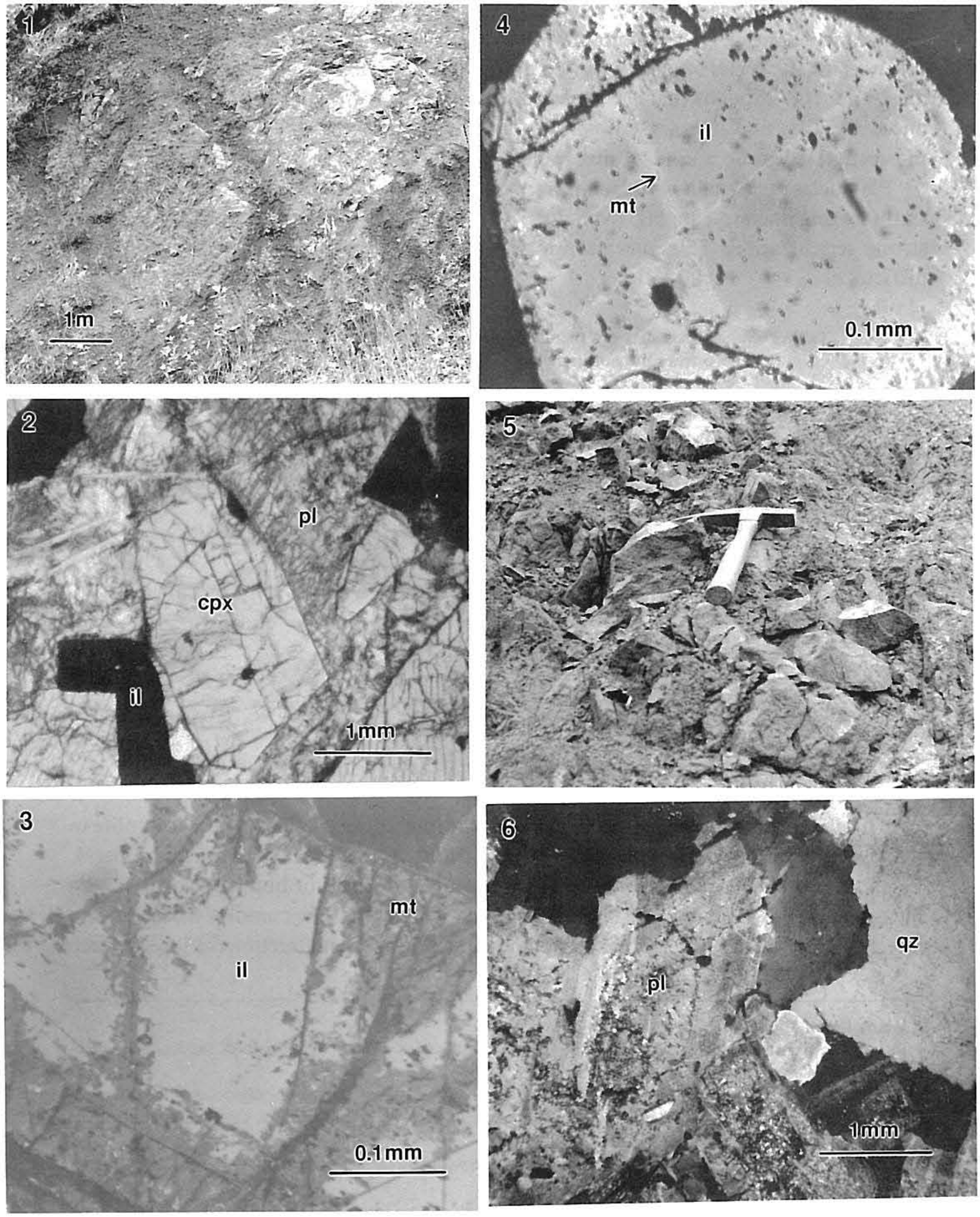
Fig. 2 Photomicrograph of thin section of the gabbro. cpx: clinopyroxene, il: ilmenite, pl: plagioclase (turbid).

Fig. 3 Photomicrograph of polished section showing the ilmenite-magnetite intergrowth. mt: magnetite, il: ilmenite. Crossed nicols.

Fig. 4 ditto, Exsolution paragenesis of magnetite-ilmenite is presented. mt: magnetite, il: ilmenite. Oil immersion.

Fig. 5 Mode of occurrence of tonalitic granite blocks in hyaloclastite (2) at the route 333, Western mass.

Fig. 6 Photomicrograph of thin section of the tonalitic granite. qz: quartz, pl: plagioclase showing zonal structure. Crossed nicols.


1
1m
4
il
mt
0.1mm
2
pl
cpx
il
1mm
5
3
mt
il
0.1mm
6
qz
pl
1mm

distinct but rarely gradual. The magnetite was examined by thermomagnetic analyser to investigate the degree of impurity. It was disclosed that this mineral is a typical specimen of the Weiss type with Curie point of 578°C. Thus the magnetite should be an ideal one. It is thought that the ilmenite-magnetite intergrowth might have been produced by diffusion intercrystalline. The starting material of the opaque minerals is thus estimated to be a kind of ulvospinel.

Plagioclase is a main constituent mineral of the gabbro and attains to 47.5 vol.%. Laths of plagioclase ranging from 1×3 to 0.5×2 mm in size are wholly turbid by strong sericitization. This alteration makes the measurements of its optic properties difficult.

Table 8 Comparison between the intercumulus phase of troctolite and gabbro from the northern Tokoro Belt

	(intercumulus phase of troctolite)			(gabbro)		
modal ratio of essential minerals	cpx 43.3%	pl 49.5%	il 7.2%	cpx 43.18%	pl 47.5%	il 9.3%
2Vz of cpx	48-53°, av.51°			(C)44-53°, av.50° (F)46-56°, av.52°		
$c \wedge Z$ of cpx	39-44°, av.42°			(C)38-49°, av.47° (F)43-52°, av.47°		
An mol% of plagioclase	55%			—		
reflectivity of ilmenite under 547nm	Ro 19.2% Re 17.8%			Ro 19.5% Re 17.4%		

cpx: clinopyroxene, pl: plagioclase, il: ilmenite
(C): coarse-grained
(F) fine-grained

The above-stated gabbro is common with the intercumulus phase of the troctolite in their mineral assemblage and modal proportion of the main constituent mineral. Furthermore, the optic properties of the constituent minerals of both two rocks resemble each other as shown in Table 8. Thus it is concluded that the cumulus troctolite and intercumulus gabbro were derived from the same origin. The intercumulus liquid which

Explanation of Plate 9

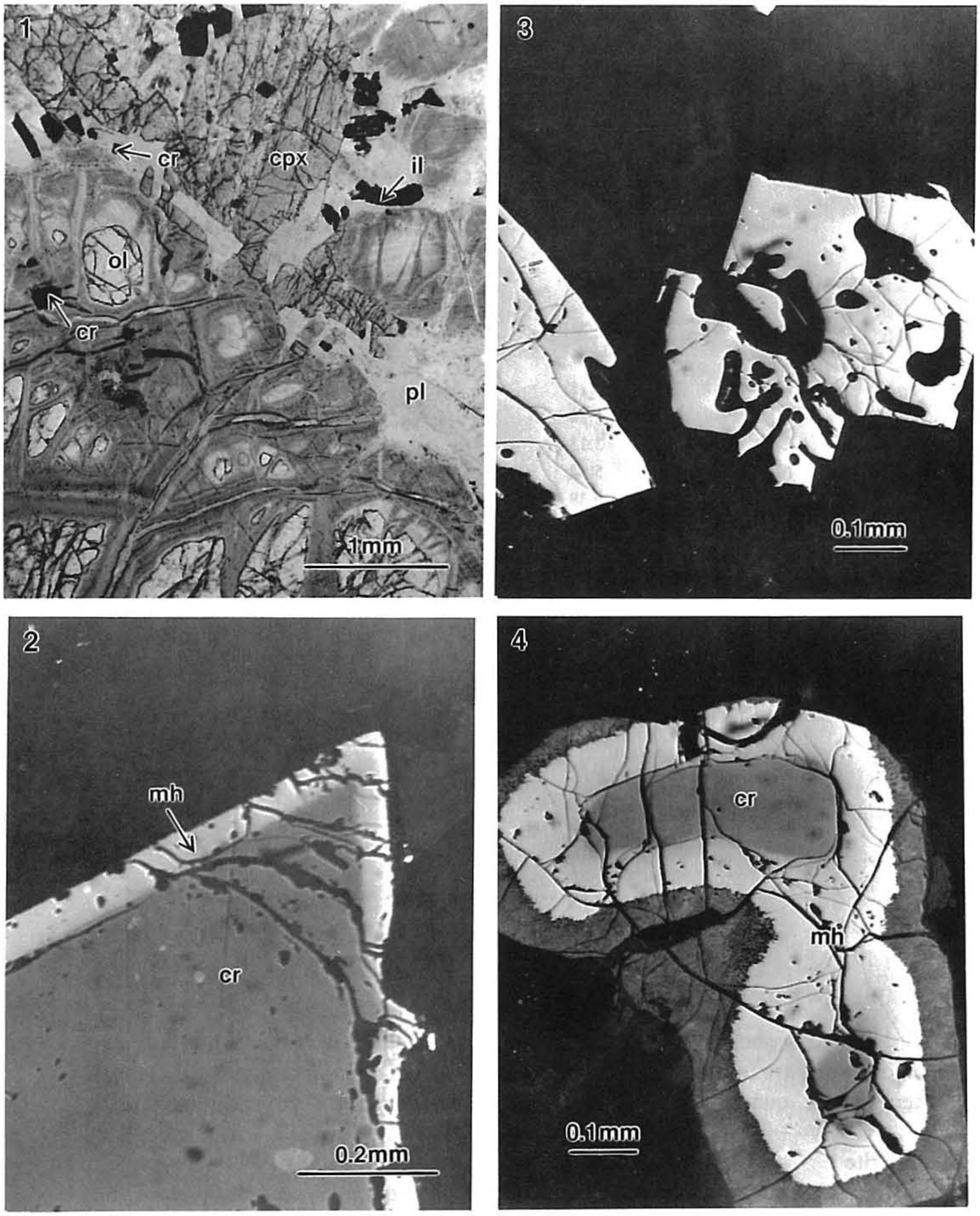
Photomicrographs illustrating the tectonic blocks of troctolite from the upper stream of the Rukushi-Ketobetsu River, Western mass, northern Tokoro Belt.

