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BASALTS AND DOLERITES IN THE SORACHI-YEZO BELT, CENTRAL HOKKAIDO, JAPAN

by

Kiyoaki Niida

(with 9 text-figures and 4 tables)

Abstract

Basalts and dolerites from the late Jurassic to early Cretaceous Sorachi Group and the Cretaceous melange complex in the central axial zone of Hokkaido are classified into the following three types: high K_2O type alkaline basalts, characterized by high abundance in K_2O, TiO_2, P_2O_5 and normative nepheline, low K_2O type alkaline basalts with high Na_2O/K_2O ratio and normative nepheline, and MORB type tholeiites, poor in K_2O, TiO_2, P_2O_5.

The basaltic pillow lavas, dolerite dykes and sheets, observed as autochthonous members of the Upper Sorachi Group, correspond to the low K_2O type alkaline basalts. The basaltic pillow lavas in the Lower Sorachi Group are of the MORB type tholeiites. Exotic blocks of basalt and dolerite in the Cretaceous accretionary melange complexes involve both the high K_2O type alkaline basalts and the MORB type tholeiites.

Introduction

A considerable amount of basaltic rock is closely associated with the late Jurassic to early Cretaceous Sorachi Group and the Cretaceous melange complexes in the central axial zone of Hokkaido. It is well known that the basaltic rocks have a wide range in chemical composition from alkaline to subalkaline, suggesting a variation in their origin (Suzuki, 1963, 1977; Bamba, 1974; Kosaka, 1975; Nakano and Komatsu, 1979; Ishizuka, 1984; Kiminami et al., 1985b; Niida and Kito, 1986; Miyashita and Katsushima, 1986; Watanabe and Niida, 1987).

Recently, tectonic evolution models, focused on the Cretaceous to Paleogene arc-trench system along the Eurasian plate, have been discussed by many authors (Okada, 1974, 1980, 1982; Dickinson, 1978; Parfenov et al., 1978; Komatsu et al., 1981, 1983; Kiminami and Kontani, 1983: Takahashi, 1983; Kimura, 1985; Kiminami et al., 1985a; Kimura and Tamaki, 1986; Maruyama and Seno, 1986; Jolivet, 1986; Niida and Kito, 1986; Kimianmi et al., 1986a, 1989). In most cases, the mode of occurrence and the chemical nature of the basaltic rocks have been taken into account in their discussions, providing an important indicator constraining the tectonic setting of the individual geological components. The geological and petrological data of the basaltic rocks, however, is still inadequate to confidently propose their origin.

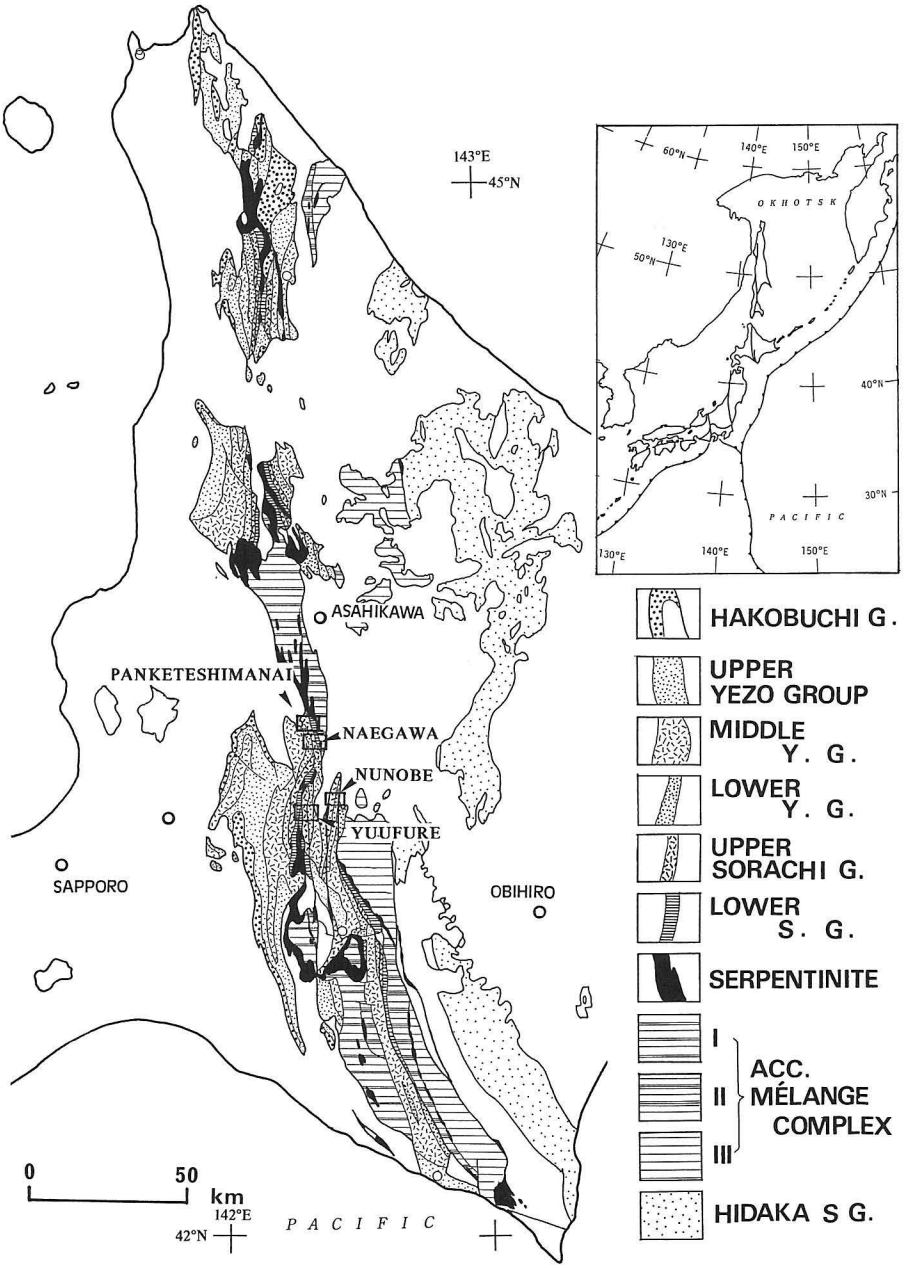
Contribution from the Department of Geology and Mineralogy, Faculty of Science, Hokkaido University, No. 2073.

