

Petrological Characteristics of the Hantaishir Ophiolite Complex, Altai Region, Mongolia: Coexistence of Podiform Chromitite and Boninite

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Abstract

Petrological and geochemical examination shows that the Hantaishir ophiolite complex of the Altai region in Mongolia contains two large ultramafic massifs (the Taishir and Naran massifs), a sheeted dyke complex, and a serpentine mélange zone containing blocks of chromitite and peridotites. The ultramafic massifs consist mainly of harzburgite and dunite with a small amount of podiform chromitite. Cr/(Cr+Al) atomic ratios of chromian spinels are high in the peridotites and sheeted dykes (>0.7), and in the chromitites (>0.8). Fo contents of olivines in the peridotites span a relatively narrow range (91.8–93.0). Most of the sheeted dykes are boninite-type high-Mg andesites. The coexistence of podiform chromitite and boninite in the Hantaishir ophiolite complex suggests that the ophiolite formed in an intra-oceanic subduction zone, from a depleted mantle source.

Key words: Dunite-harzburgite complex, boninite, chromitite, Hantaishir ophiolite, Altai Mongolia.

Introduction

Many ophiolite complexes occur in the Asian composite continent (e.g. Burrett, 1974; Zonenshain et al., 1985; Maruyama and Sakai, 1986; Liou and Maruyama, 1986; Mossakovskiy et al., 1994). The Hantaishir (Khan-Tayshir) ophiolite complex of the Altai region of Mongolia is surrounded by the Siberian, Sino-Korean, and Russian platforms, and by the Tarim Proterozoic Block. Petrological characterization of the mantle rocks of the Hantaishir ophiolite complex is important for clarification of the geodynamic evolution of the Asian composite continent which reflects the global geodynamic processes after the Rodinia break-up.

We here report the chemical characteristics of constituent minerals from the ultramafic and mafic rocks of the Hantaishir ophiolite to place some preliminary constraints on the origin of the mantle rocks. This study is the first report of mineral chemistry from the constituent rocks of the complex. In this report, we concentrate our discussion on peridotite and chromitite as mantle members and sheeted dyke rocks as a crustal member.

Gabbro and pillow lava members are also important for clarifying the characteristics of the whole ophiolite complex, and work will be carried out on these constituents in the near future. This study was performed as part of a JICA (Japan International Cooperation Agency)-IGMR (Institute of Geology and Mineral Resources of Mongolia) project, and supplemented with additional new data.

Geological Background

The Hantaishir ophiolite complex is situated in West-Central Mongolia (Fig. 1). Mongolia is divided into two major tectonic units, the North and South blocks, which are separated by the Ural-Mongolian Lineament (UML) (e.g., Tseden et al., 1992; Tomurtogoo, 1997). The Hantaishir ophiolite complex is situated at the southern end of the North Block, and is composed of a serpentine mélange zone, peridotites, pyroxenites, gabbros, sheeted dykes, pillow lavas, cherts and limestones (Fig. 1) (Zonenshain and Kuzmin, 1978; Tomurtogoo, 1997; Matsumoto et al., 1998). The serpentine mélange zone

includes vast amount of serpentinites with blocks of chromitites, peridotites, pyroxenites, gabbros, mafic volcanic rocks, cherts and limestones. Two ultramafic complexes can be distinguished, the Taishir and the Naran massifs (Fig. 1). The ultramafic complexes are composed mainly of harzburgite and dunite, and associated volcanic rocks, namely andesite, basalt and boninite (Kepezshinskas, 1986; Mossakovskiy et al., 1994). The sheeted dyke complex appears in the upper part of the complex within the gabbro (or pyroxenite) layer. Gabbro and pyroxenite are always stratigraphically and topographically above peridotite (e.g., Zonenshain and Kuzmin, 1978). Biochronology (e.g., Mossakovskiy et al., 1994) shows the Hantaishir ophiolite is of late Vendian age (590–570 Ma). That is, the igneous activity that formed the Hantaishir ophiolite complex occurred after the breakup of the Rodinia supercontinent, and mostly synchronous with the assembly of Gondwana.

