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THE OSHIRABETSU GABBROIC MASS IN THE SOUTHEASTERN PART OF THE HIDAKA METAMORPHIC BELT, HOKKAIDO, JAPAN

by

Teruyuki Takahashi

(with 9 text-figures, 3 tables and 2 plates)

Abstract

The Hidaka metamorphic belt is characterized by the presence of a large quantity of basic plutonic and metamorphic rocks. The Oshirabetsu gabbroic mass forming one of the centers of igneous activity in the Hidaka metamorphic belt, consists mainly of olivine gabbro, troctolite, coarse-grained gabbro, norite and diorite. The gabbroic rocks are highly variable in lithology and are accompanied by nickel-bearing iron sulfide deposits with graphite. Among these rock-types, olivine gabbro and a part of troctolite show cumulate texture and their chemical composition indicates that olivine gabbro and a part of troctolite are the cumulus phase of this mass. Analyses of major and trace elements of representative rock-types from the Oshirabetsu gabbroic mass reveal that the above-stated rock-types have been formed during a series of magmatic differentiation. Chemical composition within the gabbroic mass except the cumulate rocks varies smoothly and its trend shows the characteristics of calc-alkali rock series.

Nickel-bearing iron sulfide ores with graphite found in the Oshirabetsu gabbroic mass show various grade of concentration, but the ore deposits occur restrictedly in olivine gabbro and in norite. Considering the modes of occurrence of the deposits composed mainly of spotted pyrrhotite ore frequently taking interstitial form, the main ore bodies seem to have been formed through magmatic differentiation of the host gabbroic magma.

Introduction

The Hidaka metamorphic belt forming the central axial zone of Hokkaido, has been classified into a metamorphic belt of low-pressure and high-temperature type. This belt is characterized by the presence of abundant basic plutonic and metamorphic rocks. The basic plutonic rocks occupy spatially one third of the Hidaka metamorphic belt (Miyashita and Maeda, 1978), which is in contrast to other metamorphic belts in Japan (Gorai, 1973; Miyashiro and Kushiro, 1977).

The Hidaka metamorphic belt is made up of two different tectonic units, i.e. the Western Zone (Hashimoto, 1975; Miyashita and Maeda, 1978; Komatsu et al., 1979), and the Main Zone (Komatsu et al., 1979). The Western Zone is underlain by green schists, amphibolites, metagabbros and ultramafic rocks, whereas the Main Zone is composed mainly of ultramafic rocks, granulitic rocks, amphibolites, gabbroic intrusions, migmatites, biotite schists, hornfelses and of sedimentary rocks. The Main Zone shows a thermal axis from which the grade of metamorphism decreases to both sides (Miyashiro, 1977) however the Main Zone contacts with large-scale thrust along the eastern boundary of the Western Zone, therefore conspicuous zonal arrangement of metamorphic rocks is recognized on the eastern side of the Main Zone. Komatsu et al. (1979) recently stated that the Hidaka metamorphic

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belt can be considered to be the junction of two different tectonic units, oceanic crust (the Western Zone) and continental or island arc crust (the Main Zone).

The basic plutonic rocks of the Hidaka metamorphic belt form two main centers of their igneous activity. One of them is represented by the Pankenushi-Memurodake area in the northern part of the metamorphic belt and the other is by the Horoman-Oshirabetsu area in the southern part of the metamorphic belt. The gabbroic rocks in the Horoman-Oshirabetsu area are known as the host rock of the nickel-bearing iron sulfide deposits frequently accompanied by graphite (Hashimoto, 1950; Hunahashi et al., 1956; Sako, 1963; Kim, 1966; Bamba, 1981). In these previous papers high variation in lithology of the gabbroic rocks and the deposition of nickel-bearing iron sulfide were considered to have mainly caused by the metasomatism occurred in relation to the migmatization, however those gabbroic rocks have hardly been studied from the petrochemical viewpoint. This report presents the petrography and the chemical compositions of representative rocks from the Oshirabetsu gabbroic mass distributed at the southeastern part of the Hidaka metamorphic belt. Geochemistry of the gabbroic rocks and the genetic relationship between nickel-bearing iron sulfide deposits with graphite and its host gabbroic rocks have been examined.

Geologic Setting

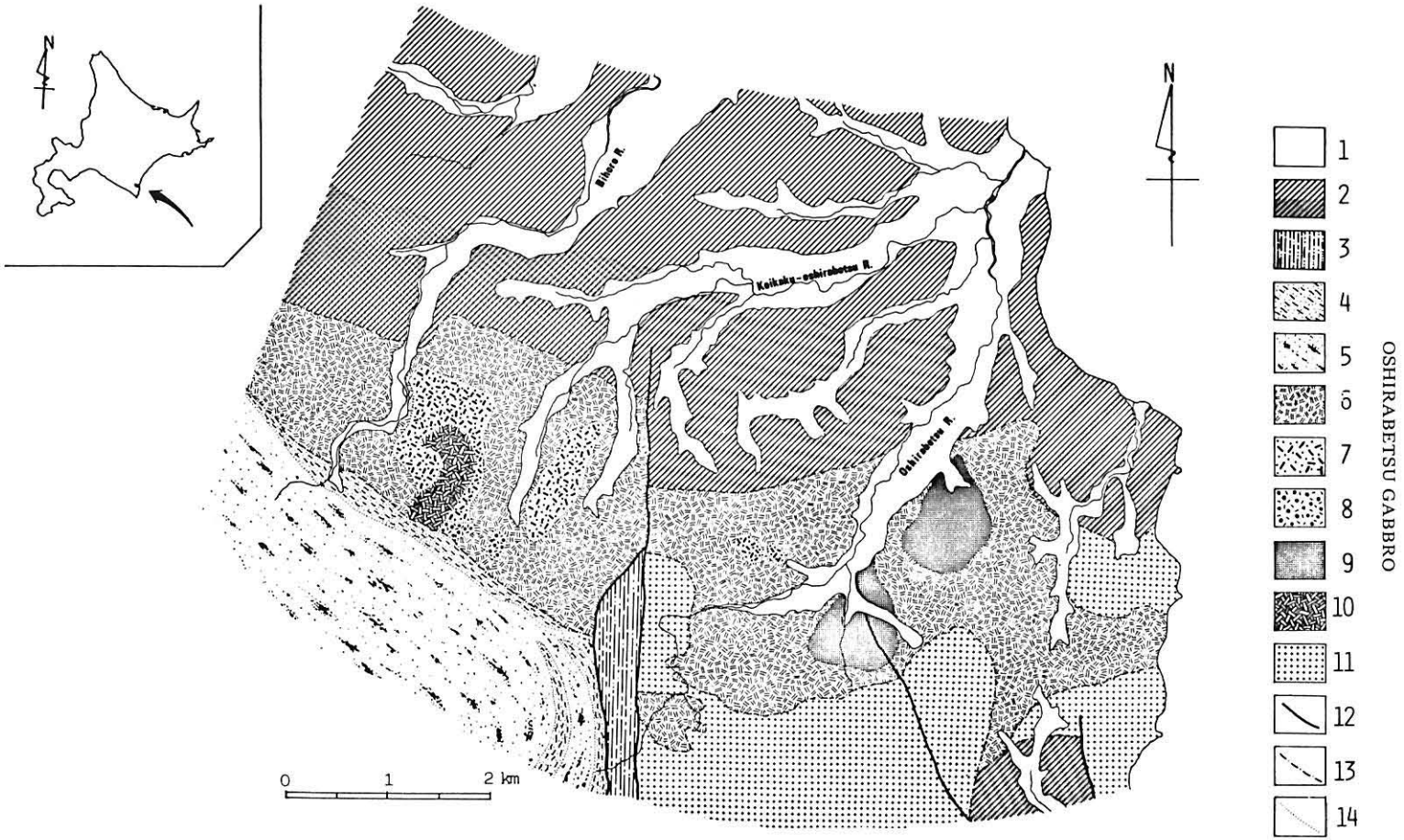
Oshirabetsu area is situated at the southeastern end of the Hidaka metamorphic belt, and it underlain by various kinds of metamorphic rocks and non-metamorphosed sedimentary rocks. The metamorphic rocks are cordierite-biotite migmatite, banded gneiss, biotite schist and hornfels, which are arranged showing that the grade of metamorphism increases southwestward in this area. The northeast of the metamorphic belt is dominated by sedimentary rocks of the Hidaka super-group possibly of Triassic to Jurassic age.

Two series of plutonic rocks, gabbros and granites, intruded into the metamorphic rocks. The granites seem to have finally intruded in this area. Intrusion of the plutonic rocks has had little contact metamorphic effect on the surrounding rocks. The gabbroic mass occupies the area of 20 square kilometers extending from east to west with two kilometers wide. The striking feature of the gabbroic rocks is highly variable in lithology, however they can be classified into following five rock-types based on their modes of occurrence and mineral assemblages; 1) olivine gabbro, 2) troctolite, 3) coarse-grained gabbro, 4) norite, and 5) diorite. Rok classification and nomenclature used in this report are not strictly in good accordance with those recommended by the IUGS Subcommission on the Systematics of Igneous Rocks (1973).