Therefore, this paper will describe the field relationships and chemical composition of basaltic rocks of the Sorachi Group from the type localities (Panketeshimanai, Naegawa, Nunobe and Yuufure) near Furano, central Hokkaido. The data on bulk rock chemistry already reported from the central axial zone of Hokkaido will be re-examined and summarized into the three different basalt types.

Geological setting

Late Mesozoic geology of Hokkaido (Text-fig. 1) is characterized by a zonal arrangement of the following terrains, all of which represent an arc-trench system formed by the early Cretaceous to Paleogene westward subduction of the Izanagi-Kula plate beneath the Eurasian plate (Kiminami et al., 1986a; Niida and Kito, 1986). In the Rebun-Kabato Belt, along the western boarder of central Hokkaido, remnants of an early Cretaceous volcanic arc are observed as volcaniclastic strata (Kumaneshiri Group: Nagata et al., 1986; Rebun Group: Ikeda and Komatsu, 1986). In the Sorachi-Yezo Belt, the Jurassic ophiolite and the early Cretaceous sedimentary cover (Sorachi Group: Kito et al., 1986) are overlain by the early to late Cretaceous terrigeneous clastic rocks (Yezo Supergroup: Okada, 1983). This stratigraphic sequence suggests a change in paleogeologic environment from a Jurassic oceanic basin to a Cretaceous fore-arc basin. A huge amount of massive serpentinite and serpentinite melange are exposed along the Sorachi-Yezo Belt, in close association with the Cretaceous high-P type metamorphic rocks and accretionary melange complexes (Niida and Kito, 1986; Niida, 1987). The Hidaka Belt is constructed of the Cretaceous to Paleogene Hidaka Supergroup (Kiminami et al., 1986b, 1990).

Basaltic pillow lavas, dolerite dykes and sheets are observed both as stratified volcanic units in the Sorachi Group and as exotic blocks in the melange complexes. The lower part of the Sorachi Group (Lower Sorachi Group), which consists of basaltic pillow lavas and late Jurassic chert, is conformably overlain by the upper part of the Sorachi Group (Upper Sorachi Group), which is composed of early Cretaceous volcaniclastic mudstone, pillow lava, acidic tuff, and siliceous shale (Kito et al., 1986; Kito, 1987; Girard et al., 1991). Niida and Kito (1986) and Kito (1987) mentioned that the lower part of the Sorachi Group can be recognized as an upper member of ophiolite derived from the Jurassic oceanic lithosphere (Horokanai ophiolite: Ishizuka, 1980, 1981). The Naegawa dolerite sheet and autochthonous basaltic pillow lava are interlayered within the upper part of the Sorachi Group in the Naegawa River and the Panketeshimanai areas near Furano (Niida et al., 1984). The early Cretaceous accretionary melange complexes I and II (Niida and Kito, 1986) contain a large number of Jurassic exotic blocks such as alkaline basalt pillow lava, chert, limestone and sandstone within the early Cretaceous matrix. The accretionary complex III (Niida and Kito, 1986), which is exposed in the western zone of the Hidaka Belt, contains Permian, Triassic and Jurassic exotic blocks within the middle to late Cretaceous matrix (Igo et al.,

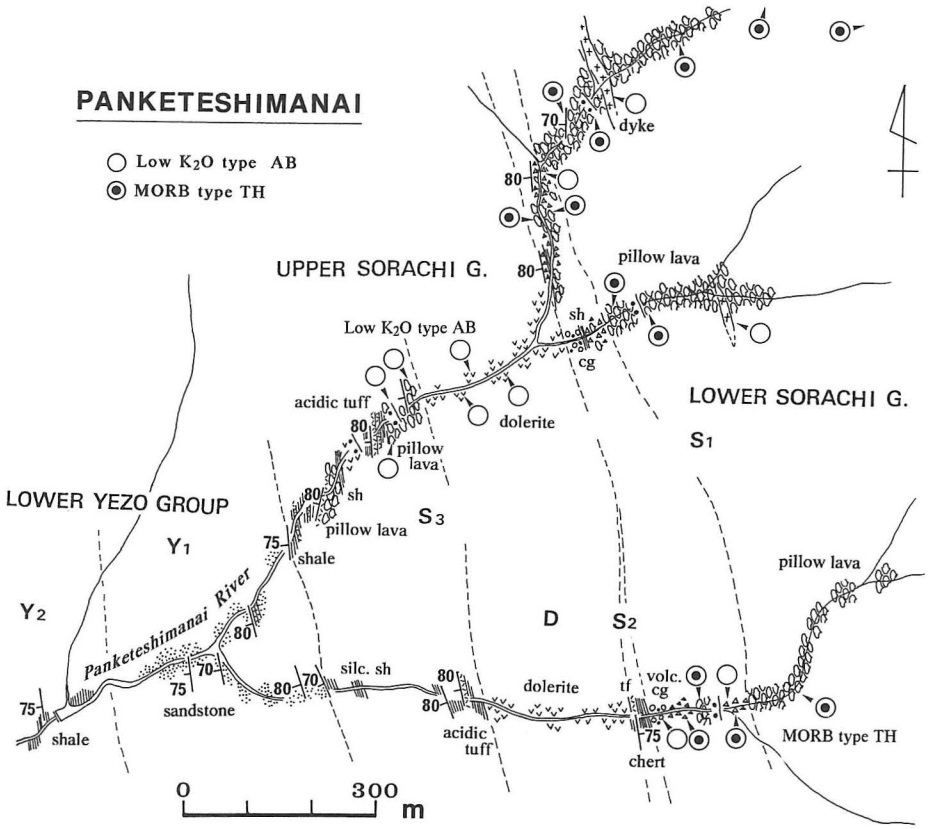


Text-fig. 1 Late Mesozoic geology of the central axial zone of Hokkaido. Boxes are typical localities of the Sorachi Group: Panketeshimanai, Naegawa, Yuufure and Nunobe.

1980 ; Kato et al., 1986 ; Kiminami et al., 1986b ; Kiyokawa, 1989).

Geology of the Panketeshimanai area

The stratigraphic relationship between the upper member of the Jurassic oceanic crust (Lower Sorachi Group) and the early Cretaceous sedimentary cover, including autochthonous basaltic pillow lavas and dolerite sheets (Upper Sorachi Group), can be well observed in the Panketeshimanai area (Text-fig. 2). A conformable field relationship between the remnants of oceanic crust (Sorachi Group) and the early Cretaceous forearc basin sediments (Lower Yezo Group) are also observable.