Fig. 1 Photomicrograph of thin section of olivine cumulate troctolite. Pyroxene-plagioclase-ilmenite-chromite assemblage shows intercumulus phase. ol: relict olivine, pl: plagioclase, cpx: clinopyroxene, il: ilmenite, cr: chromite.

Fig. 2 Photomicrograph of polished section of chromite with rim of maghemite in the intercumulus phase. cr: chromite, mh: maghemite. Oil immersion.

Fig. 3 Photomicrograph of polished section of skeletal ilmenite. Oil immersion.

Fig. 4 Photomicrograph of polished section of chromite with rim of maghemite. The boundary between chromite and maghemite is gradual. Thus it is thought that chromite-maghemite intergrowth has been materialized by diffusion. cr: chromite, mh: maghemite. Oil immersion.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produced the gabbro might have crystallized ulvospinel first under the condition of high temperature and low oxygen fugacity. Afterward, clinopyroxene and plagioclase were formed and the oxidation of ulvospinel was contemporaneously advanced with decreasing temperature and increasing fo_2 (Bamba, 1981).

Table 9 Chemical composition and CIPW norm of tonalitic granite from the northern Tokoro Belt

SiO_2	69.32	$FeO=0.9Fe_2O_3$		33.94
TiO_2	0.42	K_2O+Na_2O		49.81
Al_2O_3	13.95	MgO		16.23
Fe_2O_3	2.46			
FeO	1.47			
MnO	0.28			
MgO	1.76			
CaO	3.13			
Na_2O	5.02			
K_2O	0.38			
P_2O_5	0.14			
$H_2O(+)$	1.06			
$H_2O(-)$	0.24			
Total	99.63			
q	29.55	or	3.78	
or	2.24	ab	71.84	
ab	42.47	an	24.36	
an	14.40			
di	0.15			
hy	4.80			
mt	3.56			
il	0.79			
ap	0.32			

Analyst: H. Takahata

Dike Rocks

Numerous and various kinds of dike rocks, perhaps related to the eruption of pillow lavas, are found in the northern Tokoro Belt. They are distinguished as dolerite, keratophyre, quartz-keratophyre, trachyte, arfvedsonite-trachyte and others.

Dolerite

Several dikes of coarse-grained dolerite are found along shear zones in the mineralized area, Eastern mass. These dikes are composed of plagioclase, clinopyroxene and ilmenite. Their texture is typically ophitic as shown in Plate 2. The shape of plagioclase is prismatic and it is occasionally replaced by tiny sericite. Clinopyroxene is brownish purple in color and regarded as titaniferous augite. Rim of the crystal is often replaced by chlorite.

The chemical composition of the dolerite from the Kokuriki mine is presented in Table 10. It is alkalic, and rich in K_2O compared with the pillow lavas from the same locality. This rock falls in the composition range of the alkalibasalt series.

Table 10 Chemical composition and CIPW norm of dolerite, keratophyre, and trachyte dikes from Eastern mass, northern Tokoro Belt

	1	2	3	4	5	6	7
SiO_2	46.20	45.10	46.04	45.70	66.10	70.44	64.76
TiO_2	1.04	0.95	0.86	0.90	0.36	0.64	0.43
Al_2O_3	16.32	15.04	15.82	18.13	16.55	13.83	14.42
Fe_2O_3	3.42	8.59	8.97	7.76	4.65	1.55	2.96
FeO	7.82	4.89	3.91	5.31	0.78	1.32	2.58
MnO	0.52	0.53	0.57	0.60	0.06	0.07	0.15
MgO	5.78	7.69	6.79	5.07	0.56	0.46	0.87
CaO	10.02	8.65	8.88	7.71	3.01	1.12	0.71
Na_2O	2.85	2.60	2.60	2.71	6.19	6.60	5.26
K_2O	1.25	0.14	1.24	1.30	0.01	2.90	6.44
P_2O_5	0.42	0.49	0.25	0.45	0.06	0.24	0.05
$H_2O(+)$	3.70	4.38	2.86	4.22	1.40	1.09	1.74
$H_2O(-)$	0.25	0.18	0.31	0.32	0.26	—	—
Total	99.59	99.23	99.10	100.18	99.99	100.26	100.37
q	—	2.55	0.87	1.19	22.94	19.40	7.39
or	7.39	0.83	7.33	7.68	0.06	17.14	38.06
ab	23.74	22.00	22.00	22.93	52.38	54.99	38.32
an	28.05	28.95	27.83	33.47	14.54	—	—
c	—	—	—	—	1.03	0.76	5.45
ne	0.20	—	—	—	—	—	—
di	15.50	8.43	11.35	1.47	—	3.21	2.68
hy	—	16.51	11.65	14.90	1.39	0.04	4.23
ol	12.85	—	—	—	—	—	—
mt	4.96	12.45	11.96	11.25	1.67	1.87	1.56
il	1.97	1.80	1.63	1.71	0.68	1.22	0.82
hm	—	—	0.71	—	3.50	—	—
ap	0.97	1.13	0.58	1.04	0.14	0.56	0.12

1,2: dolerite dike from northern area of Hiyoshi
3,4: dolerite dike from the open-pit of the Kokuriki mine
5: keratophyre dike from northern area of Hiyoshi
6: quartz-keratophyre dike from southern area of Hiyoshi
7: arfvedsonite-trachyte from southern area of Hiyoshi

Analyst: S. Ito

Quartz-keratophyre

Dike swarm of quartz-keratophyre associated with a mica clay mineral rock has been found on the western side of an anticlinal axis of the Nikoro Group in the Eastern mass.

Quartz-keratophyre in question is pale green in color. This rock is compact but includes moderate amount of amygdules. The matrix shows a typical variolitic structure. The variole is made up of aggregates of fine-grained acicular clinopyroxene, actinolite and mosaic aggregates of quartz and plagioclase. The amygdules, 0.3-0.5 mm in size, are in general filled with aggregates of quartz. Chlorite is occasionally found near the margin of the amygdule. Plagioclase which forms the matrix shows acicular or lath shape. Besides, tabular phenocryst of feldspar, 0.2 mm in size, is rarely found.

Chemical composition of the quartz-keratophyre is presented in Table 10. The rock is characterized by richness in SiO_2 and K_2O, and poorness in FeO, MgO and CaO.

Mica clay mineral rock with 10 cm thick, which seems to be of chilled contact, appears at the margin of the individual dike of quartz-keratophyre. In other words, the unit block of quartz-keratophyre has selvage which is made up of mica clay mineral rock of dark grayish green color. The mica clay mineral rock has greasy feeling and is made up of aggregates of fibrous mica clay minerals. Perlitic structure is characteristic in the rock. This structure is produced by ringed aggregates of mica clay minerals. The

Table 11 Chemical composition of mica clay mineral rock from the southern area of Hiyoshi, Tokoro Belt

SiO_2	49.88	q	19.40
TiO_2	0.79	or	46.73
Al_2O_3	16.73	ab	1.10
Fe_2O_3	7.88	an	0.50
FeO	5.04	c	7.77
MnO	0.14	di	—
MgO	3.53	hy	10.49
CaO	0.39	mt	11.43
Na_2O	0.13	il	1.50
K_2O	7.91	ap	0.51
P_2O_5	0.22		
$H_2O(+)$	6.77		
$H_2O(-)$	—		
Total	99.41		