Petrography

Peridotites

The ultramafic complexes are mainly composed of harzburgite and dunite; pyroxenite and chromitite are also sometimes found. About 90% of an ultramafic complex is harzburgite; dunite occurs as dykes or pods within the harzburgite (Figs. 2a, b). Occasional chromitite pods are found only in the dunite. Ultramafic and chromitite blocks ranging from a few centimeters to several meters in diameter also occur within the mélangé zone of the Hantaishir ophiolite (Fig. 2c).

The harzburgite typically has protogranular texture. The constituent minerals are olivine (0.2–2.0 mm diameter), subhedral to anhedral orthopyroxene (0.2–3.0 mm), euhedral to subhedral chromian spinel (0.2–2.0 mm), and a very small amount of subhedral clinopyroxene (0.2–1.0 mm) (Fig. 2h, i). Most silicate minerals are

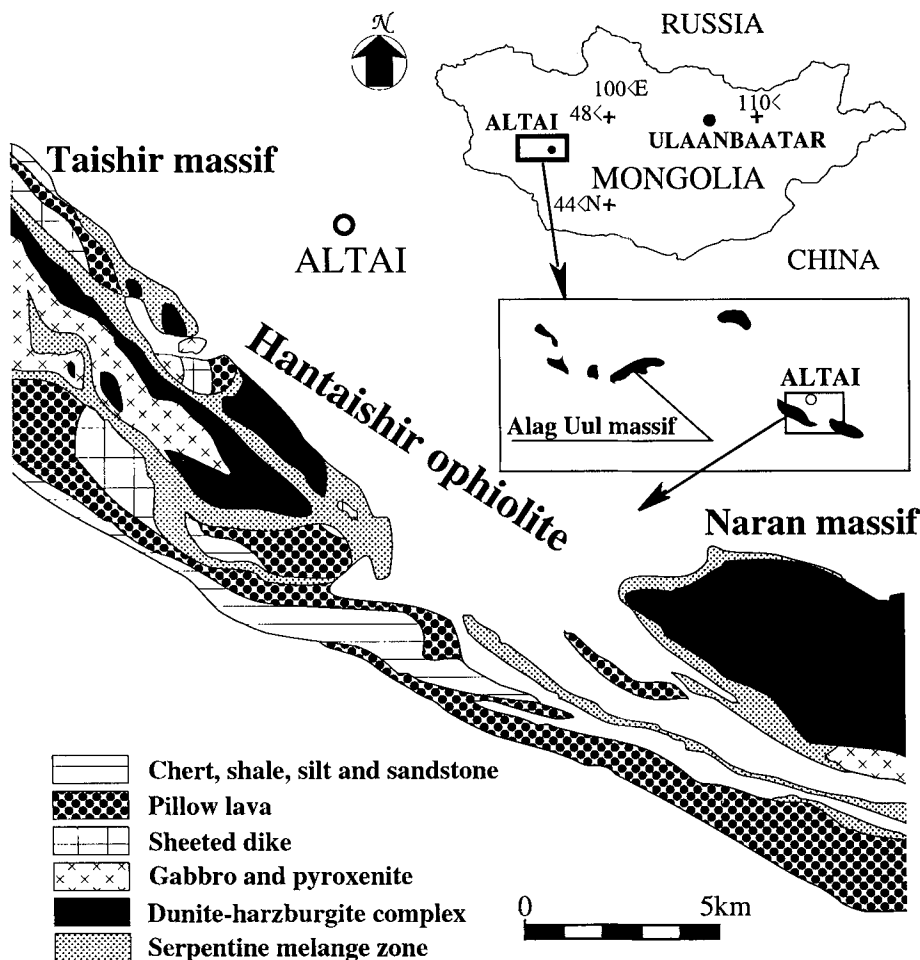


Fig. 1. Geological map of the Hantaishir ophiolite complex (modified from Zonenshain and Kuzmin, 1978 and Bat-Erden et al., 1996).