Text-fig. 2 Stratigraphic relationship between the upper member of the Jurassic oceanic crust (Lower Sorachi Group) and the Early Cretaceous sedimentary cover including autochthonous basaltic pillow lavas and dolerite sheet (Upper Sorachi Group). Early Cretaceous forearc basin sediments (Lower Yezo Group) conformably overlie the Sorachi Group. Sample localities: low K_2O type alkaline basalt (open circles), MORB type tholeiite (open circles with dot). Stratigraphic units S1, S2, S3, Y1 and Y2, after Kito (1987). D: northern extension of the Naegawa dolerite.

The Lower Sorachi Group, which is composed mostly of basaltic pillow lava, is continuously exposed along the uppermost stream of the Panketeshimanai River. The primary structure of the pillow lava is well preserved and steeply dips westward. The piles of pillow lava exceed 500 m in thickness and are covered by volcanic breccia and volcaniclastic conglomerate. Alternating beds of green chert and acidic tuff rest confomably upon the above volcanic succession. This alternating bed is traceable toward the southern area around the Naegawa River as a key bed (stratigraphic unit S2: Kito, 1987). Radiolarian fossils, indicating a Tithonian to Berriasian age, have been obtained from the green cherts (Kito, 1987). The Upper Sorachi Group is composed mostly of basaltic pillow lavas, volcanic rocks, and abyssal sedimentary rocks such as chert, siliceous shale and acidic tuff. A dolerite sheet crops out between the green cherts of unit S2 and the abyssal sedimentary rocks of unit S3, showing a concordant relationship with the country rocks. The pillow lavas also show an autochthonous relationship with the surrounding sedimentary rocks. At some exposures, volcaniclastic siltstones and pelagic claystones are rolled up and incorporated with individual pillow lobes.

The boundary between the Upper Sorachi Group and the Lower Yezo Group is sharp. The conformable contact is observed at an outcrop along the Panketeshimanai River, in which the basal sandstone of the Lower Yezo Group covers siliceous shale of the Upper Sorachi Group.

Naegawa dolerite sheet

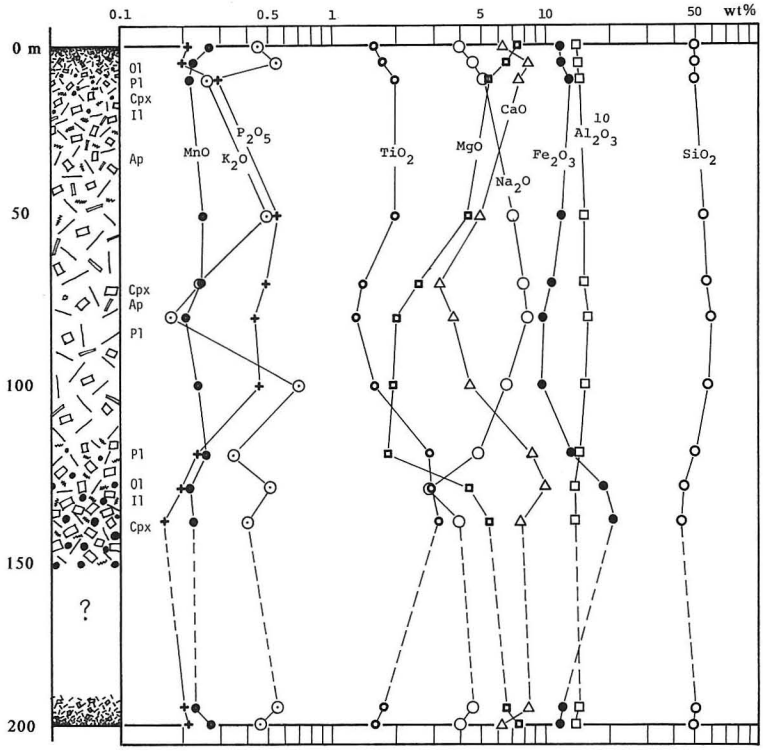
Occurrence and Petrography

The Naegawa dolerite sheet, approximately 200 m thick, crops out along the Naegawa River. The sheet can be traced for more than 8 km from the Panketeshimanai area southward within the upper part of the Sorachi Group. Both the top and bottom surfaces of the sheet are consistent with the bedding planes of stratigraphic units S2 and S3 (Kito, 1987), showing an intrusive contact relation.

Text-fig. 3 shows the lithological variation in a veritical section of the Naegawa dolerite sheet. Aphyric basalt from the chilled margin contains devitrified glass carrying a large number of variolites. Dolerite near the margin shows an ophitic texture consisting of olivine, clinopyroxene, plagioclase with small amounts of titanomagnetite and apatite. The most evolved part is located at about 70 to 100 m below from the upper border of the sheet. The evolved dolerite carries coarse grains of euhedral plagioclase and subhedral to anhedral clinopyroxene and minor amphibole and apatite. Cumulus clinopyroxene, olivine and ilmenite are found in the cumulative dolerite about 140 m below the upper border.

Bulk Rock Chemistry

Chemical compositions of the representative rocks from the Naegawa dolerite were determined by XRF analyzer (Toshiba AVF-777) for SiO_2, TiO_2, Al_2O_3, Fe_2O_3, CaO, K_2O and P_2O_5, and atomicabsorption spectrometer (Hitachi 170-30) for



Text-fig. 3 Lithological and chemical variations in vertical section of the Naegawa dolerite sheet. From the top downward, 0−5 m: chilled margin basalt, 70−100 m: most evolved dolerite, 140±10 m: cumulative dolerite, 150−190 m: no exposure, and 190−200 m: chilled margin.

MgO, MnO and Na_2O. Total H_2O was analyzed using the Penfield tube method. Zr abundance was obtained by the ICP analysis at TSL (Technical Service Laboratory). Table 1 lists the chemical analyses of dolerites from various levels of the sheet.

Major element variation in a vertical section of the Naegawa dolerite sheet is shown in Text-fig. 3. SiO_2, Al_2O_3, Na_2O, and P_2O_5 contents gradually increase toward the evolved dolerite from the quenched basalt of the upper chilled margin. The TiO_2, Fe_2O_3* (total iron as Fe_2O_3*), MnO, MgO, and CaO decrease in the evolved part, and increase in the clinopyroxene-olivine-ilmenite cumulus dolerites. The variation indicates that fractional evolution and accumulation took place in a single dolerite sheet.

All the analyses are plotted in the alkaline field of the alkali-silica diagram (Text-fig. 4), close to the alkaline-subalkaline boundary defined by Macdonald and Katsura (1964) and Kuno (1966). As shown in Text-fig. 5, K_2O contents of the Naegawa dolerite are remarkably low (0.3-0.7 wt. %). The fractionation trend is characterized by high Na_2O/K_2O ratios, which attain about 14 in the evolved doler-

Table 1 Chemical composition of dolerites from various levels of the Naegawa dolerite sheet.