Analyst: S. Miyashita

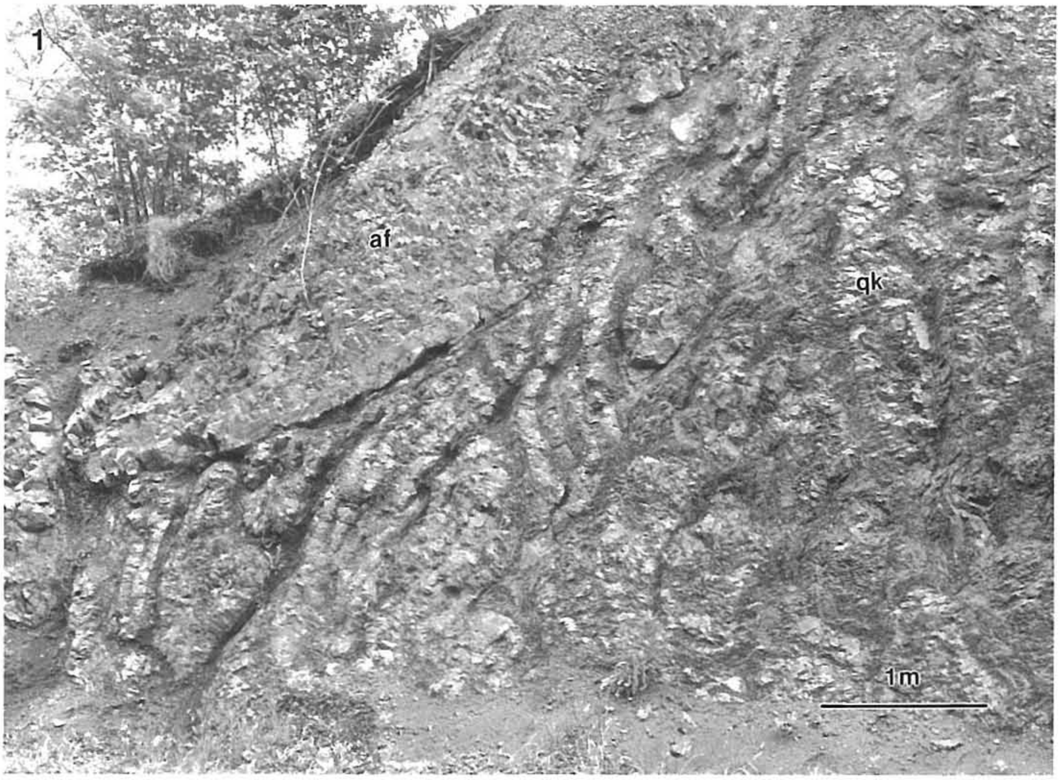
Explanation of Plate 10

Photographs illustrating quartz-keratophyre and arfvedsonite-trachyte in the Eastern mass, northern Tokoro Belt.

Fig. 1 Mode of occurrence of quartz-keratophyre (qk) and arfvedsonité-trachyte (af).

Fig. 2 Photomicrograph of thin section of arfvdsonite-trachyte. af: arfvedsonite, pl: plagioclase, ar: anorthoclase.

Fig. 3 Photomicrograph of thin section of quartz-keratophyre. Plumose plagioclase-clinopyroxene intergrowth is prominent. qz: quartz.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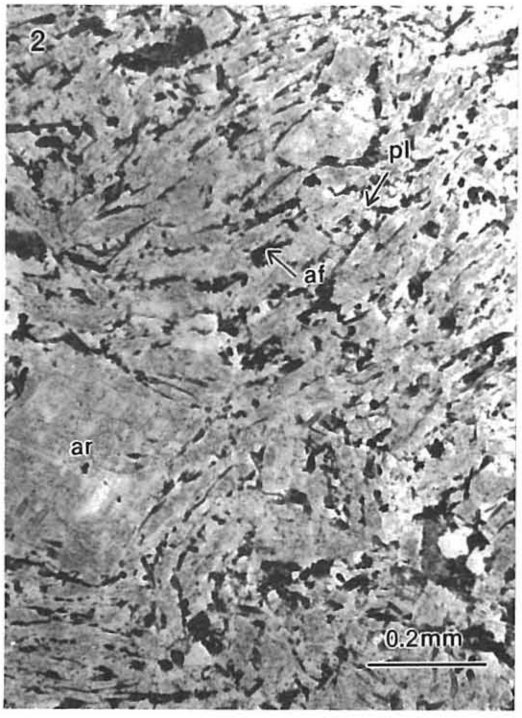
2
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3
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qz
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diameter of the ring is 1 mm and inside of the ring is occupied by quartz and/or zeolite and in places goethite.

Chemical composition of this rock is presented in Table 11. This rock tends to be poorer in SiO_2 and Na_2O and richer in K_2O, Al_2O_3, Fe and H_2O than the quartz-keratophyre.

Arfvedsonite-trachyte

Arfvedsonite-trachyte occurs being accompanied by the preceding quartz-keratophyre. From the mode of occurrence, the arfvedsonite-trachyte is regarded to have repeatedly intruded as dike before and after the quartz-keratophyre. Some blocks of the arfvedsonite-trachyte are found included in the quartz-keratophyre, while the quartz-keratophyre which is cut by arfvedsonite-trachyte is observed as shown in Plate 10.

The arfvedsonite-trachyte is compact and bluish gray in color. This rock is made up mainly of lath of albite and arfvedsonite, both 0.03×0.1 mm in size, forming a typical trachyte texture. A small amount of anorthoclase phenocryst is observed.

Chemical composition of the arfvedsonite-trachyte is presented in Table 10. The rock is characterized by poorness in MgO and CaO and richness in Na_2O and K_2O. Arfvedsonite was chemically examined by EPMA at the margin and the core. The results obtained are presented in Table 12, in which decrease in CaO and TiO_2 and increase in Na_2O from the core toward the margin are recognized. Arfvedsonite shows distinct pleochroism; X = bluish green, Y = brown, Z = greenish yellow, and $c \wedge Z = 10°$.

Albite and anorthoclase in the arfvedsonite-tracyte were both analysed by EPMA.

Table 12 Chemical composition of arfvedsonite from the Tokoro Belt and its chemical formula

	1	2**	chemical formula		
SiO_2	47.87	49.94	Si	7.994	8.000
TiO_2	2.67	0.10	Al^{IV}	0.006	
Al_2O_3	0.72	0.10	Al^{VI}	0.048	5.001
			Ti	0.013	
FeO	33.81	35.35	Fe^{3+}	0.897	
MnO	1.03	1.30	Fe^{2+}	3.839	
MgO	0.51	0.12	Mn	0.176	
			Mg	0.028	
CaO	3.16	1.31	Ca	0.225	2.815
Na_2O	6.20	7.54	Na	2.342	
K_2O	1.02	1.21	K	0.284	
H_2O*	1.84	1.84	OH		2.000
Total	98.83	99.01			

1: core of arfvedsonite 2: margin of arfvedsonite
*H_2O was calculated based on OH = 2.
**chemical formula was calculated on the basis of O = 23.
Fe^{3+} was calculated from total Fe by assuming arfvedsonite stoichmetry.

Analyst: T. Watanabe

their Ca:Na:K ratios are as follows;

Albite	Ca:Na:K = 0.2:99.2: 0.6
Anorthoclase	Ca:Na:K = 0.2:43.2:56.6

Ores and Ore Minerals

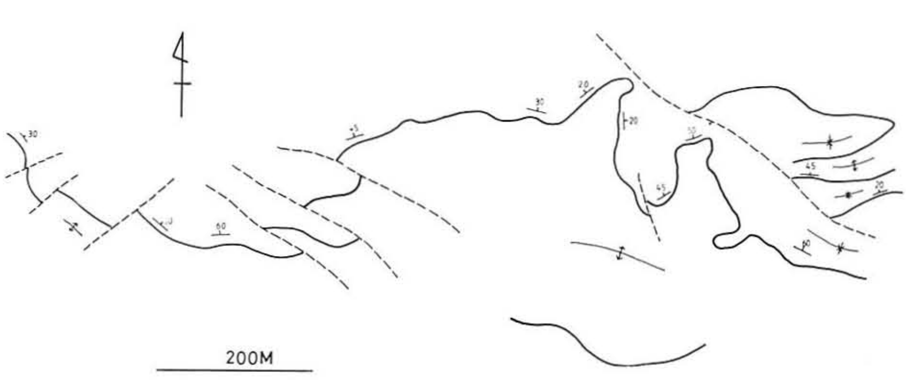
Manganiferous hematite ore

Strata-bound manganiferous hematite deposits in the northern Tokoro Belt had been exploited by Harita and Ohmachi Mining Companies since 1931 onward until 1964. 460,000 metric tons of massive iron-oxide ores with an average 33%Fe and 10%Mn were mined from the Kokuriki, Nikura and some other mines in the vicinity.

The mode of occurrence of the ore deposits are briefly introduced in Text-fig. 10 and Plate 11. The manganiferous hematite deposits of the Hokko, Nikura, Kokuriki and Shibayama mines are common with each other in the following aspects; The ores occupy a space between radiolarian chert and pillow lava. The former is hanging wall and the latter footwall. Fragments of radiolarian chert or ferruginous quartz rock, 2-3 cm in size, are frequently included in the ore (Plate 12). Network veins consisting of Mn-silicate minerals, penwithite, piedmontite and Mn-pumpellyite are common in the massive iron-oxide ore (Plates 12, 14). The scale of the lenticular orebodies varies from 50 meters long with 1 meter thick to 700 meters long with 10 meters thick. The orebodies are generally sheared and dislocated by minor faults or small scale thrusts which may be attributed to a compressive movement from east to west as shown in Text-fig. 10.