Mineralization of nickel-bearing iron sulfide is confined tothe olivine gabbro and the norite, and graphite deposits are occasionally accompanied by sulfide deposits. Sulfide and graphite ores are classified into several ore-types on the basis of their modes of occurrence.

Classification and Description of Gabbroic Rocks

The Oshirabetsu gabbroic mass is made up of above-stated five rock-types, and some of them are classified into several subfacies. The gabbroic rocks with abundant hornblende have been classified as hornblende gabbro in some previous papers (e.g. Bamba, 1981). However



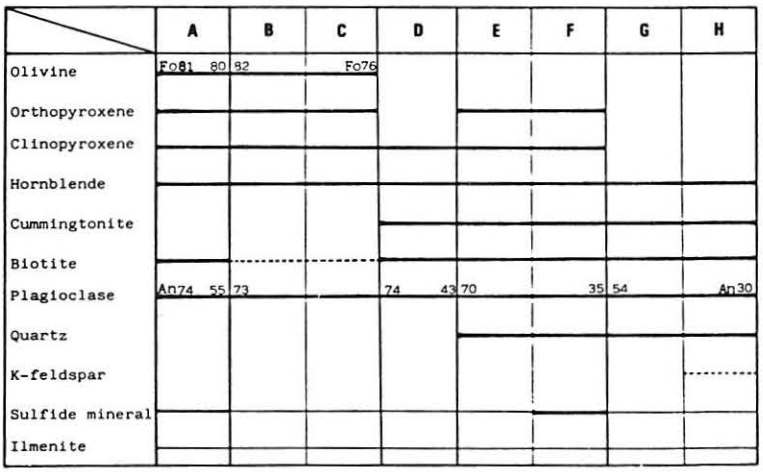
Text-fig. 1 Geological map of the Oshirabetsu area.

1: Alluvium, 2: Sedimentary rocks and hornfels, 3: Schistose hornfels, Banded gneiss, 5: Cordierite biotite migmatite, 6: Diorite, 7: Norite, 8: Coarse-grained gabbro, 9: Troctolite, 10: Olivine gabbro, 11: Granite, 12: Fault, 13: Intrusive boundary, 14: Boundary of rock-types

in this report, some of these rocks are classified as norite and the other as diorite. Because the former comprises hornblende with mostly replaced pyroxene, and the latter plagioclase of relatively low An content.

One of the characteristics of the Oshirabetsu gabbroic rocks is that hornblende and biotite, probably primary minerals, are recognized throughout all rock-types. It is in contrast to the gabbros of the Horoman plutonic complex in the southwestern part of the metamorphic belt. No hydrous mineral can be recognized in the olivine gabbro of the Horoman plutonic complex (Motoyoshi, 1980).

All rock-types are massive in appearance, and neither layered nor flow structure is observed in the gabbroic mass. Microscopic observation indicates the olivine gabbro and some troctolite to be a kind of cumulate rocks defined by Wager et al. (1960). Main constituent minerals of each rock-types are given in Text-fig. 2. The mode of occurrence and microscopic characteristics of each rock-types are as follows.



Text-fig. 2 Main constituent minerals of the representative rock-types from the Oshirabetsu gabbroic mass.
A: Olivine gabbro, B: Coarse-grained troctolite C: Fine-grained troctolite, D: Coarse-grained gabbro, E: Fine-grained norite, F: Norite, G: Hornblende diorite, H: Quartz diorite

Olivine gabbro

Olivine gabbro is restrictedly found at the middle stream of the Bihoro River, being surrounded by norite. Though the contact with norite is not observable, the olivine gabbro is seemingly a block included by norite. The olivine gabbro shows coarse-grained cumulate texture and is sheared near the boundary with norite. This rock is mainly composed of olivine, plagioclase, orthopyroxene, clinopyroxene, amphibole, biotite and ore minerals. Olivine and plagioclase are euhedral indicating cumulus phase, while the others intercumulus.

Olivine takes rounded-shape and is often strongly replaced by serpentine and chlorite, and the alteration resulted separation of magnetite in serpentinized area. Plagioclase is

lath-shaped, and its An-content ranges from 75 to 50. It is often turbid in the interior owing to alteration.

Sulfide minerals, pyrrhotite, pentlandite and chalcopyrite, are frequently observed taking interstitial form against the silicate minerals.

Troctolite

Troctolite is found only at the lower stream of the Oshirabetsu River. This rock can be divided into two subfacies based on their mineral assemblage and grain size.

Coarse-grained troctolite

This rock is mainly composed of olivine, plagioclase and clinopyroxene, with accessory orthopyroxene, hornblende and opaque minerals. This facies is relatively light-colored, because plagioclase is dominant. The first two minerals occur as cumulus phase, while the rest as intercumulus.

Olivine is euhedral and partly replaced by serpentine along the cracks. Plagioclase is euhedral or subhedral taking lath or tabular shape, and its An-content ranges from 70 to 50. A large number of crack is observed through plagioclase grain. Pyroxenes are generally accompanied by very small amount of brown hornblende.

Fine-grained troctolite

Fine-grained troctolite is composed mainly of olivine, plagioclase, orthopyroxene, clinopyroxene, accompanied by hornblende and opaque minerals. Olivine and plagioclase occur as cumulus phase, whereas pyroxenes are as intercumulus phase.

Olivine is euhedral keeping the fresh state. Plagioclase is clear and euhedral, and its An-content ranges from 70 to 45. The lathes of plagioclase are more or less orientated in parallel in places. Opaque minerals, such as ilmenite, pyrrhotite and chalcopyrite occur taking granular form.

Coarse-grained gabbro

Coarse-grained gabbro is restrictedly found at the upper stream of the Koikaku-Oshirabetsu River as a small mass. It is characterized by the presence of coarse-grained plagioclase. Olivine and orthopyroxene are not observed. Major constituent minerals are plagioclase and clinopyroxene, accompanied by accessory hornblende, biotite and opaque minerals.

Plagioclase is somewhat euhedral and often turbid, and its An-content varies from 70 to 40. Clinopyroxene occupies the irregular interspaces, and is replaced partly by amphibole. A small amount of ilmenite is commonly observed in this rock-type.

Norite

Norite can be divided into following two subfacies based on their mineral assemblage and grain size. It is noticeable that the relatively large-scale ore bodies of nickel-bearing iron sulfide associated with graphite are found in some part of norite. Norite is the major host rock of this ore deposit.

Norite

Norite is medium- to coarse-grained and generally dark-colored. This rock is composed

mainly of plagioclase, orthopyroxene, clinopyroxene, hornblende, biotite, quartz and ore minerals.

Plagioclase is euhedral or subhedral, and its An-content ranges from 65 to 35. Orthopyroxene and clinopyroxene are prismatic, and the former is more dominant than the latter. Compositional zoning is often observed in orthopyroxene. Hornblende is subhedral or anhedral and light greenish brown. Biotite is reddish brown and occurs as interstitial crystal. Quartz is interstitial and amounts 10 percent modal composition in maximum.

Main constituent mineral of sulfide ore is pyrrhotite in which subordinate amounts of chalcopyrite and pentlandite are associated. Silicate minerals associated with some sulfide ores are generally altered; e.g. pyroxenes are partly replaced by amphibole and other secondary minerals.

Fine-grained norite

This rock is very fine-grained, dark-colored and compact and is certainly included in the coarser norite. Mineral association and chemistry of the fine-grained norite resemble to those of the medium- and coarse-grained one. However, quartz and biotite in this rock are scant as compared with those in coarser-grained norite, and high grade concentration of sulfide minerals is not recognized.

Diorite

Diorite shows the largest exposure in this district. Diorite is characterized by the complexity of lithofacies, i.e. in color index, grain size, constituent minerals and texture. In this report, diorite is provisionally classified into two subfacies; hornblende diorite and quartz diorite, based on their mineral assemblages. An-content of plagioclase in diorite ranges from 50 to 30.

Hornblende diorite

This rock is characterized by the presence of abundant hornblende. The constituent minerals are plagioclase, hornblende, and accessory quartz, biotite and a little opaque minerals.

Plagioclase is euhedral or subhedral, and is slightly turbid in the interior owing to alteration. Hornblende is subhedral and shows brownish tint. Biotite is tabular and reddish, and encloses frequently ilmenite. A small quantity of quartz occupies irregular interspaces.

Quartz diorite

Quartz diorite is characterized by the presence of abundant quartz and biotite. Modal composition of quartz amounts to 20 percent in maximum, and biotite is up to 10 percent. It is composed mainly of plagioclase, quartz, hornblende and biotite taking equigranular texture. Accessory potash feldspar, apatite and opaque minerals are observed.