	1	2	3	4	5	6	7	8	9	10	11
SiO_2	50.16	49.84	49.22	54.46	57.45	58.17	57.56	49.54	44.09	42.90	60.49
TiO_2	1.55	1.71	1.90	1.90	1.39	1.26	1.54	2.82	2.91	3.10	0.97
Al_2O_3	13.90	14.36	14.15	15.15	15.20	15.62	15.30	14.11	13.51	13.84	15.59
Fe_2O_3*	11.06	11.87	13.14	11.85	10.73	9.51	9.56	13.73	18.28	20.26	7.45
MnO	0.26	0.22	0.21	0.24	0.24	0.20	0.23	0.25	0.21	0.22	0.13
MgO	7.45	6.62	5.36	2.57	1.99	1.48	1.82	4.39	5.41	4.94	2.55
CaO	6.24	8.27	7.21	4.89	3.22	3.64	4.39	8.62	9.95	7.73	2.84
Na_2O	3.98	4.46	5.07	6.87	7.79	8.05	6.54	4.84	2.80	3.94	5.99
K_2O	0.45	0.54	0.25	0.48	0.24	0.17	0.69	0.34	0.50	0.39	1.87
P_2O_5	0.21	0.20	0.28	0.54	0.48	0.43	0.45	0.23	0.19	0.16	0.26
$H_2O\pm$	4.56	3.54	3.25	2.19	1.83	1.71	2.07	2.64	4.19	4.00	2.22
Total	99.82	101.63	100.04	101.14	100.56	100.24	100.15	101.51	102.04	101.48	100.36

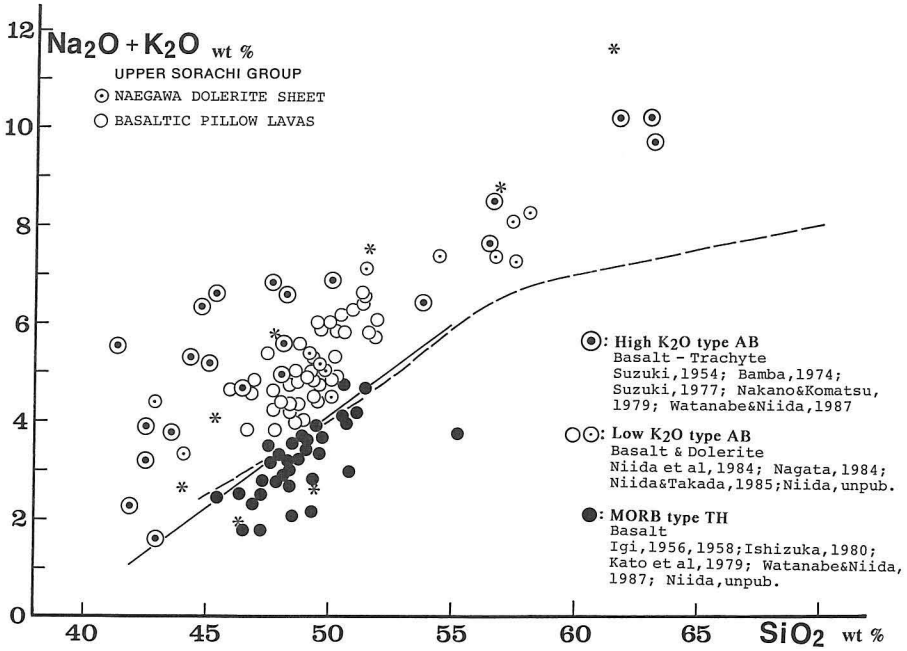
Fe_2O_3* : total iron as Fe_2O_3*

$H_2O\pm$: total H_2O in wt% analyzed by pen-field tube method

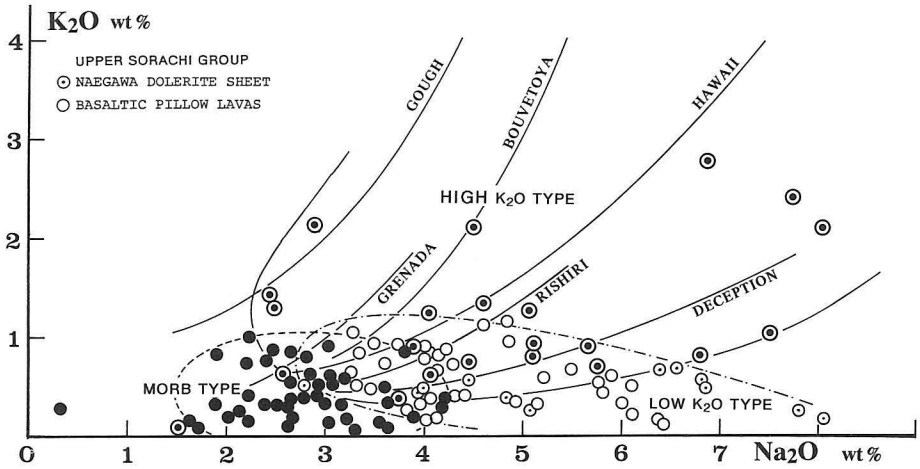
1 : aphyric basalt from the chilled margin of the Naegawa dolerite sheet. Sample No. 831127-3C.
2 : fine-grained dolerite 5 m below from the upper border of the sheet. No. 831127-2.
3 : dolerite 10 m below from the upper border of the sheet. No. 831127-1.
4 : dolerite 50 m below from the upper border of the sheet. No. 831127-4.
5 : evolved dolerite 70 m below from the upper border of the sheet. No. 831127-5.
6 : evolved dolerite 80 m below from the upper border of the sheet. No. 831127-6.
7 : evolved dolerite 100 m blow from the upper border of the sheet. No. 831127-9.
8 : cumulative dolerite 120 m below from the upper border of the sheet. No. 831127-11.
9 : cumulative dolerite 130 m below from the upper border of the sheet. No. 831127-12.
10 : cumulative dolerite 140 m below from the upper border of the sheet. No. 831127-13.
11 : fine-grained dolerite 10 m above from the bottom of the sheet. No. 831127-17.

ite. Such a low K_2O and high Na_2O/K_2O magmatism has been known in a limited volcanic region in the world; Deception island, South Shetland (Gonzaletz-Ferran and Katsui, 1970; Weaver et al., 1979), Grenada and St. Kitts islands, Lesser Antilles (Arculus, 1976; Brown et al., 1977), and Rishiri island, Hokkaido (Katsui et al., 1978). However, such an occurrence has never been reported from island arcs with continental crust, mid-oceanic ridges, or within plate ocean island and seamounts.