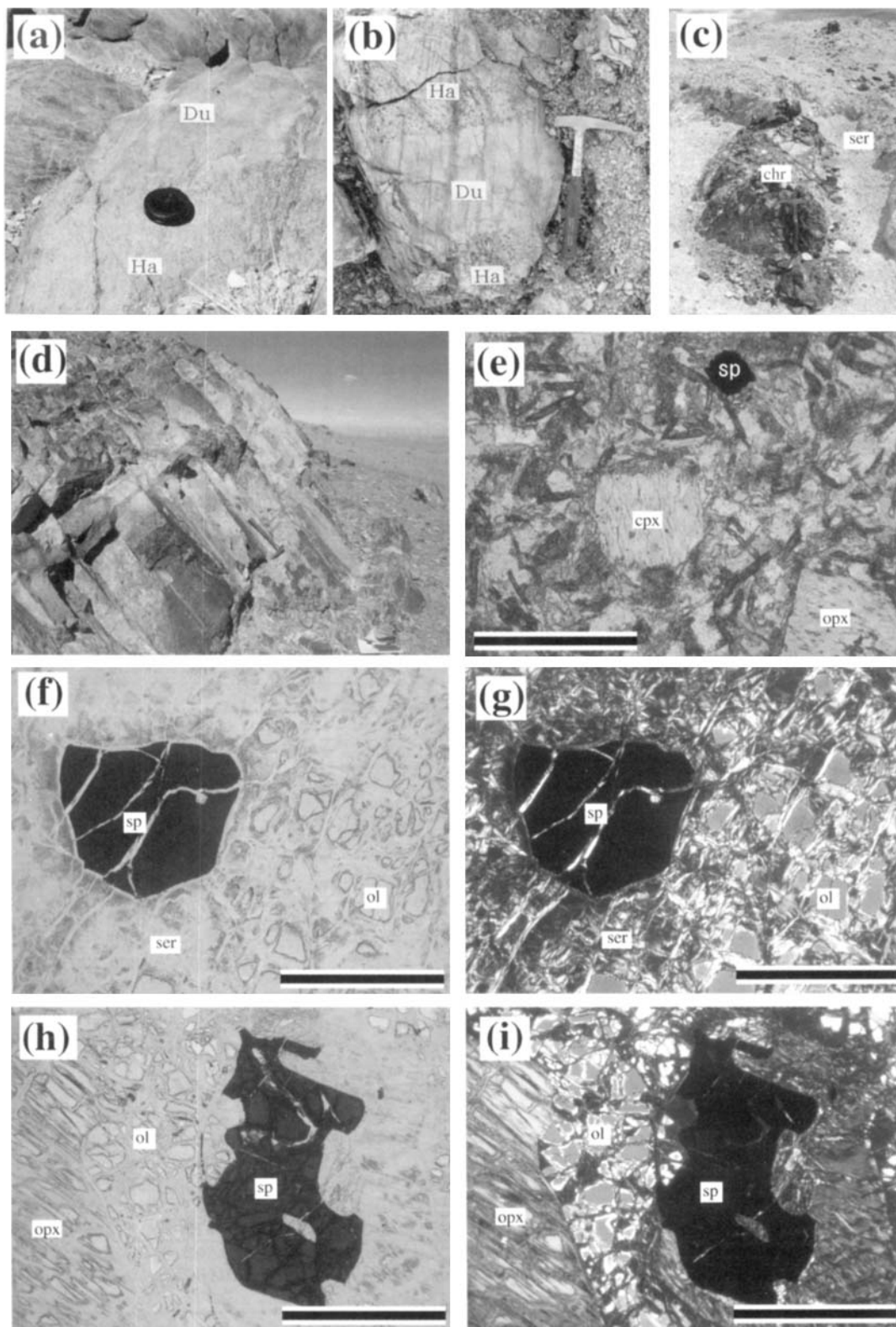


Fig. 2. Photographs and photomicrographs of peridotites and high-Mg andesites. (a) Harzburgite (Ha) with dunite (Du). (b) Dunite dyke (Du) in harzburgite (Ha). (c) Chromitite block (chr) (1m x 3m) in serpentine mélangé zone. (d) Sheeted dyke of high Mg andesite. (e) Photomicrographs of sheeted dyke of high-Mg andesite. sp-chromian spinel, cpx-clinopyroxene, opx-orthopyroxene, plane-polarized light. Scale bar is 0.5 mm. (f) Photomicrographs of dunite from the Naran ultramafic massif. sp-chromian spinel, ol-olivine, ser-serpentine, Plane-polarized light. Scale bar is 0.5 mm (g) Crossed-polarized light. (h) Photomicrographs of harzburgite from Naran ultramafic massif. sp-chromian spinel, ol-olivine, opx-orthopyroxene, Plane-polarized light. Scale bar is 0.5 mm. (i) Crossed-polarized light.

replaced by serpentine and chlorite. Chromian spinel grains are dark brown under the microscope; rims are usually opaque due to the replacement by magnetite and ferritchromite.