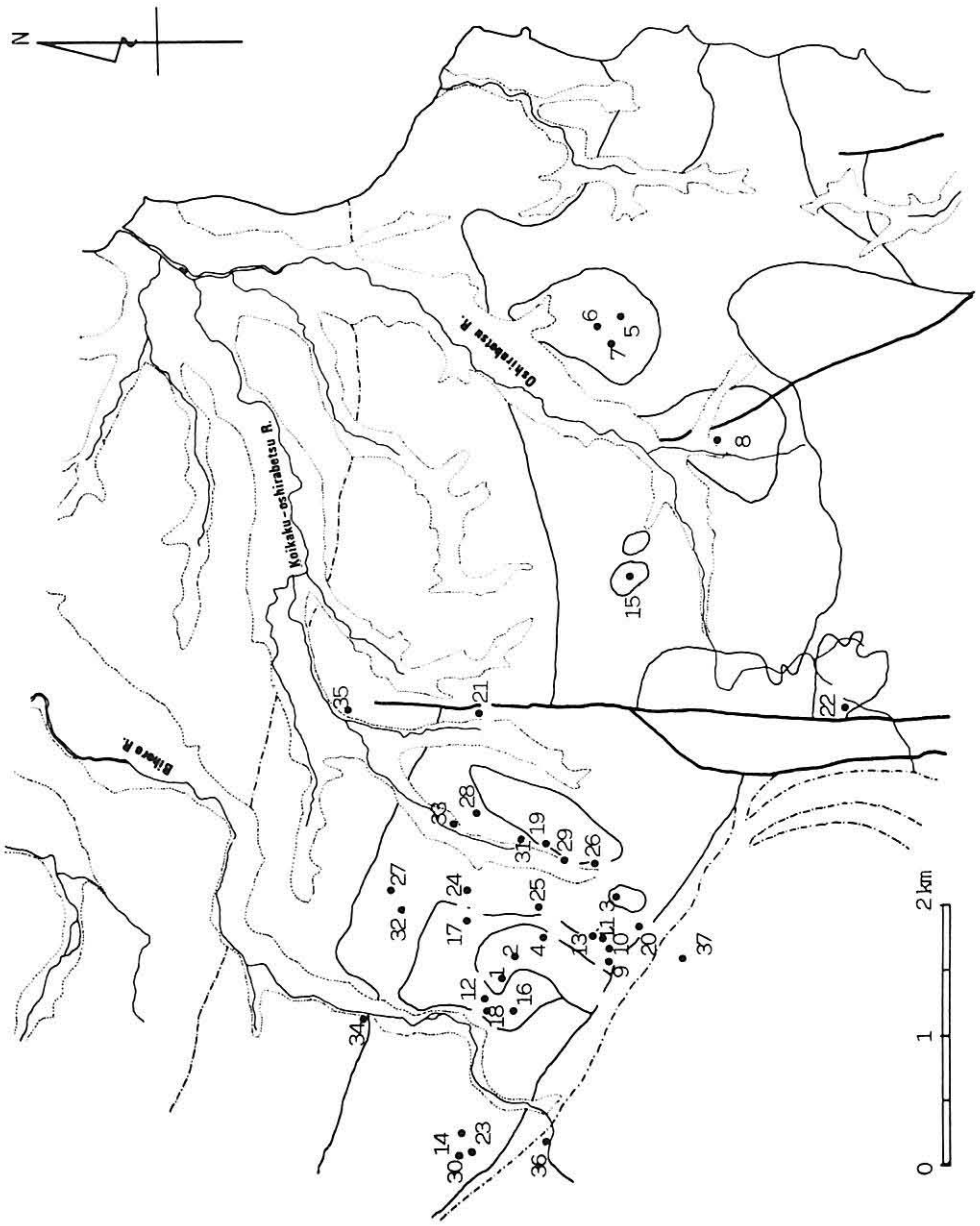
Plagioclase is subhedral and more sodic than that in hornblende diorite. Quartz is interstitial and commonly shows wavy extinction. Hornblende is euhedral or subhedral and light greenish brown to pale green. Biotite is subhedral and reddish. Ilmenite is often enclosed by tabular biotite. A small amount of interstitial potash feldspar is found.

Petrochemistry

Analytical method and procedure

Thirtyseven samples were selected from the Oshirabetsu gabbroic mass for major and trace element analyses, comprising 4 olivine gabbros, 4 troctolites, 3 coarse-grained gabbros, 9 norites, 8 diorites, 1 aplitic rock in diorite, 2 hornfelses and 2 migmatites as listed in Table 1.

Major element analyses were carried out by the following method; (1) SiO_2, Al_2O_3, TiO_2, Total Fe_2O_3, CaO, K_2O and P_2O_5 by X-ray fluorescence spectrometric analysis



Text-fig. 3 Locality map of rock samples analysed for whole rock chemistry.

Table 1 Numbers and rock-types of the samples analysed.
(01-29): for major element analysis, (01-37): for trace element analysis.

Sample No.	Rock-type	Sample No.	Rock-type
01 OG-2102	Olivine gabbro	20 HG-2501	Hornblende diorite
02 OG-2105	Olivine gabbro	21 D-3001	Biotite-hornblende diorite
03 OG-1707	Olivine gabbro	22 D-0105	Biotite-quartz diorite
04 OG-2201	Olivine gabbro	23 D-2210	Biotite diorite
05 OGT-0301	Coarse-grained troctolite	24 D-2304	Biotite-quartz diorite
06 OGT-0304	Coarse-grained troctolite	25 D-2206	Hornblende diorite
07 OGT-0302	Fine-grained troctolite	26 D-2701	Hornblende diorite
08 OGT-28	Fine-grained troctolite	27 D-0406	Hornblende diorite
09 CG-2604	Coarse-grained gabbro	28 D-0201	Hornblende diorite
10 CG-2605	Coarse-grained gabbro	29 AP-2804	Aplitic rock in diorite
11 CG-2315	Coarse-grained gabbro	30 NO-2208	Pyroxene-biotite hornfels in diorite
12 NO-2303	Norite	31 Hrf-1404	Cordierite-bearing pyroxene hornfels in diorite
13 NO-1403	Norite		
14 NO-1903	Norite	32 Hrf-0308	Pyroxene-biotite hornfels in diorite
15 NO-2903	Norite	33 Hrf-1301	Hornblende hornfels in diorite
16 NO-2004	Norite	34 71603	Biotite hornfels
17 NO-2318	Norite	35 71605	Hornfels
18 NO-2106	Fine-grained norite	36 MG-1805	Cordierite-biotite migmatite
19 NO-2703	Fine-grained norite	37 MG-2408	Cordierite-biotite migmatite

using TOSHIBA Model AFV-777, (2) FeO by titration using $K_2Cr_2O_7$, (3) MgO and MnO by atomic absorption spectrophotometric analysis using HITACHI Model AAS-170-30, (4) Na_2O by flame photometric analysis using HITACHI Model AAS-170-30, and (5) $H_2O(+)$ and $H_2O(-)$ by gravimetric determination.

Trace elements, Ni, Co, Cu, Cr, Ba, Rb and Sr were analysed by atomic absorption spectrophotometry using HITACHI Model AAS-170-30. Sulfur content was determined by gravimetric method, employing tin (II)-strong phosphoric acid ("Kiba reagent") method for sulfur extraction by Sasaki et al. (1979).

Through the analyses, the geochemical standard samples, JB-1 (olivine basalt) and JG-1 (granodiorite), were used to check the accuracy of analysis. The results of major and trace element analyses of whole rock samples from the Oshirabetsu gabbroic mass are listed in Table 2 and 3, respectively.

Major element chemistry

Plots of major elements vs. D.I. for the Oshirabetsu gabbroic rocks (gabbros, diorites and an aplitic rock) are shown in Text-fig. 4.

Implications obtained from the figure are that the olivine gabbro is rich in $FeO+Fe_2O_3$ and MgO, and poor in SiO_2, Al_2O_3 and CaO compared with the other rock-types. These features appear to be characteristics of olivine gabbro as the cumulate rock. While the other rocks, troctolites, coarse-grained gabbros, norites, diorites and an aplitic rock, change smoothly in major element contents on the whole. This tendency is known as major

Table 2 Major element contents and C.I.P.W. norm of representative rocks from the Oshirabetsu gabbroic mass (wt.%).