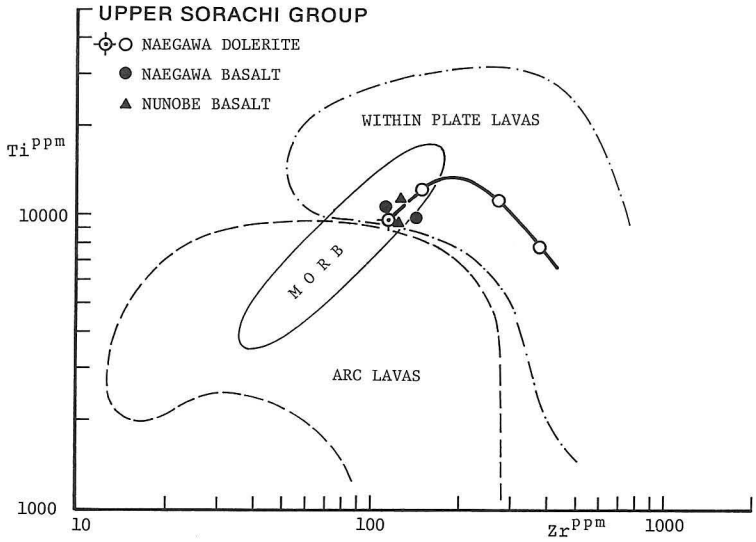
TiO_2 content of the chilled margin dolerite is more than 1.0 wt %, but not so high in comparison with that in the other tectonic settings as clearly shown in the Ti vs. Zr plot (Text-fig. 6). The analysis is within the compositional area of MORB (mid-oceanic ridge basalt), close to the field boundary between arc lavas and within plate lavas defined by Pearce (1982). The evolved dolerites extend into the field of within plate lavas.



Text-fig. 4 Alkali-silica relations for the Naegawa dolerite (open circles with small dot) and basaltic pillow lavas (open circles) in the Upper Sorachi Group. Reference analyses: high K_2O type alkaline basalt to trachyte blocks (open circles with solid dot) from the Cretaceous accretionary melange and MORB type tholeiite (solid circles) from the Lower Sorachi Group. The alkaline-subalkaline field boundaries: solid line (Macdonald and Katsura, 1964), broken line (Kuno, 1966). Stars: representative analyses of Hawaii lavas (Macdonald, 1968).



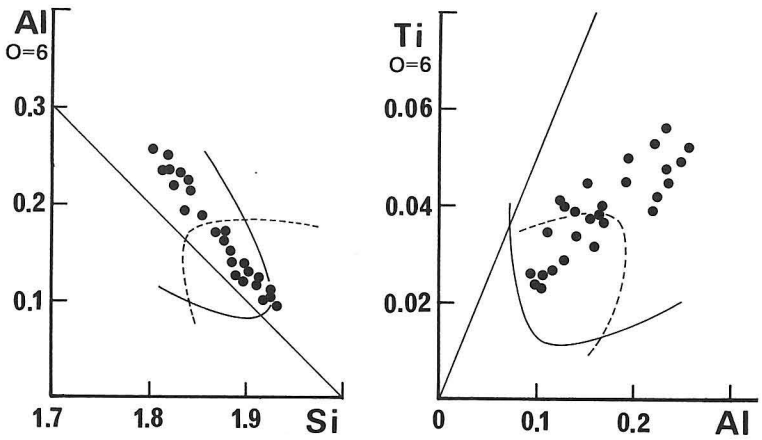
Text-fig. 5 K_2O-Na_2O relations for the Naegawa dolerite (open circles with small dot) and basaltic pillow lavas (open circles) in the Upper Sorachi Group. Reference analyses are same as in Texi-fig. 4, Compositional variation trends: Deception island (Weaver *et al.*, 1979), Grenada (Arculus, 1976), Rishiri (Katsui *et al.*, 1978), Gouph (Le Mitre, 1962), Bouvetoya (Imsland *et al.*, 1977), and Hawaii (Macdonald, 1968).



Text-fig. 6 Ti-Zr plots for the Naegawa dolerite (open circles), Naegawa basalt (pillow lava: solid circles) and the Nunobe basalt (pillow lava: solid triangles) from the Upper Sorachi Group. Composition of the chilled margin (open circle with dot) of the dolerite sheet is plotted close to the pillow basalts. Compositional ranges of MORB, arc lavas, and within plate lavas are after Pearce (1982).

Clinopyroxene Chemistry

Table 2 lists selected EPMA analyses for clinopyroxenes from the Naegawa dolerite. Al and Ti contents (numbers of ions) of the clinopyroxene cores are more than 0.1 and 0.02 respectively. Text-fig. 7 shows the Al vs. Si and Ti vs. Al



Text-fig. 7 Al vs. Si and Ti vs. Al relations (O=6) for clinopyroxenes from the Naegawa dolerite, indicating a low SiO_2 activity during crystallization. Compositional field circled by solid line for transitional to alkaline parentage (Maruyama, 1976).

Table 2 Selected EPMA analyses of clinopyroxenes from the Naegawa dolerite.