The dunite exhibits equigranular textures, and consists of olivine (0.2–2.0 mm), euhedral to subhedral chromian spinel (0.2–3.0 mm), and a small amount of anhedral orthopyroxene, 0.1–4.0 mm across (Figs. 2f, g). Most silicate minerals are again replaced by serpentine and chlorite.

Chromitite bodies are always enclosed by dunite envelopes, and their size varies in diameter from a few to several meters. Modal proportions of chromian spinel in the chromitite bodies exceed 70 percent. Texturally the chromitites are mostly massive and sometimes disseminated, and nodular, anti-nodular or orbicular textures were not observed. Chromian spinel (0.2–5.0 mm diameter) and olivine (0.2–2.0 mm) are the main primary minerals. Clinopyroxene (0.1–2.0 mm) is rarely found. Serpentine and/or chlorite, and sometimes uvarovite, occur at grain boundaries and along cracks in chromian spinel.

Sheeted dyke complex

The sheeted dyke complex is continuous over an outcrop length of 4 km (Fig. 2d). Individual dykes vary from 5 cm to 2 m in width. The rocks of the sheeted dyke complex are fine-grained and massive, green to grey, and have intersertal and intergranular textures. Phenocrysts are plagioclase (1.0–2.0 mm across), clinopyroxene (0.1–4.0 mm) and orthopyroxene (0.1–4.0 mm), along with small amounts of chromian spinel (0.1–2.0 mm) and olivine (0.1–2.0 mm) (Fig. 2e). The matrix is composed of glass, plagioclase, orthopyroxene, and clinopyroxene, but it has been extensively altered to chlorite. Clinopyroxene and olivine phenocrysts have also suffered chloritic alteration.

Mineral Chemistry

Mineral compositions were determined at Kanazawa University using an Akashi alpha-30A scanning electron microscope equipped with an energy-dispersive spectrometer. Selected analyses are listed in table 1.

Table 1. Selected SEM analyses of chromian spinels from the Hantaishir ophiolite.