Sample No.	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15
SiO_2	44.48	45.42	46.55	43.39	47.54	47.38	49.02	48.35	52.79	50.75	52.65	54.44	53.33	58.45	55.25
TiO_2	.42	.42	.26	.31	.26	.23	.49	.28	.99	.47	.63	1.44	.32	.99	.94
Al_2O_3	7.27	7.68	14.38	6.64	23.18	23.07	19.52	20.34	17.55	17.91	17.19	16.54	18.08	16.76	15.67
Fe_2O_3	3.32	1.58	1.19	3.12	.94	.80	.99	.60	1.46	.96	.98	.98	.32	1.11	1.01
FeO	7.54	9.76	6.25	7.64	3.34	3.39	4.96	4.57	5.40	4.01	4.75	7.37	5.32	5.91	7.06
MnO	.17	.18	.11	.16	.07	.07	.16	.14	.13	.11	.12	.16	.12	.13	.17
MgO	25.05	26.78	19.37	26.13	9.30	9.20	10.41	10.76	6.85	8.90	9.90	5.69	9.67	4.48	5.81
CaO	4.41	3.95	7.20	3.76	11.61	11.99	10.41	11.34	8.93	12.56	8.88	7.88	9.22	5.53	9.31
Na_2O	.87	1.14	1.40	.68	1.96	1.94	2.58	2.16	2.79	2.06	2.22	3.03	2.13	3.32	3.20
K_2O	.18	.18	.15	.08	.74	.56	.42	.08	.74	.56	.42	.75	.33	1.46	.55
P_2O_5	.06	.08	.06	.07	.05	.05	.05	.04	.12	.06	.07	.26	.05	.21	.16
$H_2O(+)$	5.01	2.03	2.87	7.32	1.51	1.81	.94	1.28	1.89	1.74	1.85	.04	.78	1.14	.69
$H_2O(-)$					.04							.96			
S	.05			.24	.04		.04				.01	.13	.08		
Total	99.43	99.53	100.15	99.91	100.02	100.11	100.06	99.94	99.64	100.09	99.67	99.67	99.75	99.49	99.82
C.I.P.W. norm															
Q	–	–	–	–	–	–	–	–	3.62	–	3.01	6.21	2.88	11.72	5.38
C	–	–	–	–	–	–	–	–	–	–	–	–	–	.17	–
or	3.34	3.01	3.01	2.66	1.06	1.06	.89	.47	4.37	3.31	2.48	4.43	1.95	8.63	3.25
ab	7.36	9.65	11.85	5.75	16.59	16.42	21.83	18.28	23.61	17.43	18.79	25.64	18.02	28.09	27.08
an	14.22	14.33	31.45	13.74	53.92	53.71	41.24	45.57	33.18	37.95	35.70	29.31	38.80	26.09	26.77
di wo	3.03	1.98	1.62	1.86	1.40	2.27	5.00	4.35	4.32	10.00	3.30	3.37	2.76	–	7.67
di en	2.32	1.44	1.21	1.42	1.04	1.67	3.52	3.09	2.81	7.17	2.34	1.86	1.85	–	4.22
di fs	.40	.35	.26	.25	.23	.39	1.05	.89	1.21	1.93	.67	1.39	.72	–	3.17
hy en	23.02	15.35	13.91	24.51	8.57	6.75	6.04	7.26	14.25	19.85	22.32	12.32	22.24	11.16	10.26
hy fs	3.96	3.74	2.95	4.23	1.87	1.56	1.81	2.08	6.11	5.31	6.42	9.25	8.49	8.54	7.72
ol fo	25.97	34.97	23.21	27.44	9.50	10.16	11.48	11.53	–	1.80	–	–	–	–	–
ol fa	4.92	9.39	5.44	5.22	2.29	2.60	3.79	3.65	–	.54	–	–	–	–	–
mt	4.81	2.29	1.73	4.52	1.35	1.16	1.44	.87	22.12	1.39	1.42	1.42	.46	1.61	1.46
il	.89	.80	.49	.59	.49	.44	.93	.53	1.88	.89	1.20	2.73	.61	1.88	1.79
ap	.14	.19	.14	.15	.12	.12	.12	.09	.28	.14	.16	.60	.12	.49	.37
D.I.	10.78	12.66	14.86	8.41	17.65	17.47	22.72	18.75	27.98	20.74	24.28	36.28	22.98	48.44	35.71

(analysed by T. Takahashi)

Table 2 (continued)

Sample No.	16	17	18	19	20	21	22	23	24	25	26	27	28	29
SiO_2	54.75	54.13	53.47	52.58	55.66	60.40	62.85	61.39	60.71	55.36	56.44	56.71	56.43	64.23
TiO_2	.61	.50	.88	1.14	.60	.91	.91	.74	.94	2.17	.99	.83	.44	.43
Al_2O_3	18.00	17.26	16.64	19.87	17.04	16.20	16.40	16.11	16.77	17.33	18.21	16.78	18.93	19.55
Fe_2O_3	.79	.56	.83	.91	.94	.88	.80	1.10	1.16	1.04	.87	1.47	.79	.64
FeO	5.17	4.72	6.34	7.58	4.57	4.71	3.81	4.72	4.88	7.37	6.81	4.47	3.82	1.84
MnO	.05	.16	.14	.16	.11	.11	.08	.11	.12	.15	.14	.12	.10	.04
MgO	7.52	8.57	7.56	5.27	7.03	4.23	2.98	4.45	3.39	3.89	4.93	5.85	5.06	1.58
CaO	7.92	9.79	9.12	7.04	7.88	5.75	5.47	4.79	5.16	7.06	6.65	7.26	7.99	4.53
Na_2O	3.33	2.10	2.69	3.12	2.52	3.20	3.77	3.26	3.52	3.86	3.03	2.99	3.05	5.32
K_2O	.80	.65	.39	.32	1.26	1.83	1.33	1.66	1.29	1.17	.70	1.14	1.11	.55
P_2O_5	.12	.09	.06	.05	.10	.18	.19	.14	.21	.42	.20	.15	.08	.08
$H_2O(+)$	.64	1.34	1.12	.76	2.29	1.22	1.05	1.68	1.67	.71	1.14	1.76	1.83	1.32
$H_2O(-)$						.04								
S			.08		.02	.04	.03				.16			
Total	99.70	99.87	99.32	99.17	100.02	99.70	99.67	100.15	99.82	100.53	100.27	99.53	99.63	100.11
							C.I.P.W. norm							
Q	2.31	5.07	3.98	5.19	7.49	14.26	18.37	16.50	16.74	5.67	10.36	9.74	9.31	18.34
C	–	–	–	1.71	–	–	–	.58	.70	–	.86	–	–	2.16
or	4.73	3.84	2.30	1.89	7.45	10.81	7.86	9.81	7.62	6.91	4.14	6.74	6.56	3.25
ab	28.18	17.77	22.76	26.40	21.32	27.08	31.90	27.59	29.79	32.66	25.64	35.30	25.81	45.02
an	31.80	35.75	32.18	34.60	31.46	24.43	23.90	22.85	24.23	26.50	31.68	29.00	34.68	21.95
di wo	2.80	5.11	5.29	–	2.91	1.22	.83	–	–	2.41	–	2.52	1.85	–
di en	1.83	3.47	3.28	–	1.94	.71	.48	–	–	1.20	–	1.67	1.18	–
di fs	.77	1.25	1.70	–	.76	.45	.32	–	–	1.16	–	.67	.55	–
hy en	16.90	17.88	15.55	13.38	15.57	9.82	6.95	11.08	8.44	8.49	12.28	12.90	11.42	3.94
hy fs	7.15	6.43	8.06	11.14	6.07	6.18	4.66	6.74	6.67	8.21	10.41	5.18	5.27	2.21
ol fo	–	–	–	–	–	–	–	–	–	–	–	–	–	–
ol fa	–	–	–	–	–	–	–	–	–	–	–	–	–	–
mt	1.15	.81	1.20	1.32	1.36	1.28	1.16	1.59	1.68	1.51	1.26	2.13	1.15	.93
il	1.16	.95	1.67	2.68	1.14	1.73	1.73	1.41	1.78	4.12	1.88	1.58	.84	.82
ap	.28	.21	.14	.12	.23	.42	.44	.32	.49	.97	.46	.35	.19	.19
D.I.	35.17	26.68	29.04	33.48	36.26	52.15	58.12	54.48	54.15	45.23	40.13	41.78	41.67	66.61