	1	2	3	4	5	6	7	8	9	10
SiO_2	50.16	51.26	49.30	48.68	48.19	48.49	50.43	49.85	51.30	51.05
TiO_2	1.43	0.91	1.58	1.74	1.87	1.70	1.37	1.30	1.09	1.04
Al_2O_3	2.77	2.11	4.28	5.68	4.95	5.33	3.55	3.81	3.20	2.93
FeO*	14.03	11.69	9.76	9.57	10.37	9.85	9.16	8.77	8.41	8.79
MnO	0.52	0.49	0.20	0.26	0.30	0.32	0.23	0.23	0.23	0.21
MgO	13.17	13.16	13.05	13.45	12.95	14.05	14.03	14.06	14.94	14.84
CaO	18.52	19.91	21.10	20.16	20.39	20.07	20.92	21.12	20.98	20.61
Na_2O	0.39	0.40	0.46	0.48	0.44	0.43	0.37	0.42	0.44	0.36
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Total	100.99	99.93	99.73	100.12	99.46	100.24	100.07	99.56	100.59	99.83
Si	1.888	1.933	1.856	1.821	1.825	1.814	1.883	1.870	1.896	1.903
Al^{IV}	0.112	0.067	0.144	0.179	0.175	0.186	0.117	0.130	0.104	0.097
Al^{VI}	0.011	0.027	0.046	0.071	0.046	0.049	0.039	0.038	0.035	0.032
Ti	0.041	0.026	0.045	0.049	0.053	0.048	0.038	0.037	0.031	0.029
Fe**	0.442	0.369	0.307	0.299	0.328	0.308	0.286	0.275	0.260	0.274
Mn	0.017	0.016	0.006	0.008	0.010	0.010	0.007	0.007	0.007	0.007
Mg	0.739	0.740	0.733	0.750	0.731	0.783	0.781	0.786	0.823	0.824
Ca	0.747	0.804	0.851	0.808	0.827	0.804	0.837	0.849	0.831	0.823
Na	0.029	0.029	0.033	0.035	0.032	0.032	0.026	0.030	0.032	0.026
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fe**	22.9	19.3	16.2	16.1	17.4	16.3	15.0	14.4	13.6	14.3
Mg	38.3	38.7	38.7	40.4	38.7	41.3	41.0	41.2	43.0	42.9
Ca	38.8	42.0	45.1	43.5	43.9	42.6	44.0	44.4	43.4	42.8
Sample No.	1128-4	〃	1128-1	〃	〃	〃	1128-13	〃	〃	〃
Analysis No.	3	8	20	21	23	27	34	35	42	48

FeO* : total iron as FeO*

Fe** : Fe^{2+}

Numbers of cations : based on 6 oxygens

relations for clinopyroxenes. The analyses are plotted within the transitional and alkaline parentage fields defined by Maruyama (1976). The plots indicate that the Naegawa clinopyroxenes crystallized from a transitional to alkaline magma with relatively low SiO_2 activity. Accordingly, this result supports the estimation of magma parentage for the Naegawa dolerite from the bulk rock chemistry.

Pillow lavas and dykes in the Upper Sorachi Group

Occurrence and Petrography

Basaltic pillow lavas and dykes are observed as autochthonous volcanic bodies in the Upper Sorachi Group in the Panketeshimanai, Naegawa, Nunobe and

Yuufure areas. Basaltic volcaniclastic siltstones are commonly associated with the pillow lavas, showing a sedimentary contact on the pillow lobe and tube surface. The pillow lavas are closely packed with small amounts of volcaniclastic sediment as interpillow material. The individual pillow piles are generally thin, ranging from a few meters to several tens of meters. Small volumes of amygdules less than 0.4 mm in diameter are often seen within the basalt lavas. The degree of vesiculation, however, is rather weak. Hyaloclastic brecciation is hardly observed in the field. Most of the pillow basalts and dolerites show an aphyric to ophitic texture, which is made up mainly of clinopyroxene, plagioclase, and opaque minerals. The rocks are slightly altered by the zeolite to prehnite-pumpellyite facies metamorphism. Interstitial glass is mostly devitrified into secondary minerals.

Bulk Rock Chemistry

Basaltic pillow lavas and dolerite dykes from the Upper Sorachi Group were

Table 3 Chemical compositions of pillow lavas and dyke rocks from the Naegawa River, Panketeshimanai, Nunobe and Yunfure River areas.

	1	2	3	4	5	6	7	8	9	10	11
SiO_2	51.65	49.50	51.40	51.41	48.42	48.63	49.55	46.93	48.30	48.39	47.87
TiO_2	1.58	0.87	1.49	1.79	1.20	2.36	1.10	1.00	1.04	1.07	1.22
Al_2O_3	14.90	13.47	15.71	15.23	13.63	10.48	14.14	15.40	14.74	13.20	12.89
Fe_2O_3*	13.07	10.94	11.82	11.19	12.19	19.76	12.13	11.95	12.22	11.24	12.35
MnO	0.49	0.19	0.23	0.22	0.17	0.26	0.19	0.16	0.18	0.22	0.22
MgO	4.11	8.51	4.34	3.20	6.65	4.11	8.15	8.22	8.05	7.85	7.69
CaO	6.21	9.89	4.28	7.81	10.92	6.06	9.81	12.57	11.78	11.73	11.74
Na_2O	5.18	3.28	6.42	5.88	3.95	4.15	3.28	2.18	2.42	2.64	3.07
K_2O	0.57	1.06	0.12	0.63	0.30	0.81	0.04	0.16	0.35	0.37	0.15
P_2O_5	0.23	0.08	0.24	0.35	0.10	0.20	0.09	0.09	0.09	0.08	0.10
$H_2O\pm$	3.19	3.09	3.69	2.78	3.59	3.24	2.71	2.15	1.87	3.63	4.05
Total	101.18	100.88	99.74	100.49	101.12	100.06	101.19	100.81	101.04	100.42	101.35

Fe_2O_3* : total iron as Fe_2O_3.*

$H_2O\pm$: total H_2O in wt. % analyzed by pen-field tube method.

Analyses No. 1-6 : low K_2O type alkaline basalt, and No. 7-11 : MORB type tholeiite

1 : aphyric basalt pillow lava, Naegawa River, Sample No. 83830-4.
2 : aphyric basalt pillow lava, Panketeshimanai River, No. 85601-7.
3 : aphyric basalt pillow lava, Nunobe Quarry, No. 83829-5.
4 : aphyric basalt pillow lava, Nunobe Quarry, No. 83829-6.
5 : delerite dyke, Yuufure River, No. 85825-2.
6 : dolerite dyke, Yuufure River, No. 85825-3.
7 : aphyric basalt pillow lava, Panketeshimanai River, No. 85601-9.
8 : aphyric basalt pillow lava, Mt. Nae-yama, No. 85602-14 KO.
9 : aphyric basalt pillow lava, Mt. Nae-yama, No. 85602-5 NI.
10 : aphyric basalt pillow lava, Yuufure River, No. 85825-1.
11 : aphyric basalt pillow lava, Yuufure River, No. 85825-1B.

analyzed by XRF and AA spectrometer. Table 3 lists the representative 6 analyses of the pillow lavas and dyke rocks from the Naegawa River, Panketeshimanai, Nunobe and Yuufure River areas.

All the analyses are plotted in the alkaline field of the alkali-silica diagram (Text-fig. 4). Compositional ranges of Na_2O+K_2O and SiO_2 contents are rather small and the plots form a cluster around those of the chilled margin analyses of the Naegawa dolerite sheet. Most of the basalt and dolerites contain considerable amounts of normative nepheline, based on the calculation using the ratio $Fe_2O_3/FeO=0.15$ (Brooks, 1976).