Mineral	Sheeted dyke		Rocks from mélange zone						Rocks from the Naran massif				
	boninite		chromitite		dunite		harzburgite		chromitite		dunite		harzburgite
No.	spinel	cpx	spinel	cpx	spinel	olivine	spinel	olivine	spinel	spinel	olivine	spinel	olivine
	81821	G1	8902sp4	8902ln2	8901sp2	8901ol2	8903sp1	8903ol1	8906sp2	8904sp2	8904ol2	8905sp4	8905ol1
SiO ₂	0.56	53.76	0.01	51.79	0.16	40.48	0.35	41.01	0.00	0.26	41.17	0.38	40.54
TiO ₂	0.31	0.06	0.08	0.21	0.16	0.11	0.11	0.00	0.05	0.14	0.02	0.12	0.02
Al ₂ O ₃	9.52	0.83	14.37	6.42	11.39	0.38	12.62	0.36	7.61	8.10	0.20	13.32	0.33
Cr ₂ O ₃	57.23	0.12	56.20	3.09	55.56	0.06	54.71	0.07	63.00	59.33	0.14	55.39	0.09
FeO*	18.57	7.12	12.83	1.21	18.78	7.01	19.76	7.91	13.88	18.73	7.19	20.37	7.70
MnO	0.24	0.09	0.08	0.00	0.33	0.09	0.30	0.05	0.07	0.39	0.08	0.40	0.13
MgO	11.92	18.92	14.58	22.09	11.05	49.66	10.81	49.87	12.87	10.51	50.41	10.55	49.52
CaO	0.34	17.68	0.20	12.86	0.20	0.09	0.17	0.08	0.13	0.23	0.09	0.20	0.06
Na ₂ O	0.04	0.07	0.00	0.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07
K ₂ O	0.04	0.01	0.04	0.19	0.00	0.03	0.04	0.03	0.01	0.08	0.05	0.00	0.04
Total	98.78	98.66	98.39	98.79	97.63	97.92	98.85	99.38	97.62	97.77	99.35	100.74	98.50
Number of atoms													
O	4	6	4	6	4	4	4	4	4	4	4	4	4
Si	0.019	1.985	0.000	1.851	0.005	0.999	0.012	1.000	0.000	0.009	1.001	0.012	0.998
Ti	0.008	0.002	0.002	0.006	0.004	0.002	0.003	0.000	0.001	0.004	0.000	0.003	0.000
Al	0.373	0.036	0.542	0.270	0.450	0.011	0.490	0.010	0.301	0.325	0.006	0.507	0.010
Cr	1.504	0.004	1.421	0.087	1.473	0.001	1.426	0.001	1.671	1.599	0.003	1.415	0.002
Fe*	0.516	0.22	0.343	0.036	0.527	0.145	0.545	0.161	0.390	0.534	0.146	0.550	0.159
Mn	0.007	0.003	0.002	0.000	0.009	0.002	0.008	0.001	0.002	0.011	0.002	0.011	0.003
Mg	0.591	1.042	0.695	1.176	0.552	1.825	0.531	1.811	0.644	0.534	1.826	0.508	1.817
Ca	0.012	0.7	0.007	0.492	0.007	0.002	0.006	0.002	0.005	0.008	0.002	0.007	0.002
Na	0.002	0.005	0.000	0.064	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003
K	0.002	0.001	0.002	0.009	0.000	0.001	0.002	0.001	0.001	0.003	0.002	0.000	0.001
Total	3.034	3.996	3.014	3.991	3.027	2.988	3.023	2.987	3.015	3.027	2.988	3.013	2.995
Cr#	0.801		0.724		0.766		0.744		0.847	0.831		0.736	
Fe ³⁺ #	0.051		0.018		0.037		0.038		0.015	0.033		0.031	
Mg#	0.597		0.696		0.553		0.533		0.643	0.537		0.512	
Fo						92.6		91.8			92.6		92.0

FeO* and Fe*, total iron as FeO and Fe, respectively. Cationic fractions in spinel were calculated assuming spinel stoichiometry. Cr#, Cr/(Cr+Al) atomic ratio; Fe₃+#, Fe₃+/((Cr+Al)+Fe₃+) atomic ratio; Mg# = Mg/(Mg+Fe₂+) atomic ratio.

Peridotites

Cr/(Cr+Al) atomic ratios (Cr#) of chromian spinels from the Naran ultramafic massif range from 0.70 to 0.75 in harzburgite, 0.75–0.82 in dunite and 0.75–0.85 in chromitite. Chromitites have spinels with the highest Cr#, reaching the metallurgical grade. Chromian spinels in harzburgite-dunite from the mélange zone near the Naran massif have Cr# ranging between 0.70 and 0.75. Two types of spinels are recognized in the chromitites: one has Cr# ranging from 0.70 to 0.75 and the other from 0.80 to 0.85. Slight differences in spinel chemistry are observed between equivalent rocks from the massif and from the mélange zone (Fig. 3). We analyzed 8 samples of dunite, 14 samples of harzburgite and 9 samples of chromitite from Naran massif. We also analyzed 7 samples from six blocks of dunite, 5 samples from five blocks of harzburgite and 10 samples from seven blocks of chromitite from the mélange zone.

Fo contents of olivines in dunite and harzburgite from both the Naran massif and the mélange zone are almost constant, with compositions ranging only from Fo₉₂ to Fo₉₃. Clinopyroxenes from the chromitites are TiO₂-poor (<0.21 wt.%) and Cr₂O₃-rich (around 3.0 wt.%) (Table 1).