Chemical composition of the ore (Suzuki et al., 1965) is presented in Table 13.

Hematite. Aggregates of very fine-grained, 0.01 mm in size, or dusty hematites form the compact ore. The manner of aggregate of hematite is shown in Plate 14. Amoeba-like aggregates are microscopically observable at high magnifications. Impurity of the hematite was examined by EPMA and 0.38 wt%Mn at maximum was



Text-fig. 10 Map showing the tectonic features of the manganiferous hematite ore bed in the Kokuriki mine. The left lateral offsets of the ore bed is observed. This tectonic pattern is a characteristic feature of the Eastern mass of the northern Tokoro Belt.

Table 13 Chemical composition of manganiferous hematite ores from Kokuriki and Nikura mines

	1	2
SiO_2	15.90	11.80
Al_2O_3	5.44	2.64
Fe_2O_3	53.64	53.26
FeO	0.12	0.22
MnO	13.71	18.30
MgO	1.66	1.08
CaO	3.68	6.24
P	0.67	0.77
$H_2O\ (+)$	3.41	3.44
$H_2O\ (-)$	1.28	1.25
S	0.09	0.03
Total	99.60	99.03

1: Kokuriki mine, 2: Nikura mine
(Suzuki et al., 1956)

Explanation of Plate 11

Photographs illustrating the mode of occurrence of the manganiferous hematite ore from the Fukuyama mine, Eastern mass, northern Tokoro Belt.

Fig. 1 mh: manganiferous hematite ore, ch: radiolarian chert.

Fig. 2 ditto, mh: manganiferous hematite ore, p: pillow lava.

Explanation of Plate 12

Photograph of a slab of the manganiferous hematite ore from the Kokuriki mine. The relationship between Mn-pumpellyite and penwithite veins is shown. Penwithite vein follows the Mn-pumpellyite vein. hm: hematite, ch: chert, fq: ferruginous quartz rock, pw: penwithite vein, mp: Mn-pumpellyite vein.

Explanation of Plate 13

Photomicrographs of thin section of the ferruginous quartz rock and the manganiferous hematite ores.

Fig. 1 Ferruginous quartz rock from the Kokuriki mine. Intergrowth of hematite (h)-ferruginous quartz (fq) is shown.

Fig. 2 Segregation of euhedral hematite from the ferruginous quartz is seen in a small cavity. h: hematite, q: quartz.

Fig. 3 Mn-pumpellyite (mp) and penwithite (pw) veins in the hematite ore from the Kokuriki mine. Penwithite vein follows Mn-pumpellyite vein. h: hematite, nt: neotocite.

Fig. 4 Gel structure of the ore from the Kokuriki mine. qz: quartz, h: hematite.

Fig. 5 Mode of occurrence of Mn-pumpellyite (mp) in hematite (h).

Fig. 6 Mode of occurrence of piedmontite (pm) vein in the Mn-pumpellyite vein.

Explanation of Plate 14

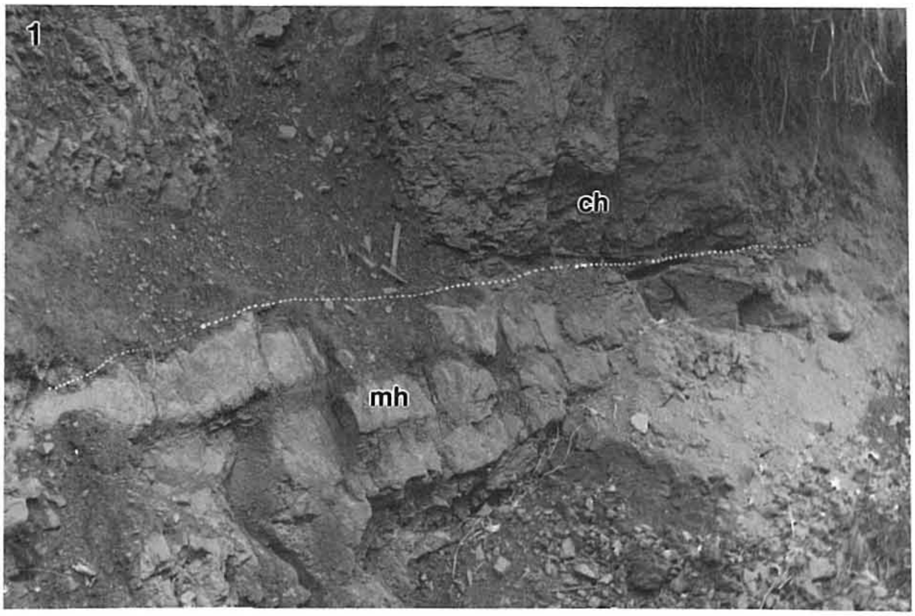
Photomicrographs of polished section of the manganiferous hematite ores from the Kokuriki mine, Eastern mass of the northern Tokoro Belt.

Fig. 1 Manner of aggregation of dusty hematite. Gel structure is observed. h: hematite, qz: quartz aggregates. Oil immersion.

Fig. 2 ditto, in higher magnification. Amoeba-like aggregates of hematite is observed. h: hematite, qz: quartz.

Fig. 3 ditto, in maximum magnification. Oil immersion.