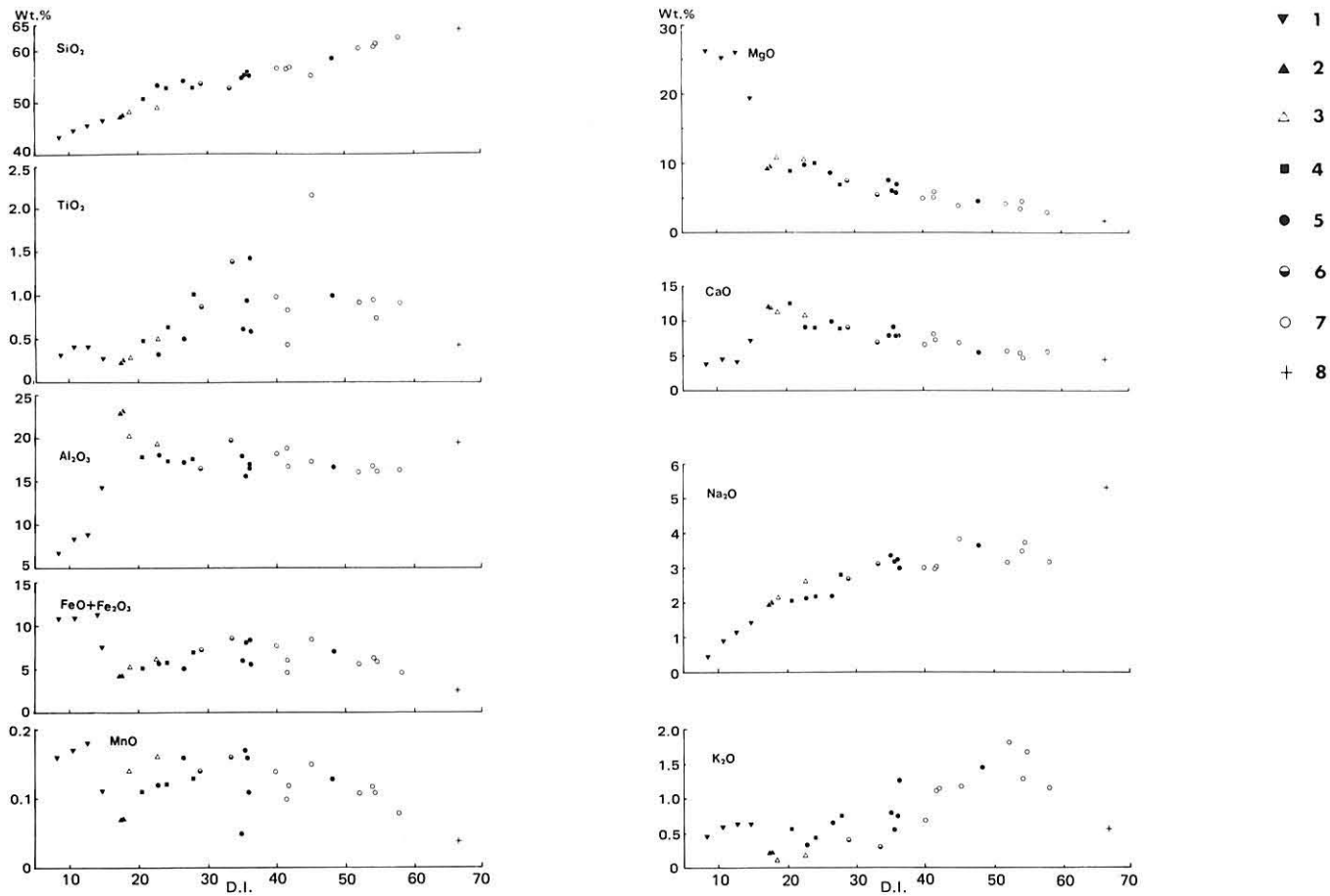
(analysed by T. Takahashi)

Table 3 Trace element contents of representative rocks from the Oshirabetsu gabbroic mass (ppm).

Sample No.	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
Ni	51	59	230	300	109	111	201	255	91	104	152	74	85	90	42	66	86	75	112	46
Co	84	88	81	94	48	49	56	58	47	41	49	33	51	42	43	45	44	50	54	42
Cu	27	20	72	104	58	53	113	73	28	24	27	35	29	53	15	22	22	24	50	22
Cr	357	294	173	301	335	379	414	352	329	1055	370	172	417	149	149	362	410	322	159	273
Ba	67	71	78	39	30	23	43	32	91	106	56	213	63	278	91	75	122	117	121	219
Rb	13	6	7	10	2	5	tr.	tr.	6	9	5	9	9	43	10	22	16	8	5	30
Sr	160	128	158	80	233	232	225	223	240	165	208	315	228	350	205	283	205	250	490	268

Sample No.	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
Ni	70	45	83	72	77	87	50	68	42	81	277	107	118	55	73	83	89
Co	38	33	37	37	43	46	40	38	26	49	73	50	53	32	34	37	31
Cu	32	16	30	62	30	44	17	20	4	114	162	67	101	131	78	54	50
Cr	141	65	149	127	103	173	232	227	22	79	260	109	137				
Ba	281	159	232	171	175	109	118	92	150	488	109	158	65	176	203	252	287
Rb	45	38	48	29	28	18	23	7	28	18	20	7	4	23	90	108	80
Sr	235	233	298	283	318	428	233	305	553	538	500	613	505	398	390	273	295

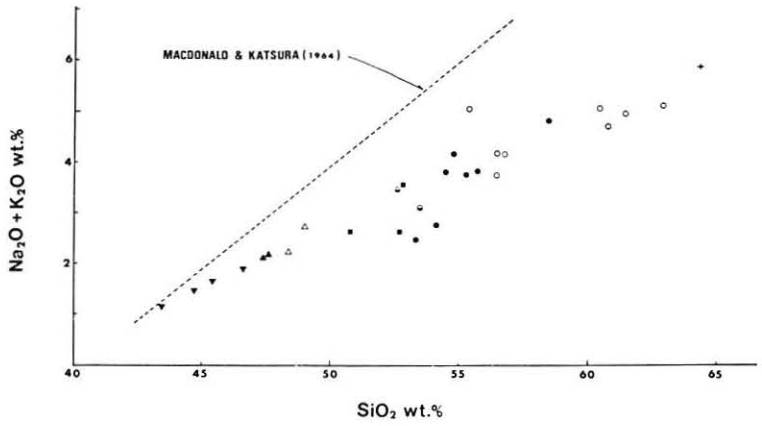
(analysed by T. Takahashi)



Text-fig. 4 D.I. – Oxides variation diagram for representative rocks from the Oshirabetsu gabbroic mass.
1: Olivine gabbro, 2: Coarse-grained troctolite, 3: Fine-grained troctolite, 4: Coarse-grained gabbro, 5: Norite, 6: Fine-grained norite, 7: Diorite, 8: Aplitic rock in diorite

characteristic generally recognized in the igneous complex produced through crystallization differentiation. As the differentiation proceeds, SiO_2 increases, whereas MgO and CaO decrease markedly. TiO_2, $FeO+Fe_2O_3$ and MnO reach the maximum values at about D.I. = 35, on the other hand, Na_2O and K_2O at about D.I. = 50. These trends are noticeable characteristics of the Oshirabetsu gabbroic mass.

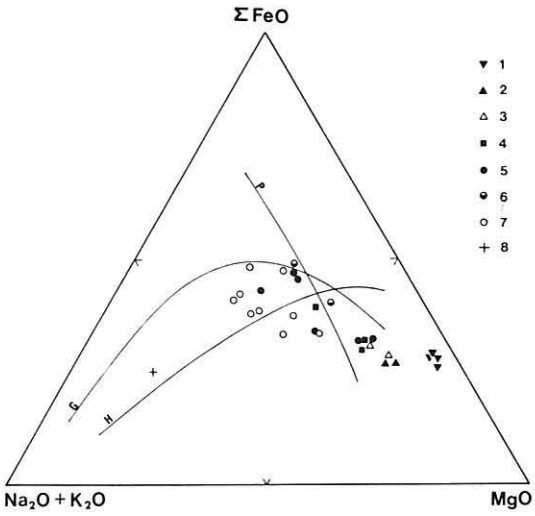
Plots of Na_2O+K_2O vs. SiO_2 is shown in Text-fig. 5. The broken line proposed by Macdonald and Katsura (1964) indicates the boundary between alkali and non-alkali rock types in Hawaii. All samples from the Oshirabetsu gabbroic mass are plotted in the non-alkali rock field as easily recognized from the figure.



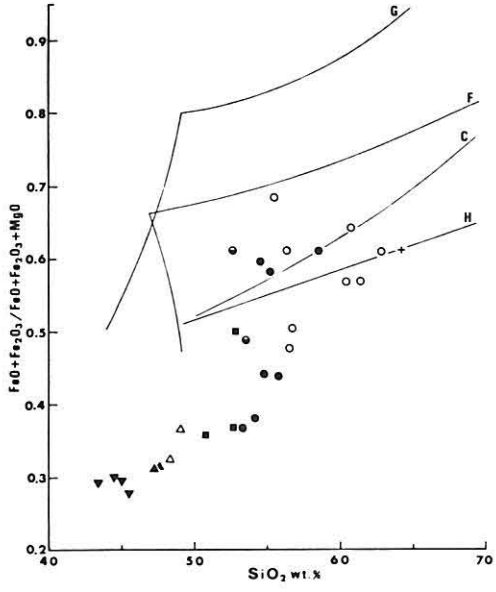
Text-fig. 5 Alkali – silica variations of the classified rock-types from the Oshirabetsu gabbroic mass.
Symbols are same as those in Text-fig. 4.

The differentiation trend of the Oshirabetsu gabbroic mass is also shown in AFM diagram (Text-fig. 6), which indicates a trend of the calc-alkali rock series. In the Main Zone of the Hidaka metamorphic belt, two different rock series, tholeiitic and calc-alkali rock series, have already been distinguished. The former is represented by the Pankenushi gabbroic intrusion (Maeda, 1978, 1981), and the latter is by the Horoman plutonic complex (Motoyoshi, 1980). Both the Oshirabetsu gabbroic mass and the Horoman plutonic complex are found in the southern part of the Main Zone of the Hidaka metamorphic belt. Though both of them belong to the calc-alkali rock series, the Oshirabetsu gabbroic mass shows a trend of slight iron enrichment in the early to middle stages of the magmatic differentiation compared with that of the Horoman plutonic complex. This tendency is more conspicuously represented in the diagram $FeO+Fe_2O_3/FeO+Fe_2O_3+MgO$ vs. SiO_2 (Text-fig. 7).