Sheeted dyke complex

Cr# of chromian spinels from the sheeted dike rocks range from 0.71 to 0.82, but the majority lies between 0.80 and 0.82. Their TiO₂ contents are low (less than 0.40 wt.%). Clinopyroxene is poor in TiO₂ with contents of

less than 0.32 wt.%; whereas Cr₂O₃ contents are moderately high, with the maximum value of 0.53 wt.%.

Bulk Chemical Compositions of the Sheeted Dyke Rocks

Bulk chemical compositions of samples from the sheeted dyke complex were determined by Ohdate Analysis and Technical Center Co. Ltd., using ICP-AES and wet chemical methods. Analyses are listed in table 2.

SiO₂ contents range from 53.63 wt.% to 63.15 wt.%, corresponding to basaltic andesite to andesite (Table 2). All samples have high MgO, Cr and Ni contents, ranging from 5.20 to 14.13 wt.%, 82 to 1200 ppm, and 43 to 288 ppm respectively. Rb and Sr contents are relatively low, compared with the abundances of TiO₂, P₂O₅ and Y. These bulk chemical features are basically concordant with the results of Zonenshain and Kuzmin (1978).

Discussion

Origin of the ultramafic massifs

The ultramafic massifs of the Hantaishir ophiolite in the Altai region consist of harzburgite, dunite and a small amount of chromitite. The dunite and chromitite are always present in harzburgite in the whole mantle section of the Hantaishir ophiolite complex. Lithological features suggest their derivation from the transition zone of the uppermost mantle member of the Hantaishir ophiolite

Table 2. Bulk rock chemical composition of the Hantaishir high-Mg andesite.

Sample no.	no.41	M09a	no.38	M10	M08	M09b	no.40	M04	Boninite ^(*)	Sanukite ^(*)
SiO ₂	53.63	53.74	58.10	59.38	59.63	61.35	62.09	63.15	57.60	56.95
TiO ₂	0.19	0.20	0.19	0.46	0.19	0.19	0.23	0.19	0.15	0.72
Al ₂ O ₃	11.12	11.27	15.12	13.02	14.12	8.63	14.50	13.18	11.10	14.01
Fe ₂ O ₃	1.78	4.67	1.18	5.38	3.88	4.49	1.80	2.87	9.38	7.66
FeO	5.68	3.22	5.68	3.42	3.19	3.02	4.43	2.80	as Fe ₂ O ₃	as Fe ₂ O ₃
MnO	0.16	0.14	0.10	0.14	0.11	0.17	0.12	0.09	0.18	0.13
MgO	14.13	12.59	5.69	5.24	5.82	10.36	5.20	6.73	12.30	8.96
CaO	8.86	8.46	8.87	3.09	8.34	5.74	4.16	3.62	7.33	7.01
Na ₂ O	1.17	1.72	2.58	4.98	2.77	2.86	5.61	5.33	1.56	2.73
K ₂ O	0.05	0.27	0.09	1.31	0.56	0.83	0.12	0.34	0.47	1.68
P ₂ O ₅	0.06	0.05	0.05	0.07	0.04	0.07	0.07	0.04	0.03	0.15
H ₂ O-	0.30	0.25	0.16	0.19	0.22	0.26	0.19	0.33	-	-
LOI	3.35	3.20	1.32	2.38	1.22	2.16	1.39	1.27	-	-
Total	100.48	99.78	99.13	99.06	100.09	100.13	99.91	99.94	100.10	100.00
Cr	1200	653	586	82	326	593	132	180	1020	560
Ni	288	181	105	53	112	152	43	64	229	203
Rb	<1	2	<1	3	3	4	<1	1	10.2	67.2
Sr	54	56	41	44	43	61	77	25	66.8	269
V	224	47	251	67	220	206	221	188	-	-
Y	4	5	4	12	6	6	5	5	4.1	19.2
Nb	<5	21	<5	23	20	19	<5	17	0.5	5.9
FeO*/MgO	0.52	0.59	1.18	1.58	1.15	0.68	1.16	0.80	0.69	0.77

Major elements in wt.%, minor elements in ppm. FeO*, total iron as FeO. ^(*) Average values from Shiraki (1993).

suite. Petrochemical characterizations of rocks from the Naran massif are discussed below.