Fig. 4 Euhedral hematite crystals are present in the quartz predominant area. Oil immersion. h: hematite, qz: quartz.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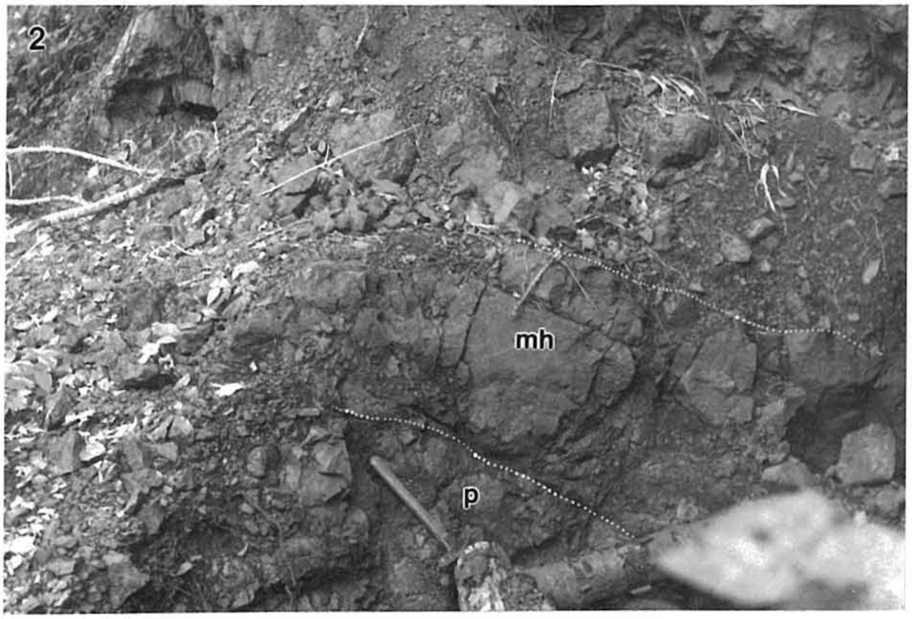
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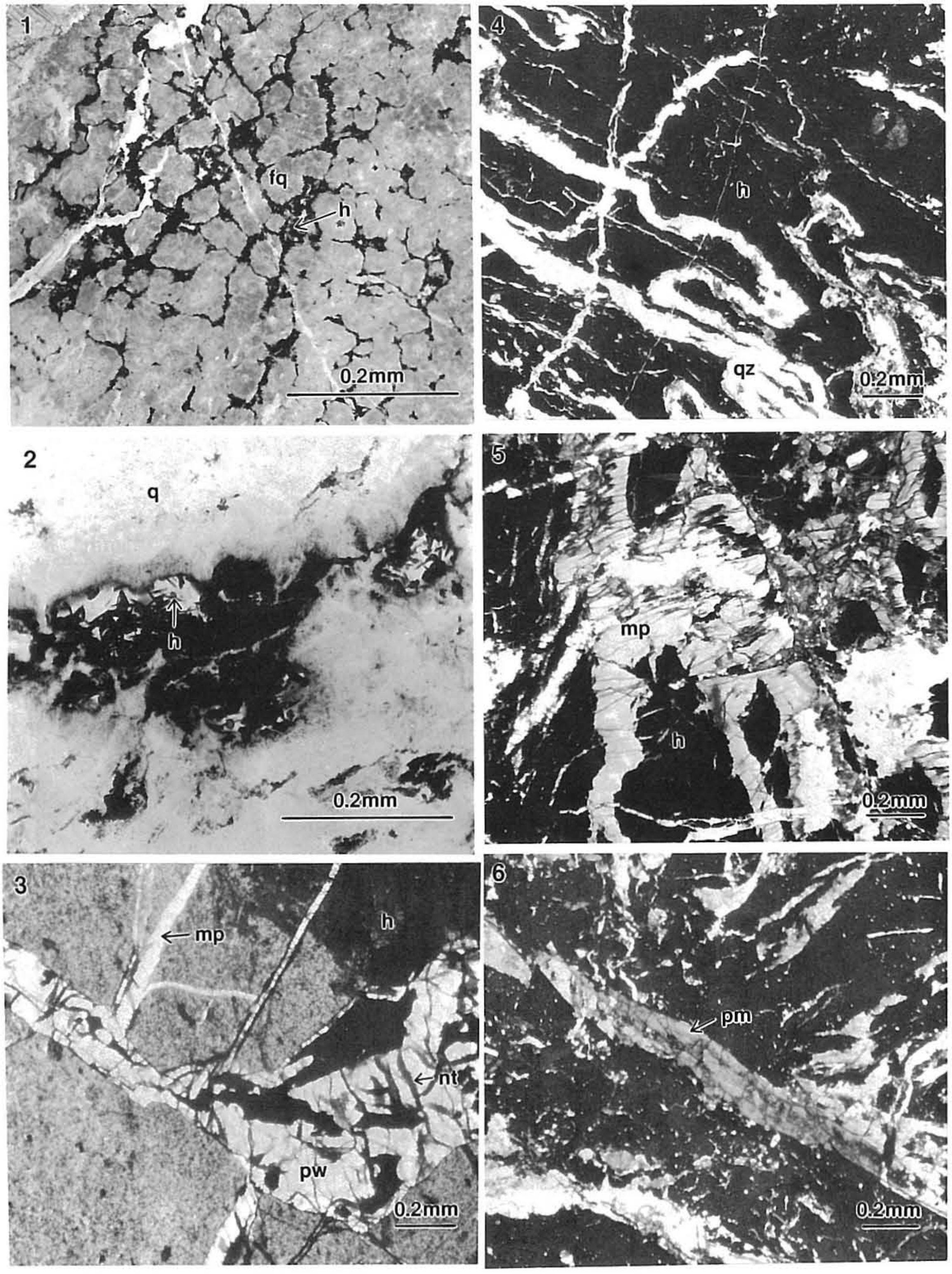
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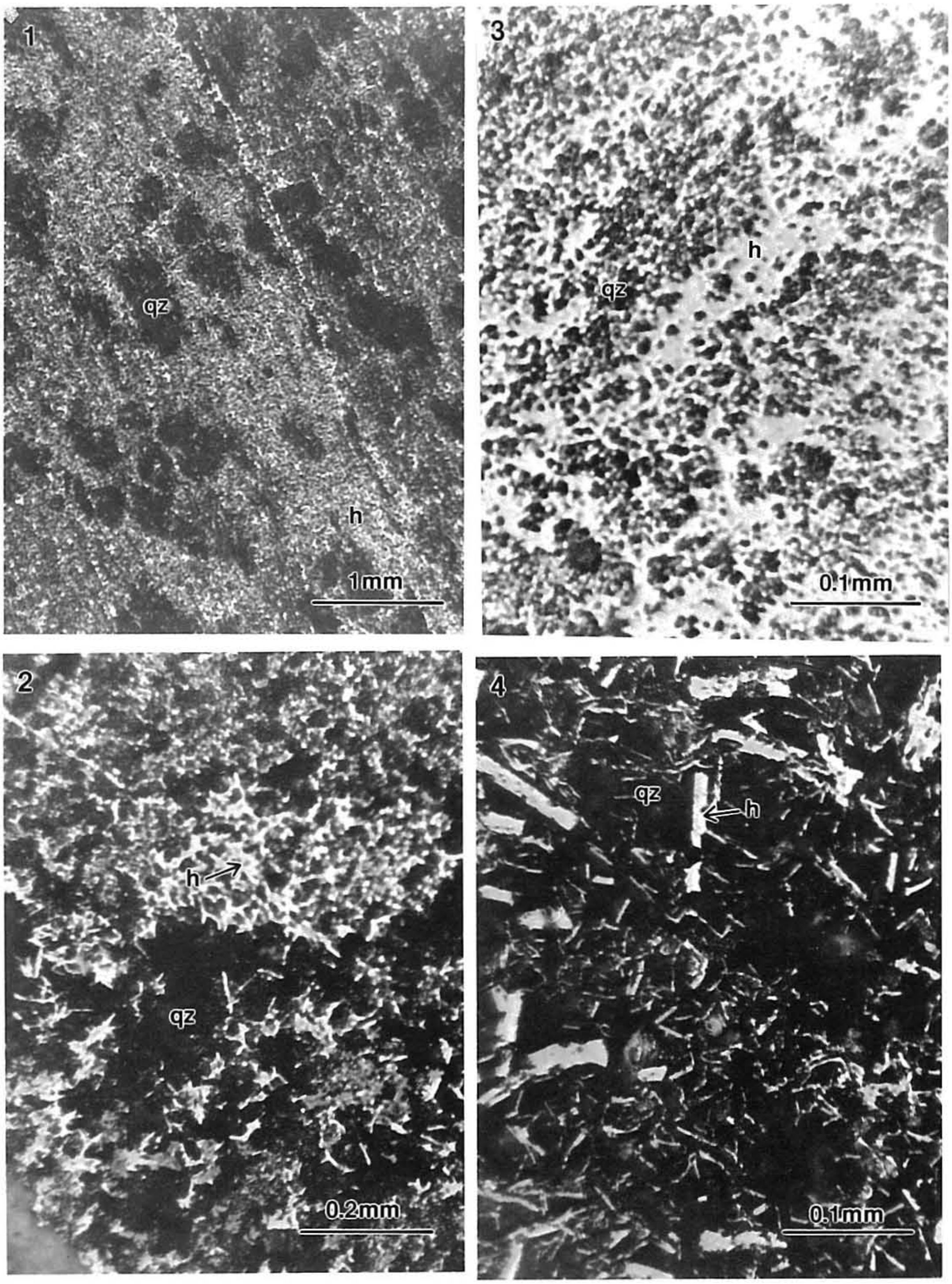
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2
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4
qz
h
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detected (Togari, 1982, personal communication). Therefore it is thought that the hematite is extremely pure.

Penwithite. Cracks of the massive hematite ore are generally filled with filmy aggregates of penwithite which is dark brown in color. Microscopic observation and X-ray powder diffraction have revealed that the penwithite ($MnO \cdot SiO_2 \cdot 2H_2O$) is amorphous. Penwithite is generally accompanied by neotocite ($MnO \cdot SiO_2 \cdot H_2O$) as shown in Plate 13. TDA examination for the vein has disclosed that the vein is composed mainly of neotocite.

Piedmontite. Piedmontite, pinkish red in color, occurs in massive hematite ores showing network veinlets. The piedmontite is easily distinguished from its peculiar color. From the modal proportions, the piedmontite is regarded to be an important Mn source of the ore.

Mn-pumpellyite. Togari et al. (in press) discerned a new mineral "Mn-dominant pumpellyite" which forms network veins in massive hematite ores from the Kokuriki and Shibayama mines in the Eastern mass of the northern Tokoro Belt. This mineral is generally accompanied by piedmontite.

Mn-dominant pumpellyite in question is dark pinkish yellow in color. Pleochroism is peculiar, i.e. X = dark yellow, Y = dark pinkish yellow, Z = reddish brown. This mineral occurs showing aggregates of fibrous crystals, 0.02 × 0.2 mm in size, and is generally invaded by penwithite as shown in Plate 13.

Table 14 Paragenetic relationship of minerals related to the formation of manganiferous hematite ores from the Eastern mass of northern Tokoro Belt

Minerals \ Phase	Precipitation	Replacement	Filling
Ferruginous quartz	————		
Hematite I	————		
Hematite II		————	
Quartz		————	
Mn-pumpellyite			———
Piedmontite			——
Penwithite (Neotocite)			—

Mn-oxide ore

Strata-bound Mn-oxide ore deposits are known in the Western mass, but their scale is extremely small. Total production of the Mn-oxide ores from this terrain was about 5,000 metric tons with grade of 20-40%Mn.

Mode of occurrence of the Mn-oxide ore is somewhat different from the preceding manganiferous hematite ores in the Eastern mass, i.e. lenticular or irregular shaped Mn-oxide ore deposits occur in siliceous rocks or peculiar silicastone (yellow jasper)

Table 15 X-ray powder reflection data for the pyrolusite from the Hokkaido mine, Western mass of the northern Tokoro Belt

1		2	
d(A)	I	d(A)	I
3.48	10		
3.14	100	3.13	100
2.41	50	2.41	55
2.21	10	2.24	15
2.13	25	2.13	25
1.98	15	1.98	15
1.81	5		
1.63	50	1.62	25
1.56	25	1.56	5
1.43	15	1.43	5
1.40	15		

1: ASTM Card 12-716, pyrolusite
2: pyrolusite from the Hokkaido mine

Analyst: M. Okutani

which are intercalated in the Jurassic tuffites or hyaloclastites. Mn-oxide ores are compact associated with disseminated parts. In general, banded structure being materialized by pyrolusite rich layer and quartz rich layer is observed as shown in Plate 15.

Compact ores are made up of mosaic aggregtes of granular pyrolusite, 0.1 mm in

---

Explanation of Plate 15

Fig. 1 Photograph of a slab of Mn-oxide ore from the Hokkaido mine, Western mass, northern Tokoro Belt. The banded structure of the ore is made up of Mn-oxide rich layer and quartz rich layer. p: pyrolusite, qz: quartz.