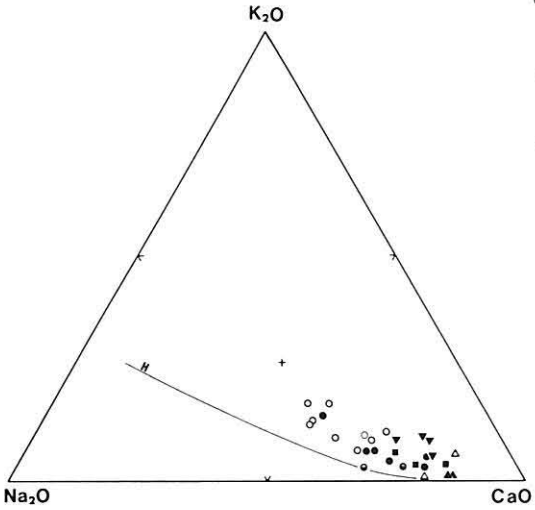
The trend of the Oshirabetsu gabbroic mass in K_2O-Na_2O-CaO diagram is shown in Text-fig. 8, together with that of the Horoman plutonic complex. In comparison with the Horoman plutonic complex, K_2O content is relatively enriched in the Oshirabetsu gabbroic mass.



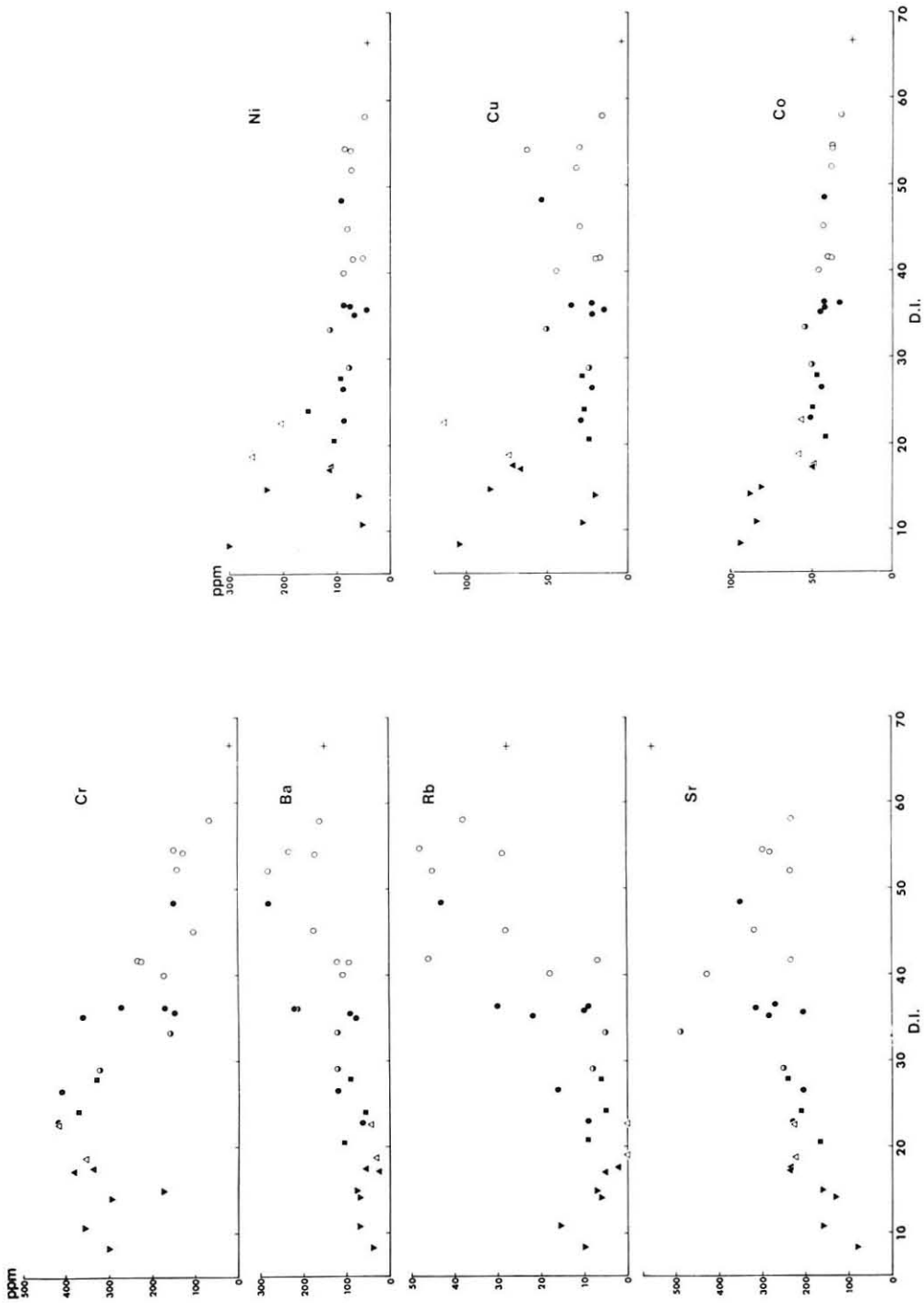
Text-fig. 6 AFM diagram for the Oshirabetsu gabbroic rocks.
Symbols are same as those in Text-fig. 4.
P: Pankenushi gabbroic intrusion (Maeda, 1981) H: Horoman plutonic complex (Motoyoshi, 1980) G: Guadalupe igneous complex (Best, 1963)



Text-fig. 7 $(FeO + Fe_2O_3)/(MgO + FeO + Fe_2O_3) - SiO_2$ diagram showing the variation of the Oshirabetsu gabbroic mass.
Symbols are same as those in Text-fig. 4.
G: Galapagos Islands (McBirney and Williams, 1969) F: Viti Levu, Fiji (Gill, 1970) C: Cascade (Turner and Verhoogen, 1960) H: Horoman (Motoyoshi, 1980)



Text-fig. 8 $K_2O - Na_2O - CaO$ diagram showing the variation of the Oshirabetsu gabbroic mass.
Symbols are same as those in Text-fig. 4.



Text-fig. 9 D.I. – trace elements variation of the representative rocks from the Oshirabetsu gabbroic mass. Symbols are same as those in Text-fig. 4.

Trace element chemistry

The behavior of trace elements, Ni, Co, Cu, Cr, Ba, Rb and Sr of the Oshirabetsu gabbroic mass, indicates the igneous trend as well as that of major elements on the whole.

The relationship between D.I. and content of each element is shown in Text-fig. 9. As the magmatic differentiation proceedes, the content of Cr, Ni and Co decreases markedly. Cr, Ni and Co are incorporated mainly in ferromagnesian minerals because ionic radii of these elements are similar to that of Fe or Mg. Decreasing in the content of Cr, Ni and Co is generally in good accordance with the mineral composition and modal variation of the gabbroic rocks. Rb and Ba are also included in potassium minerals, mainly biotite and K-feldspar, therefore the content of Rb and Ba is provably influenced by the modal variation of potassium minerals. Maximum concentration of Sr is seen at about D.I. = 40. Sr in igneous rocks is mostly contained in plagioclase (Mason, 1966; and others), moreover Banno and Yamazaki (1979) reported that plagioclase of intermediate An-content shows the highest concentration of Sr during crystallization differentiation. Behavior of Sr in the Oshirabetsu gabbroic mass is also seemed to be in good accordance with this fact.

Though Cu tends to be concentrated in residual liquid through magmatic differentiation, the content of Ni and Cu, which indicates a high preferential concentration to sulfide minerals (MacLean and Shimazaki, 1976; Rajamani and Naldrett, 1978; Mysen and Popp, 1980), seems to be relatively high in the diorite facies in spite of the deposition of nickel-bearing iron sulfide liquid in the norite facies. It is known that in the mineralized area the influence of mineralization has generally been remained strongly after ore deposition. Taking this effect into consideration, enrichment of Ni and Cu in diorite and in neighbouring hornfels and migmatite, the wall rock of the gabbroic mass, seems to be reasonable.

For the present, primary magma and condition of crystallization of the Oshirabetsu gabbroic mass have not been considered in detail, however judging from the results of petrochemical examination, the Oshirabetsu gabbroic mass is appeared to have formed through crystallization differentiation of basaltic magma indicating a trend of calc-alkali rock series with slight iron enrichment in the early to middle stages of the differentiation.

Nickel-bearing Iron Sulfide Deposits Accompanied by Graphite

Nickel-bearing iron sulfide ores are found in the Oshirabetsu gabbroic mass showing various grade of concerntration, but the ore deposits occur resrictedly in olivine gabbro and norite. The ore deposits have vaguely regarded to be the magmatic deposit because which are closely associated with the host gabbroic rocks. The deposits are often accompanied by graphite.

The nickel-bearing iron sulfide ores can be classified into following four types; 1) spotted, 2) net-worked, 3) semi-massive, and 4) massive. Bamba (1981) showed the physical and chemical properties of sulfide minerals from the Oshirabetsu gabbroic mass, and he considered the sulfide ores to have formed at orthomagmatic to pneumatolytic-hydrothermal stages.

Spotted ore is the most dominant among the above-stated four types. Whereas massive and semi-massive ores are structurally controlled and occur as vein or fissure-filling form, so the massive ore accordingly seems to be the latest product throughout the mineralization. In

this report, only the genesis of the spotted ore is examined.