Cr# of chromian spinels in igneous rocks depends mainly on the Cr/Al ratios of the magmas with which they were in equilibrium. In general, chromian spinels in abyssal peridotites have low Cr#s (<0.6), whereas those from alpine type peridotites show a wider range (e.g., Dick and Bullen, 1984). Arai (1987, 1994) examined the relationship between spinel Cr# and olivine Fo contents in peridotites and Mg-rich lavas. He proposed that the Fo-Cr# relations in peridotite are variable, basically depending on melting conditions (e.g., pressure, temperature and water vapor pressure). Cr# of chromian spinels from all types of peridotites in the Hantaishir ophiolite vary from 0.69 to 0.88 (Figs. 3a, b), whereas

olivine Fo contents lie in a narrow range from 91.8 to 93.0. These relations suggest a fore-arc setting for the peridotites of the Hantaishir ophiolite (Fig. 3c).

Cr#s of chromian spinels in harzburgites from the Naran massif and from the mélangé zone are almost identical, varying from 0.70 to 0.75 (Fig. 3a). However, Cr# of chromian spinels in dunites and chromitites from both the Naran massif and the mélangé zone differ slightly. That is, Cr# of chromian spinels in dunites from the Naran massif range from 0.75 to 0.82 and in chromitites from the same massif range from 0.75 to 0.85, and Cr# of chromian spinels in dunites from the mélangé zone range from 0.74 to 0.76 and in chromitites from the mélangé zone range from 0.72 to 0.84 (Figs. 3a,b). TiO₂ contents of chromian spinels in dunites and chromitites from both