Fig. 2 Pelagic limestone with quartzite layer from Chirai, Western mass. q: quartzite, ca: calcite.

Explanation of Plate 16

Photomicrographs of a thin section and polished sections of manganese-oxide ores from the Hokkaido mine, Western mass, northern Tokoro Belt.

Fig. 1 Photomicrograph of thin section of low-grade Mn-oxide ore. Colloform structure is distinct. p: pyrolusite, qz: quartz.

Fig. 2 Photomicrograph of polished section of low grade Mn-oxide ore. p: pyrolusite, qz: quartz. Oil immersion.

Fig. 3 ditto, in large magnification. Oil immersion. p: pyrolusite.

Fig. 4 Photomicrograph of polished section of high grade Mn-oxide ore. Manner of aggregation of pyrolusite is distinguishable by the strong anisotropism. Mosaic aggregates of pyrolusite (p) are observed. Crossed nicols. Oil immersion.

Explanation of Plate 17

Photomicrographs of polished section of massive sulfide ores from the Bushi mine, Western mass of the northern Tokoro Belt.

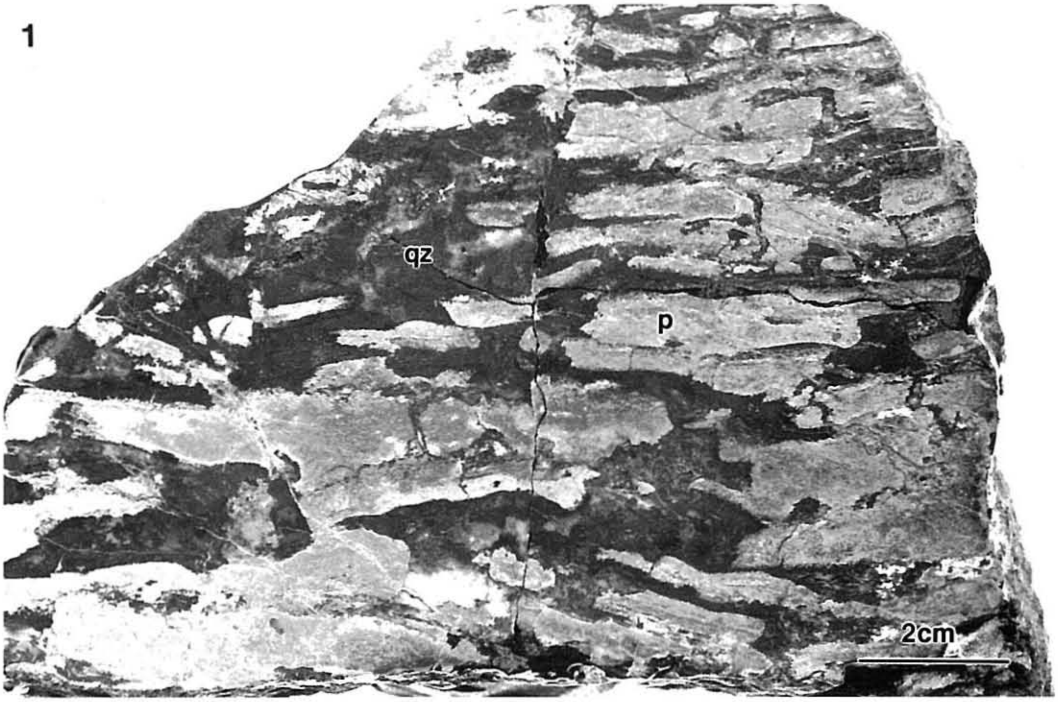
Fig. 1 High-grade copper ore. py: pyrite, cp: chalcopyrite. Oil immersion.

Fig. 2 Low-grade copper ore. py: pyrite, cp: chalcopyrite. Cataclastic structure is characteristic. Oil immersion.

Fig. 3 Low-grade copper ore. Banded structure is observable. Oil immersion. py: pyrite, cp: chalcopyrite.

Fig. 4 Photomicrograph showing the intergrowth of pyrite and hematite. Sulfide is partly replaced by hematite. py: pyrite, h: hematite, q: quartz. Oil immersion.

1



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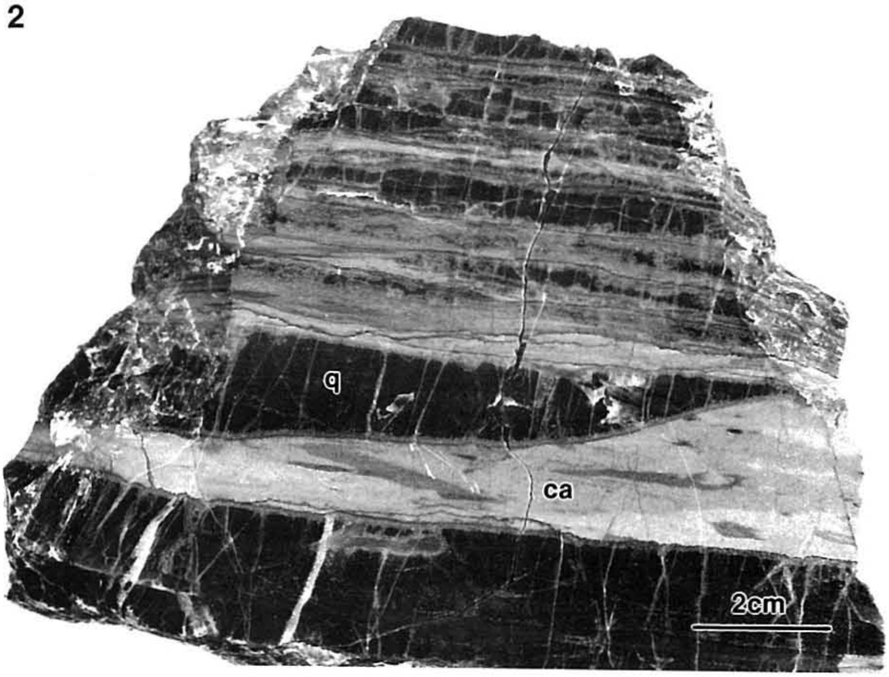
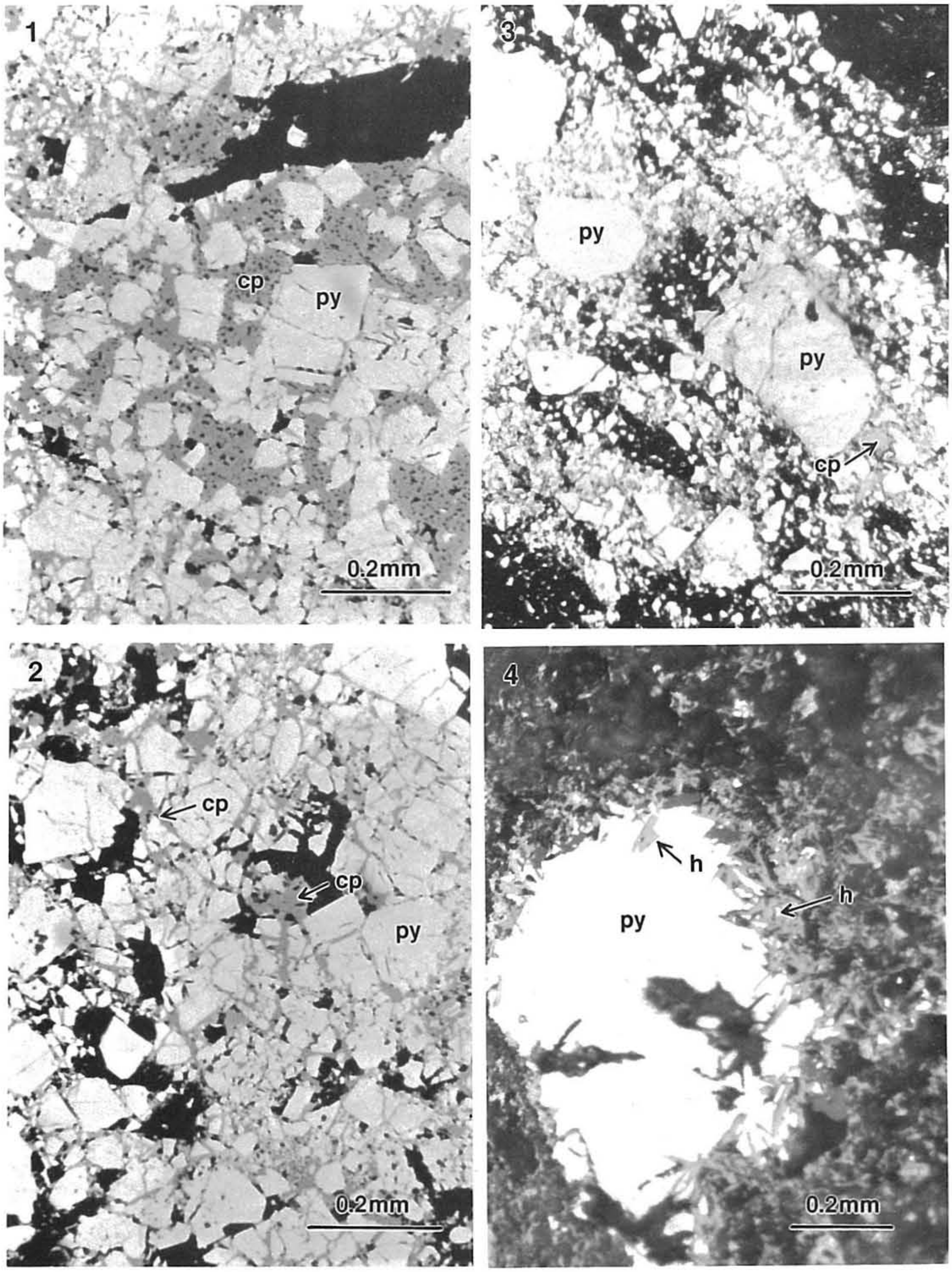
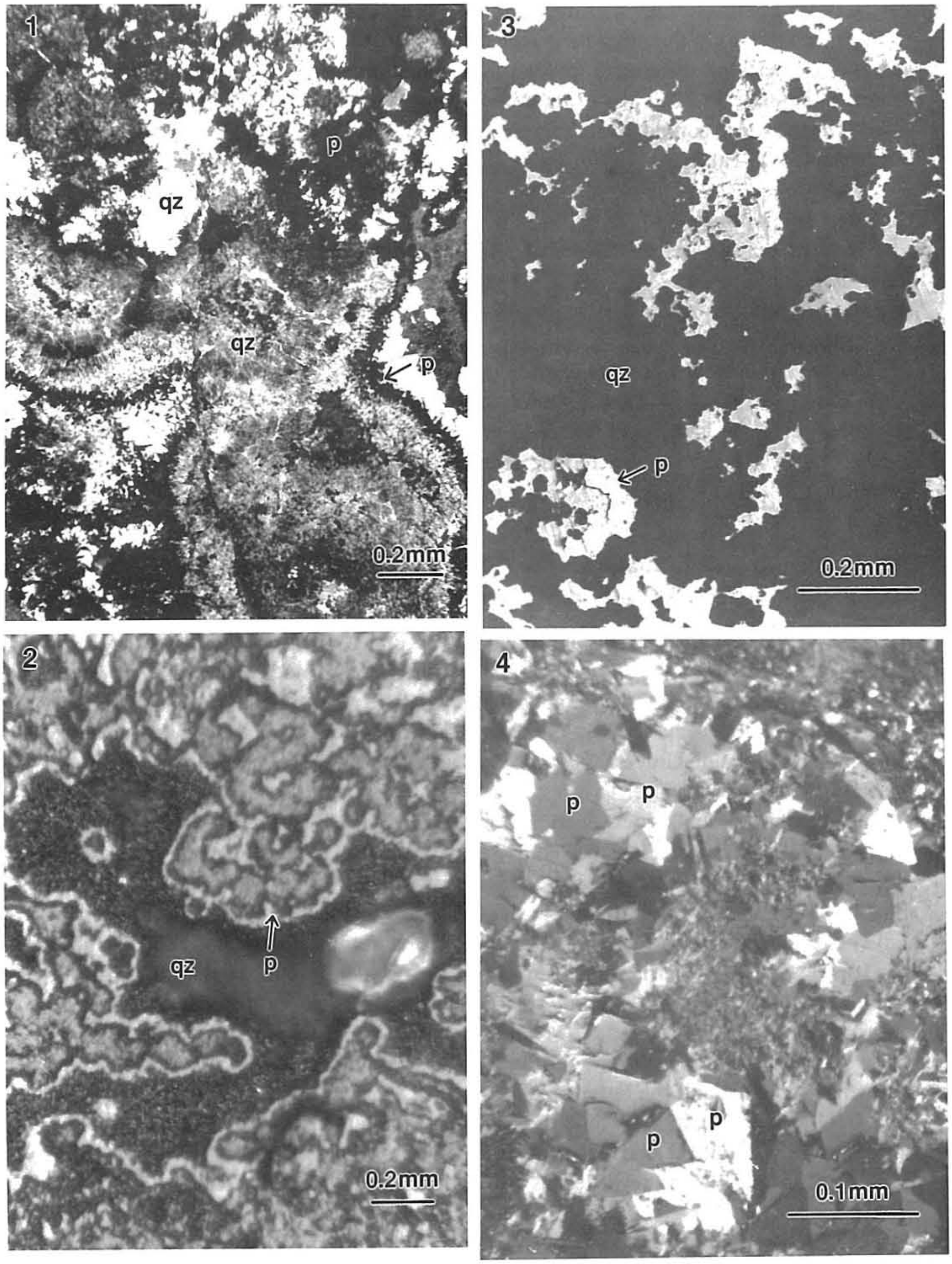