Nickel-bearing iron sulfide deposits

Mineralization of nickel-bearing iron sulfide is confined to the olivine gabbro and norite, however a small scale-mineralization is observed in the olivine gabbro and a rather large-scale one is in the norite. The ore deposit in norite consists mainly of spotted ore, but contains some massive and semi-massive ores. Massive and semi-massive ores can not be found in the olivine gabbro. The deposit is one of the essential constituent units of the Oshirabetsu gabbroic mass, and which may be regarded as a facies of norite with abundant nickel-bearing iron sulfide.

Spotted ore in olivine gabbro tends to show an irregular interstitial form against silicate minerals, while typical spotted ore having rounded-shape as a whole occurs in norite. From these facts, it seems that nickel-bearing iron sulfide melt has been separated from the silicate melt. It is said to be orthomagmatic nickel copper sulfide deposits, e.g. for the Sudbury deposit in Canada, sulfide melt has been separated from silicate melt as an immiscible sulfide melt (Shimazaki, 1979). Taking the characteristic behavior of nickel in magmatic process into consideration, nickel-bearing sulfide melt might have been separated from silicate melt in the very early stage of magmatic process. Such an immiscible sulfide melt is also expected at the nickel concentration in the Oshirabetsu gabbroic mass.

Main constituent mineral of the Oshirabetsu sulfide ore is pyrrhotite. A small amount of pentlandite and chalcopyrite always accompanies pyrrhotite, and these are not found independently. Pentlandite is more abundant in spotted ore than in massive ore. Especially in olivine gabbro, pentlandite as well as pyrrhotite is one of the major constituent minerals of sulfide ore.

Naldrett (1969) referred about the ore from Sudbury that the interstitial ore occurs in rocks containing primary pyroxene (now uralitized), whereas the buck-shot ore (so-called spotted ore) invariably occurs in rocks containing primary amphibole. He considered that the differences between the interstitial ore and the buck-shot ore might be caused by the difference in P_{H_2O} during the crystallization. In comparison with the interstitial ore, the buck-shot ore was probably formed under a wet environment.

Spotted ore in norite from the Oshirabetsu gabbroic mass has features of both interstitial and buck-shot ores from Sudbury. Actually in the spotted ore from this mass, sulfide minerals increase with increasing of hydrous minerals, amphbole and biotite, and pyroxenes are partly or nearly replaced by amphibole.

The Hidaka orogeny has been regarded to have evolved from the end of Mesozoic to Tertiary, and the Oshirabetsu gabbroic mass is considered to be the product of the basic igneous activity of the late stage of the orogeny (Hashimoto, 1975). From the viewpoint of geologic time, therefore, the nickel-bearing iron sulfide deposit embedded in the Oshirabetsu gabbroic mass is young compared with other orthomagmatic nickel sulfide deposits in the world.

Graphite Deposits associated with Nickel-bearing Iron Sulfide Deposits

Graphite occurs often associated with sulfide. There are four types of graphite ore as

follows: 1) disseminated, 2) pisolitic, 3) massive, and 4) vein-form. The last two were unequivocally formed under structural control, and occur along the fault and in the sheared zone. While, the first two are found closely associated with nickel bearing iron sulfides.

The mechanism of carbon concentration as well as the origin of carbon is still in question, however there should be certain genetic relation between sulfide and graphite. The role of graphite in the earth's crust was considered by Miyashiro (1964) and Yui (1966). Ishihara (1977) referred that oxygen fugacity which seems to be regulated by the carbon-bearing crustal materials plays a significant role during generation and solidification of granitic magma. Furthermore, Sasaki and Ishihara (1979) indicated based on the evidence of sulfur isotopic composition that there might be an interaction between the crustal materials and gabbroic rocks as well as granitic rocks.

It is interesting to consider the origin of a large quantity of carbon forming graphite deposits, and the role of carbon which plays during solidification of the gabbroic magma and the deposition of sulfide in the Oshirabetsu gabbroic mass.

Conclusion

(1) The Oshirabetsu gabbroic mass is composed mainly of olivine gabbro, troctolite, coarse-grained gabbro, norite and diorire, and which appears to have formed through crysrallization differentiation of basaltic magma indicating a trend of calc-alkali rock series. It shows slight iron enrichment in the early to middle stages of the differentiation.

(2) Nickel-bearing iron sulfide deposits embedded in the Oshirabetsu gabbroic mass have probably formed through the magmatic differentiation of host gabbroic magma.

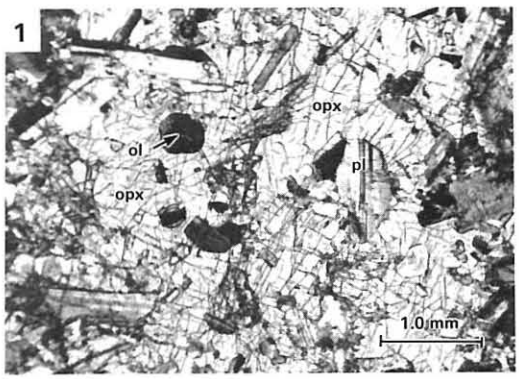
Acknowledgements

I whish to express my thanks to Prof. T. Bamba, Hokkaido University, for drawing my attention to this problem and his constant encouragements, and to Drs. J. Watanabe, C.W. Kim and T. Tsuchiya for their daily discussion on this problem. I would especially like to thank Prof. Y. Katsui, Hokkaido University, for his helpful criticism of this manuscript.

Explanation of Plate (I)

Photomicrographs of thin sections of the representative rock-types from the Oshirabetsu gabbroic mass.

1) Olivine gabbro
   ol: olivine, opx: orthopyroxene, pl: plagioclase (crossed nicols)
2) Fine-grained troctolite
   ol: olivine, pl: plagioclase, opx: orthopyroxene (crossed nicols)
3) Coarse-grained gabbro
   cpx: clinopyroxene, pl: plagioclase, hrb: hornblende (crossed nicols)
4) Norite
   opx: orthopyroxene, pl: plagioclase (crossed nicols)
5) Norite
   opx: orthopyroxene, pl: plagioclase (crossed nicols)
6) Norite (including spotted sulfide)
   pl: plagioclase, opx: orthopyroxene (now uralitized), bi: biotite, po: pyrrhotite (crossed nicols)
7) Hornblende diorite
   hrb: hornblende, pl: plagioclase, bi: biotite (crossed nicols)
8) Quartz diorite
   hrb: hornblende, pl: plagioclase, bi: biotite, qtz: quartz (crossed nicols)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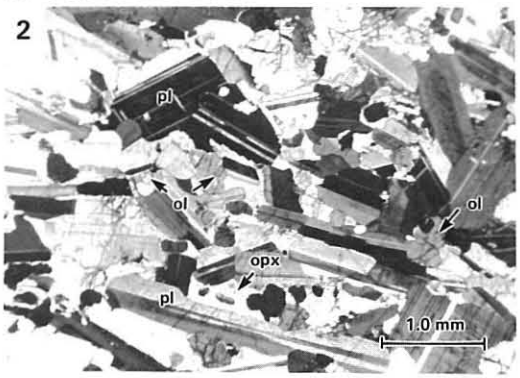
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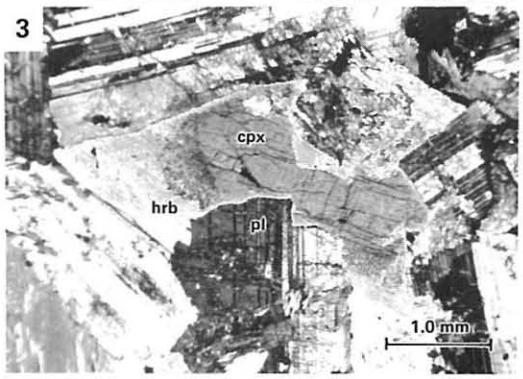
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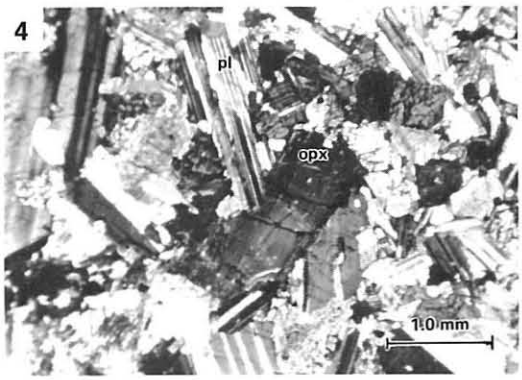
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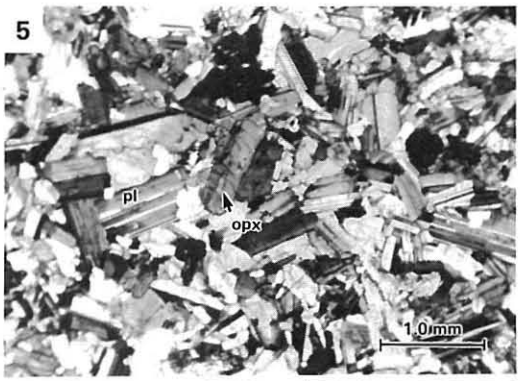
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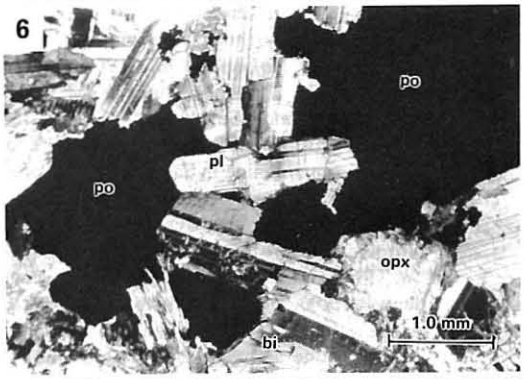
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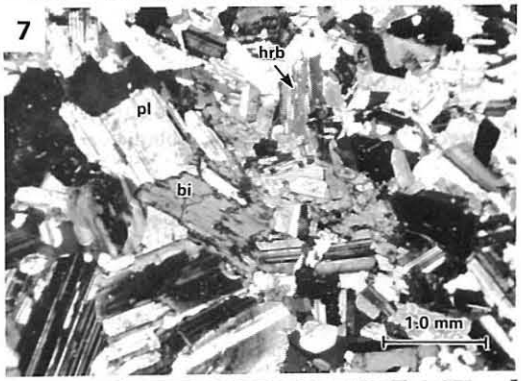
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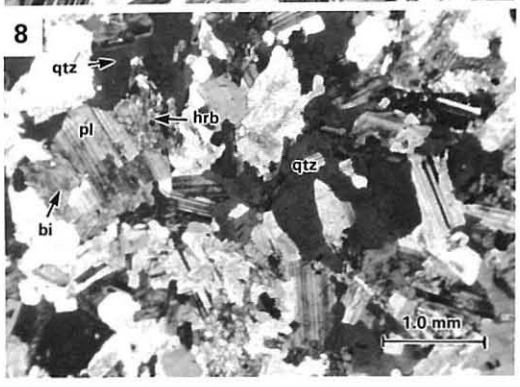
8
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Grateful acknowledgements are due to Dr. A. Sasaki, Geological Survey of Japan, for his kind guidance in determination of sulfur content, and to Dr. S. Ishihara, G.S.J., for his stimulating advice.