Major element chemistry of the rocks from the Upper Sorachi Group shows a similar magmatic nature to the Naegawa dolerite. The K_2O contents are notably low, less than 1.0 wt % (Text-fig. 5). The Na_2O/K_2O ratios are clearly high, generally more than 4, and are different from those of the within plate alkaline basalt lavas such as Hawaii (Macdonald, 1968), Gouph (Le Mitre, 1962) and Bouvetoya (Imsland et al., 1977).

Concentrations of some trace elements in the Naegawa pillow lavas and the Nunobe pillow lavas cover the whole range of the chilled margin of the Naegawa dolerite sheet, as shown in the Ti vs. Zr plot (Text-fig. 6).

Pillow lavas of the Lower Sorachi Group

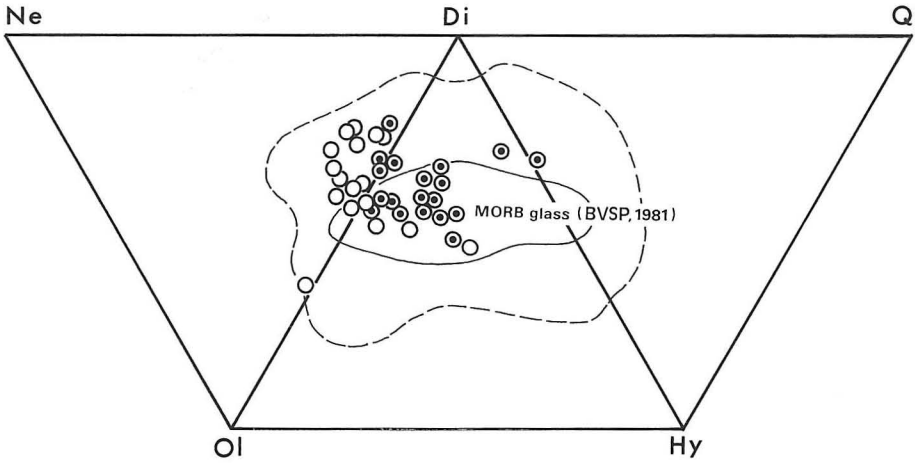
Mode of Occurrence

Aphyric basaltic pillow lavas predominate in the Lower Sorachi Group. The primary close-packed structure of the pillow lavas is well preserved in the Panketeshimanai and Yuufure areas, showing an extremely poor vesiculation. Hyaloclastites in association with the pillow lavas are scarcely observed in the field. A volcanic pile of pillow lavas more than 500 m thick can be observed continuously along the Panketeshimanai River (Text-fig. 2). Although no age determination has been reported from this area, some Jurassic radiolarian fossils have been known from the cherts interbedded with the pillow lavas (Kito et al., 1986). According to Kito (1987), the basaltic pillow lavas are overlain by the S2 green chert bed, which contains the latest Jurassic radiolarian fossils. Therefore, the pillow lavas of the Lower Sorachi Group are recognized as upper members of the Jurassic ophiolite in central Hokkaido.

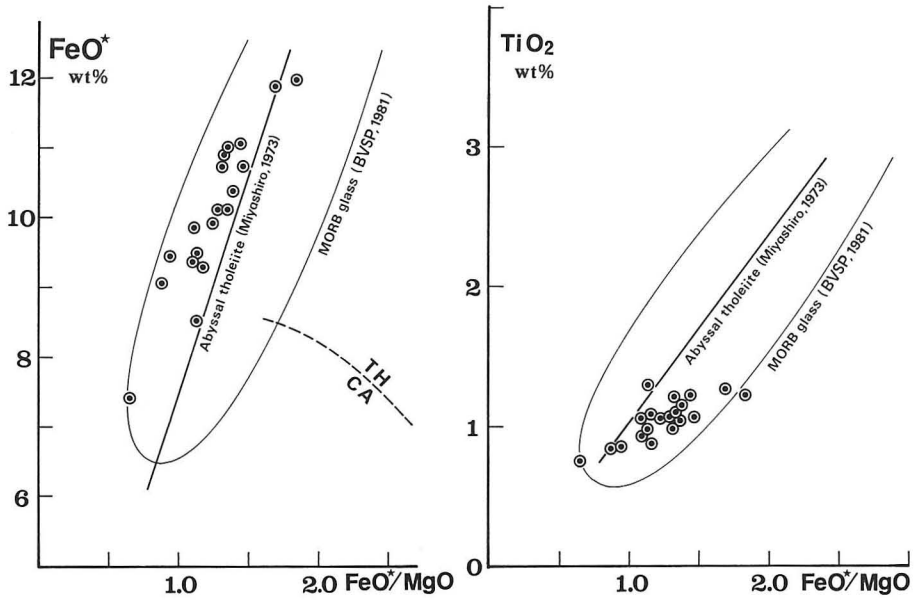
Hornblende-bearing dolerite dykes intruding into the pillow lavas are observed at several outcrops of the Lower Sorachi Group. The chemical compositions are comparable to those of the pillow basalt and dolerite sheet in the Upper Sorachi Group.

Bulk Rock Chemistry

Table 3 lists 5 representative analyses for the aphyric basalt pillow lavas from the Lower Sorachi Group of the Panketeshimanai and Yuufure areas. Most of the analyses are plotted in the subalkaline field of the alkali vs. silica diagram (Text-



Text-fig. 8 Normative ne-ol-di-hy qz tetrahedron. Open circles: Naegawa dolerites and pillow lavas from the Upper Sorachi Group. Open circles with solid dot: pillow lavas from the Lower Sorachi Group. Compositional field circled by solid line for MORB glass and broken line for MORB (B. V. S. P., 1981).



Text-fig. 9 FeO* vs. FeO*/MgO and TiO_2 vs. FeO*/MgO variations for the pillow lavas from the Lower Sorachi Group in the Panketeshimanai and Yuufure areas. Compositional field circled by solid line for MORB glass ranges (B. V. S. P., 1981). Solid straight line: average trend of abyssal tholeiite, broken line: boundary between tholeiitic (TH) and calc-alkaline (CA) fields, after Miyashiro (1973).

fig. 4) and the olivine tholeiite field of the normative ne-ol-di-hy-qz tetrahedron (Yoder and Tilley, 1962), showing a tholeiitic magmatic nature (Text-fig. 8). As shown obviously in Text-fig. 9, the FeO*-FeO*/MgO and TiO_2-FeO*/MgO variations of the pillow lavas are enclosed by the range of MORB (B. V. S. P., 1981). The cluster of analyses slightly shifts from the average trend for abyssal tholeiite (Miyashiro, 1973) towards the higher FeO* and the lower TiO_2 fields. The TiO_2 contents are clearly higher than those of island-arc volcanic rocks (Gill, 1981).