Plate 16




1
p
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size. Crystal boundaries are distinguishable each other by the strong unisotropism as shown in Plate 16. On the other hand, the disseminated ore is composed of rythmic aggregates of acicular pyrolusite and mosaic quartz showing colloform structure as presented in Plate 16. The Mn-oxide mineral was examined by X-ray and it was identified that the ore is composed mainly of pyrolusite. The X-ray powder reflection data are presented in Table 15.

Cupriferous pyrite ore

Mode of occurrence of the massive sulfide ore in the Western mass is obscure because the mines had been closed and we cannot observe the outcrop. It is presumed that the ore occurs accompanied with pillow lava or sandy hyaloclastite from the surrounding geology.

The ore from the Bushi mine is made up mainly of pyrite and chalcopyrite. Pyrite, 0.1-0.5 mm in size, is euhedral and the interspaces of pyrites are filled with chalcopyrite. There is a report that high grade ores contain 8% Cu. Cataclastic structure is one of the most characteristic features of the massive sulfide ores from this terrain.

REE Abundances in Pillow Lavas of the Eastern and Western Masses

REE measurements for the pillow lavas and quartz-keratophyre in the northern Tokoro Belt have been made with the aim to search the geologic environments where these rocks were produced, especially to compare the rocks of the Eastern mass with those of the Western mass of the northern Tokoro Belt. The analyses were made by Koshimizu, Hokkaido University, at the Institute for Atomic Energy, Rikkyo University by the following procedure.

The samples of bulk rocks were irradiated with U.S. Geological Survey standard samples (G-2, AGV-1) (Flanagan, 1969) at neutron flux of $5 \times 10^{11} n/cm^2/sec$ for 24 hours in a TRIGA Mark II Reactor. Counting was done with a Ge (Li)-detector and plus height analyzer at 7 days and 40 days after irradiation.

The results obtained are presented in Table 16, and the data are plotted in Text-fig. 11. It is observed that REE patterns of the pillow lavas of the Eastern mass and those of the Western mass are different from one another. The former shows solid type (Masuda et al., 1966; Tanaka, 1977) and the latter liquid type, respectively. The two types of REE fractionation are correlative to their major elements features, i.e. the former is tholeiitic and the latter alkalic. In other words, the former is richer in MgO and CaO and poorer in TiO_2, alkalis, P_2O_5 than the latter.

It is thought that the original magma which pillow lava of the Eastern mass of the northern Tokoro Belt is regarded as tholeiitic whereas that in the Western mass is alkalic.

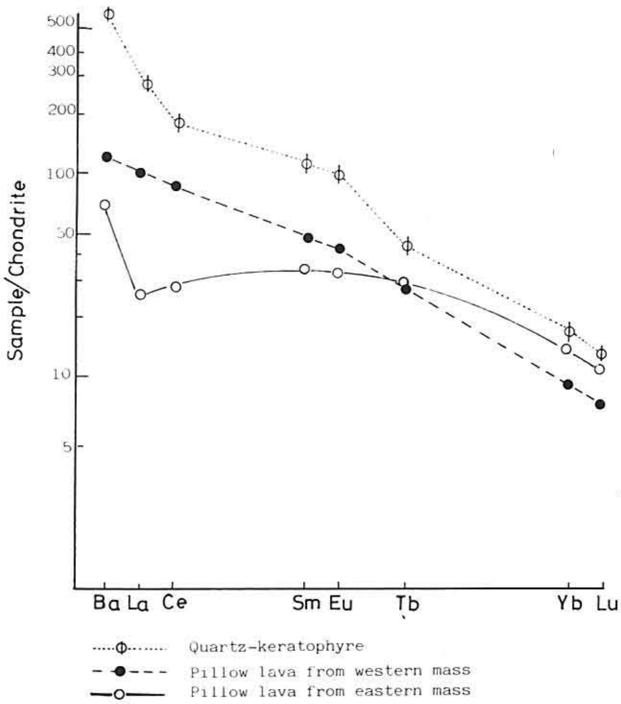
The REE contents of the quartz-keratophyre, a representative of later phase of the volcanism are abundant compared with the associated pillow lavas.

Table 16 REE and Ba abundances (in ppm) in Jurassic pillow lavas and related dike rock from the northern Tokoro Belt

	1	2	3
La	8.71	34.30	93.0
Ce	24.60	73.80	156.0
Sm	6.36	9.53	18.5
Eu	2.33	3.05	6.71
Tb	1.39	1.39	2.06
Yb	2.95	1.92	3.77
Lu	0.46	0.29	0.53
Ba	309.	529.	2361.