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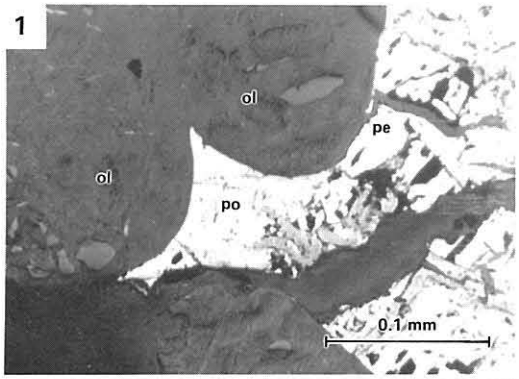
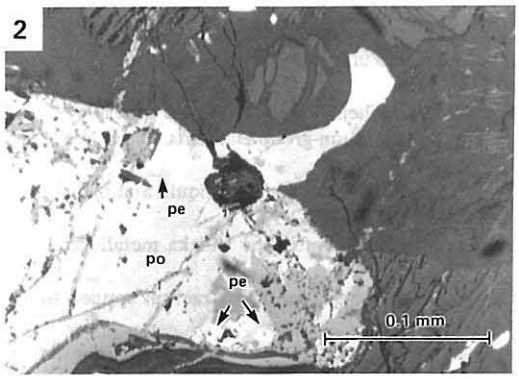
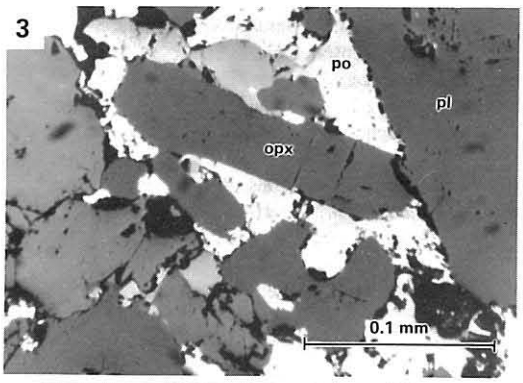
Explanation of Plate (2)

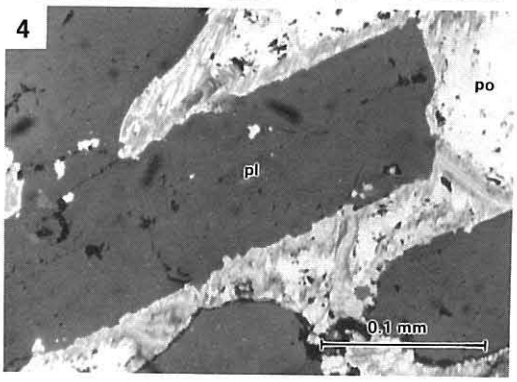
Photomicrographs of polished sections of ores from the Oshirabetsu gabbroic mass.

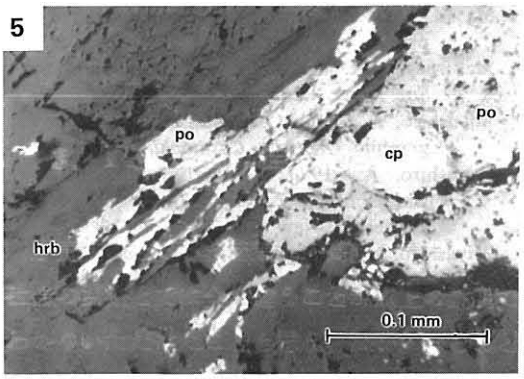
1) Ni-bearing iron sulfide ore taking interstitial form in olivine gabbro.
   po: pyrrhotite, pe: pentlandite, ol: olivine (almost replaced by serpentine) (crossed nicols)
2) Ditto
   po: pyrrhotite, pe: pentlandite (crossed nicols)
3) Ni-bearing iron sulfide ore in norite.
   po: pyrrhotite, pl: plagioclase, opx: orthopyroxene (crossed nicols)
4) Ditto
   po: pyrrhotite, pl: plagioclase (crossed nicols)
5) Ditto
   po: pyrrhotite, cp: chalcopyrite, hrb: hornblende (crossed nicols)
6) Pyrrhotite associated with graphite in norite.
   po: pyrrhotite, gph: graphite (crossed nicols)
7) Pisolitic graphite ore
   gph: graphite, po: pyrrhotite, qtz: quartz (crossed nicols)
8) Ditto
   gph: graphite, qtz: quartz (crossed nicols)

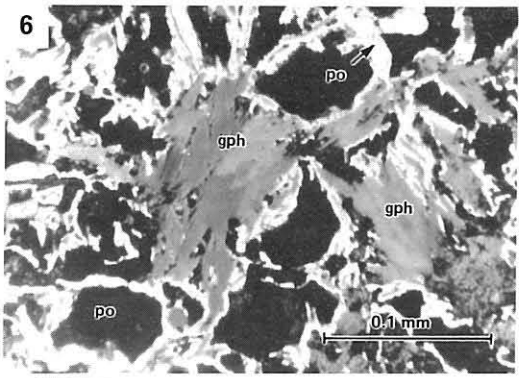

1
ol
pe
ol
po
0.1 mm

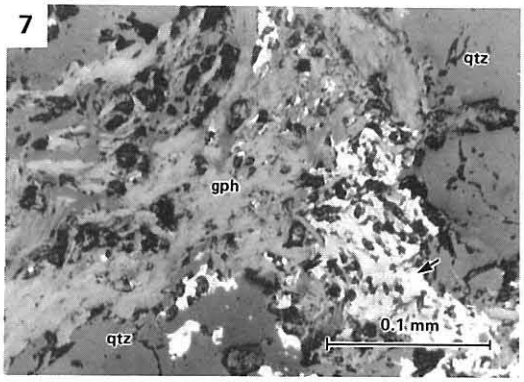

2
pe
po
pe
0.1 mm

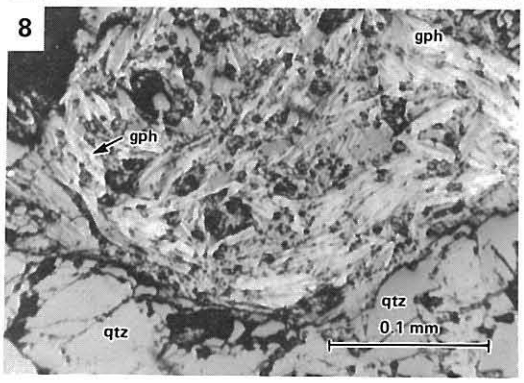

3
po
pl
opx
0.1 mm


4
po
pl
0.1 mm


5
po
po
cp
hrb
0.1 mm


6
po
gph
gph
po
0.1 mm


7
qtz
gph
qtz
0.1 mm


8
gph
gph
qtz
qtz
0.1 mm

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