Three Basalt Types

The basalts and dolerites from the late Jurassic to early Cretaceous Sorachi Group and from the Cretaceous melange complex in central axial zone of Hokkaido are classified into the following three different types based on the bulk rock chemistry, as shown in Text-figs. 4 and 5. The first one is a high K_2O type alkaline basalt, which is characterized by a high abundance in K_2O, TiO_2, P_2O_5 and normative nepheline. The second is a low K_2O type alkaline basalt, which is extremely poor in K_2O (high Na_2O/K_2O) and mostly nepheline-normative. The third one is a MORB type tholeiite, which is poor in K_2O, TiO_2, P_2O_5, and commonly contains normative hypersthene, showing a low FeO*/MgO ratio. Based on the above major element chemistry criteria, three basalt types can be easily distinguished. Moreover, each basalt type shows a good correspondence to those in the individual geologic units of the Sorachi-Yezo Belt, as prefaced by Niida and Kito (1986).

Table 4 lists the chemical characteristics, mode of occurrence, source geological units and possible origins for the three basalt types. The basaltic pillow lavas, dolerite dykes and sheets occur as autochthonous members of the Upper Sorachi Group (S3) and correspond to the low K_2O type alkaline basalts. The basaltic pillow lavas in the Lower Sorachi Group, that is stratigraphically traceable as the lowest unit overlain by the Upper Sorachi Group (Kito et al., 1986; Niida and Kito, 1987), are MORB type tholeiites. Excellent field examples of basalt type in the Sorachi Group are shown in Text-fig. 2, in which sample locations of the above two types clearly separate into the Upper and the Lower Sorachi Groups. Exotic blocks of basalts and dolerites in the Cretaceous accretionary melange complexes involve both the high K_2O type alkaline basalts and the MORB type tholeiites.

Early Cretaceous Magmatism in the Sorachi-Yezo Belt

Major element chemistry of the early Cretaceous basalts and dolerites in the Upper Sorachi Group, which are characterized by a low K_2O and high Na_2O/K_2O alkaline signatures (Text-figs. 4 and 5), suggests an unique tectonic environment for the basalt magmatism. Such a low K_2O and high Na_2O/K_2O alkaline basalt is not common in the world. As mentioned previously, the basalts reported from Deception island in South Shetland, Grenada and St. Kitts island in Lesser Antilles,

Table 4 Chemical characteristics, mode of occurrence, source geological units and possible origins for the basalt pillow lavas, dolerite dykes and sheets in the central axial zone of Hokkaido.

MAGMA/ROCK TYPE	CHEMISTRY	OCCURRENCE	SOURCE	ORIGIN
High K_2O type AB * aphyric basalt * pl-cpx basalt * kaer dolerite * trachyte	K_2O, TiO_2, P_2O_5-rich ; ne-normative	Pillow lava, dyke ; severe vesiculation ; associated with hyaloclastite, epiclastics, chert and limestone	Exotic blocks in the Cretaceous accretionary melange complex	Permian-jurassic seamounts and oceanic islands
Low K_2O type AB * aphyric basalt * dolerite	K_2O-poor ; high Na_2O/K_2O ; mostly ne-normative	Pillow lava, dyke, dolerite sheet ; poor vesiculatdon ; associated with pelagic shale, chert and tuff	Autochthonous members (S3) of the Upper Sorachi Group (Uppermost ophiolite)	Early Cretaceous primitive arc on the Jurrasic oceanic crust
MORB type TH * aphyric basalt * dolerite	K_2O, TiO_2, P_2O_5-poor ; low FeO*/MgO ; mostly hy-normative	Pillow lava, dyke ; poor vesiculation ; associated with minor hyaloclastite	Predominants (S1) of Lower Sorachi Group (Upper ophiolite)	Jurassic oceanic crust
			Exotic blocks in the Cretaceous accretionary melange complex	Permian-Jurassic oceanic crust

and Rishiri island in Hokkaido have low K_2O and high Na_2O/K_2O alkaline signatures. These islands are all situated in relatively immature island arcs without continental crust or in back-arc basins. However, there is no report from continents, island arcs with continental crust, mid-oceanic ridges, or within plate ocean island and seamounts. The unique signature in major element chemistry is also suggested from the Ti-Zr relations (Text-fig. 6), of which analyses are clustered into the overlapped field among the compositional ranges of MORBs, arc lavas and within plate lavas.

The role of Na_2O on basaltic magma generation has not been examined in detail, although K_2O has been discussed by many petrologists and geochemists. Pressure dependence of Na_2O in primary basalt magma is believed to occur (Kushiro, 1968; Takahashi and Kushiro, 1983). Takahashi (1988) demonstrated that there is a good correlation between Na_2O content of convergent zone high-alumina basalt and the age of subducting oceanic lithosphere, and suggested the high Na_2O basalt is generated at a deeper level within high-temperature mantle wedge during the young stage of subducting oceanic lithosphere. Weaver et al. (1979) showed that all the Bransfield Strait basalts (including Deception Island) have high Na_2O/K_2O ratios and explained that the magmatism was associated with the initial stages of back-arc basin spreading.

It may be important to note that high Na_2O basalts have been generated on major transfrom faults exhibiting more than 1,500 km in dislocation distance. Deception Island is located on such a transform fault, where the eastern extension divides the Scotia and Antarctic plates (Forsyth, 1975). High Na_2O alkaline basalts also occur in Grenada at the southern end of Lesser Antilles island arc (Arculus, 1976). Grenada is the closest island to the El Pilar-San Sebastian-Oca fault, which represents a transform plate boundary between the Caribbean plate and the South American plate (Silver et al., 1975). The early Cretaceous basalts and dolerites of the Upper Sorachi Group in Hokkaido are also considered to have been generated along a transform fault suggested to be the latest Jurassic boundary between the Eurasia plate and the Farallon plate by Niida and Kito (1986). This unique tectonic setting suggests that the upper mantle peridotite associated with large transform movement is a possible source for the high Na_2O basaltic magma. It is plausible that the high Na_2O magma generation was controlled by the source mantle composition as well as pressure, because the source mantle peridotites might have been hydrated and enriched in Na_2O by transform fault movement prior to generation of the high Na_2O magma.

Taking the late Mesozoic geology of Hokkaido into consideration, it is probable that the early Cretaceous basalt magmatism was initiated as arc-related magmatism, as discussed by Niida et al. (1984) and Niida and Kito (1986).

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