1: Pillow lava from Eastern mass
2: Pillow lava from Western mass
3: Quartz-keratophyre from Eastern mass

Analyst: S. Koshimizu



Text-fig. 11 Chondrite-normalized REE patterns of the pillow lavas and related rock from the northern Tokoro Belt.

Formation Processes of Manganiferous Hematite Ores, Massive Sulfide and Mn-Oxide Ores

Krauskopf (1957) has explained a mechanism of separation of manganese from iron in sedimentary processes through thermochemical experiments. He concluded that isolation of manganese in solution can be accomplished by precipitating the iron first. This is most effectively done by adding alkali gradually to a solution containing both metals, keeping the solution in contact with atmospheric oxygen. The reaction can be demonstrated in the laboratory under conditions similar to those in nature by letting dilute acid percolate through crushed lava and then through limestone; iron disolved from the lava is precipitated in the limestone, and the solution is left with a high Mn/Fe ratio. This suggests a possible explanation for the origin of many manganese deposits, especially those associated with lavas and tuffs, but it requires that iron oxides in amount many times that of the manganese be deposited in the rocks through which the solutions have passed.

Similar consideration on the behavior of Mn and Fe metals in submarine hot spring process has been made by Stanton (1972).

On the other hand, Hewitt (1966) proposed a model of the separation process of Fe and Mn based on the depth of deposition, i.e. deposition of iron from hydrothermal solution should be materialized in a deeper zone and manganese may precipitate in an epithermal zone. Thus mixed iron-manganese minerals are produced in an intermediate zone.

The mineralization processes related to the formation of iron-oxide, manganese-silicates of the Eastern mass and manganese-oxide ores of the Western mass in the northern Tokoro Belt can be partly explained by the above-stated experiments and considerations.

The ore geneses of these ore deposits are summarized as follows;

a) Formation of the manganiferous hematite ores in the Eastern mass

1st Stage. Submarine effusive process which produced pillow lavas of tholeiitic basalt in the Eastern mass yielded ferruginous silica gel from which ferruginous quartz bed at the top of a pillow lava bed might have been formed. The silica gel was oxidized and fine-grained or dusty hematite was separated first. The presence of peculiar gel structure which is made up of hematites and bleached ferruginous quartz suggests that the separation of iron might have taken place from a gel state.

2nd Stage. Interaction between the precursor and the subsequent volcanism represented by dolerite dikes produced hydrothermal solution in which manganese ions were dissolved. Such an idea was once introduced by Rösler (1962) as to the iron-oxide ore deposits of upper Devonian in Ostthuringen, Germany. The hydrothermal solution in question rose as far as the top of the pile of greenstones and invaded into the preconsolidated hematite ores perhaps occupying the top of the pile, and formed numerous veinlets consisting or Mn-pumpellyite, piedmontite, then penwithite or neotocite. The cataclastic structure of the ore were contemporaneously formed.

The peculiar distributioin of mangano-silicate minerals which are restrictedly found within the hematite ores may be explained by above-stated model.

b) Formation of the massive sulfide and Mn-oxide ores in the Western mass

Taylor (1983) stated that sulfide deposition is generally limited to the physicochemical conditions in the immediate vicinity of exhalative vents related to pillow lavas, while iron and manganese oxides can precipitate under conditions approaching to normal ocean water and can therefore be formed up to several kilometers from consanguinous sulfide mineralization.

The distribution relationship between the cupriferous pyrite ores of the Bushi, Sakaibashi mines and Mn-oxide ores of the Saroma, Wakasa and Hokkaido mines in the Nikoro Group is applicable to the Taylor (1983)'s model.

Geologic environments of the cupriferous pyrite ore deposition and the Mn-oxide ore deposition in this terrain may be different each other, i.e. the former is closely related to the pillow lavas, and the latter to the tuffite that is made up of very fine-grained glass shards indicating a deposit distant from the vents. Thus the zoned distribution of these two kinds of ore deposits is explained as follows; Massive sulfides may have been formed at or near the exhalative vents and Mn-oxides were separated at the distal position. In other words, the former was formed in a reductive environments where various kinds of metals ascended but the latter in oxidation environments far from the vents.

Jasperoid associated with Mn-oxide ores suggests that the temperature at or during the formation of manganese oxide ores was low. It is thought that the separation of manganese from solution was probably taken place at subaqueous environments.

Geologic Environments Producing the Two Masses

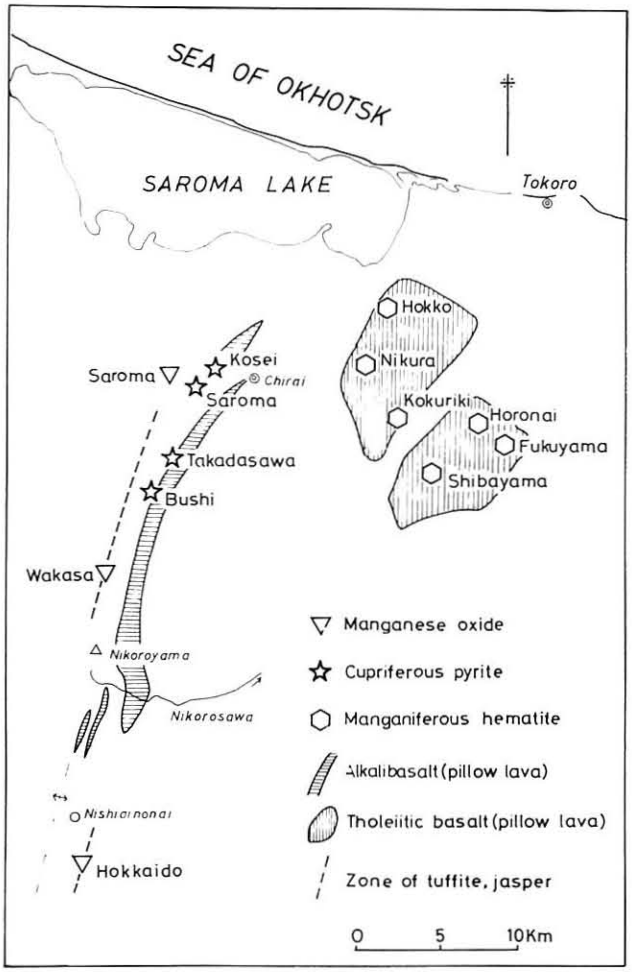
Second look on the Central Axial Zone of Hokkaido has been taken place in recent ten years, and many interesting new findings have been provided, i.e. the presence of ophiolite sequences in the Kamuikotan Tectonic Belt and the Western Zone of Hidaka Metamorphic Belt have been confirmed by Ishizuka (1980) and Miyashita (1981) respectively based on an attempt to reconstruct the complicated strata of the greenstones. Consequently, these strata has been recognized as a tectonic block derived from the oceanic crust.

On the other hand, the geologic situation of the Main Zone of the Hidaka Metamorphic Belt has been explained that the metamorphism of the Main Zone reaches to the highest grade (granulite facies) at the western boundary of the Main Zone (Arita, et al., 1978), and the Main Zone contacts to the Western Zone with intercalation of thin mylonite zone. Hence, the boundary between the Main Zone and the Western Zone of the Hidaka Metamorphic Belt implies collision boundary between continental crust and oceanic crust (Komatsu et al., 1982).

The Tokoro Belt in question occupies the eastern side of the Hidaka Metamorphic Belt. Thus the geologic situation of the Tokoro Belt is being watched with a great interest.

The Tokoro Belt is characterized by the preponderant occurrence of greenstones with intercalation of radiolarian chert believed to be of late Jurassic in age and the overlying turbidite strata called Yubetsu and Saroma Groups of Upper Cretaceous.

Troctolite and gabbro have been found in the Nikoro Group showing tectonic contact or as tectonic blocks. From above-stated facts, the presence of ophiolite sequence has been estimated (Bamba, 1981) in the northern Tokoro Belt. Besides, strata-bound manganiferous hematite deposits are found in a part of the pillow lavas of tholeiitic basalt in the Eastern mass (Text-fig. 12). While, strata-bound manganese oxide ore



Text-fig. 12 Map showing the distributions of manganiferous hematite, massive sulfide and manganese oxide ore deposits and related volcanogenic rocks in the northern Tokoro Belt.

deposits and cupriferous pyrite deposits are known in the Western mass as shown in Text-fig. 12. From their zoned distribution in the Western mass, these two kinds of ore deposits are regarded as the products of a paired mineralization which is perhaps independent of the manganiferous hematite deposits in the Eastern mass.

The geologic environments of the Eastern and the Western masses of the northern Tokoro Belt have been investigated from their constituents, especially from the bulk rock chemistry, microscopic texture and REE abundances of the pillow lavas in both masses. The data suggest that these two masses show notable contrasts. It is concluded that the Tokoro greenstones have not been produced in a same geosynclinal basin, i.e. the Eastern mass greenstones may have been formed in an abyssal sea floor and the Western mass greenstones in a seamount (Niida et al., 1983).

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