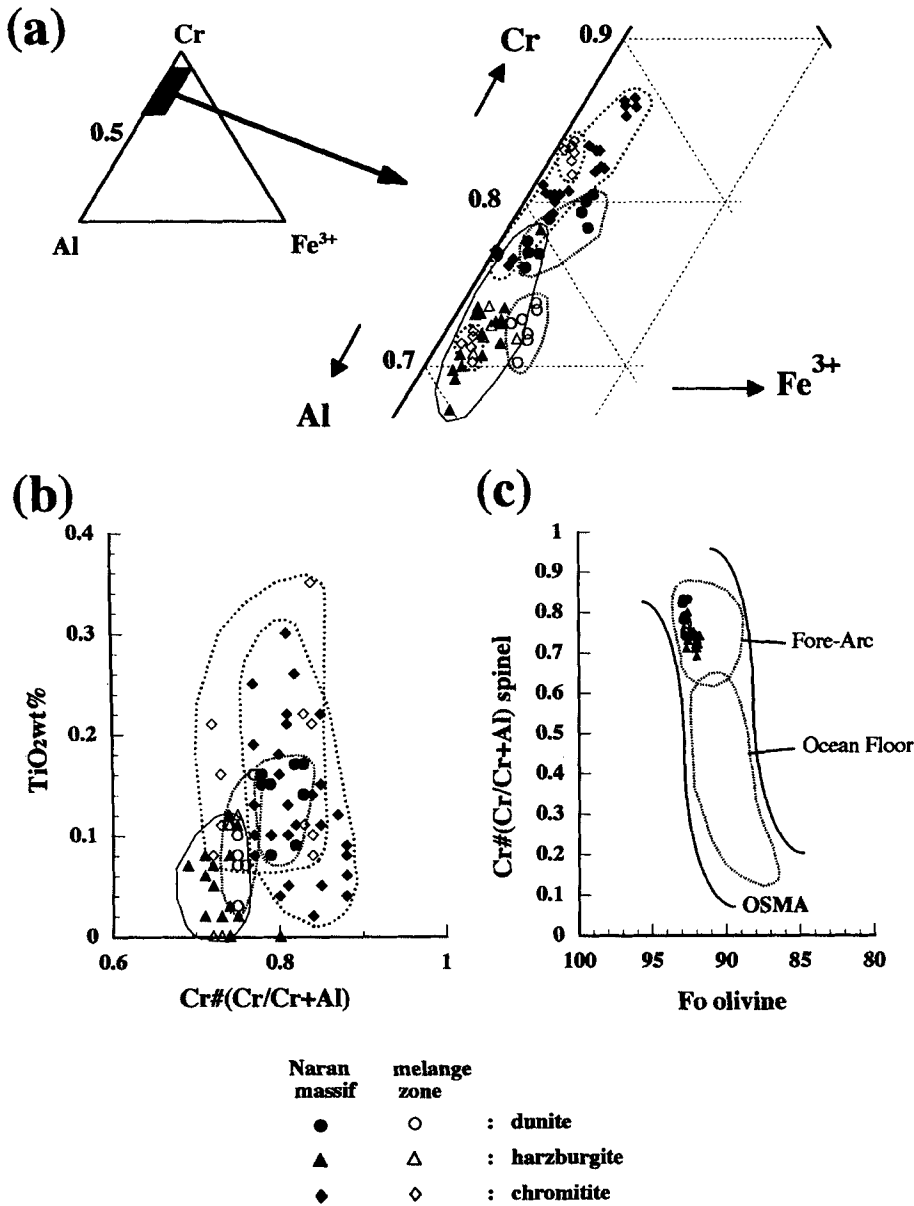


Fig. 3. Chemical composition of chromian spinel from the Hantaishir ophiolite. (a) Trivalent cation ratios of chromian spinel (b) TiO₂ wt.% vs Cr#(Cr/Cr+Al) atomic ratio in chromian spinel. (c) Relationships between olivine F_o content and Cr#(Cr/Cr+Al) atomic ratio of coexisting spinels. OSMA, olivine-spinel mantle array, which is the mantle spinel peridotite restite trend (Arai, 1987, 1994).

the Naran massif and the mélange zone also differ slightly. That is, TiO_2 contents of chromian spinels in dunites from the Naran massif range from 0.08 to 0.18 and in chromitites from the same massif range from 0.02 to 0.30, and TiO_2 contents of chromian spinels in dunites from the mélange zone range from 0.02 to 0.16 and in chromitites from the mélange zone range from 0.07 to 0.35 (Fig. 3b). Lithology-dependent difference in Cr# and TiO_2 contents thus exists in chromian spinel. The different chemical features of spinel in each lithology and coexisting harzburgite, dunite and chromitite in same outcrops suggest that the dunites did not form by simple fractional crystallization, and that the chromitites do not represent simple residues (e.g., Arai and Yurimoto, 1994, 1995; Matsumoto and Arai, 2001a, b). According to the recent interpretation of the origin of podiform chromitite (Arai and Yurimoto, 1994; Zhou et al., 1994), the dunite envelope around chromitite is essentially 'discordant dunite' (Kelemen, 1990) which is an interaction product between melt and harzburgite. Peridotite/melt reaction within the uppermost mantle has been proposed as a mechanism for the formation of chromitite associated with dunite (e.g., Noller and Carter, 1986; Arai and Yurimoto, 1994; Zhou et al., 1994; Arai, 1997; Matsumoto and Arai, 2001b).

High-Mg andesite as the sheeted dyke complex

Bulk rock chemical compositions of rocks from the sheeted dyke complex of the Hantaishir ophiolite are typical of high-Mg andesite (HMA), particularly with respect to their low FeO^*/MgO ratios (Fig. 4a) and high Cr and Ni contents in the andesite SiO_2 range. HMA is often characterized by primitive compositional features, suggesting their derivation by only slight fractionation from magmas which were in equilibrium with mantle peridotites (e.g., Sato, 1977; Kuroda et al., 1978; Tatsumi and Maruyama, 1989; Crawford et al., 1989). Shiraki (1993) divided subduction-related HMA into boninite and sanukite types. Boninite-type HMA (or boninite proper), which occurs in intra-oceanic island arcs, is highly depleted in incompatible elements, especially in high-field strength elements (HFSE). In contrast, sanukite-type HMA (sanukitoid), which occurs in active continental margins and collision zones associated with calc-alkali rocks, shows no depletion in incompatible elements, but is enriched in large-ion lithophile elements (LILE). The more or less uniform chemical composition of the sheeted dykes (especially LILE) may be caused by alteration and/or weathering. However, comparison of the elemental concentrations in relatively fresh rock sometimes allows distinction between boninite and sanukite (e.g., Shiraki, 1993). The sheeted dykes of the Hantaishir ophiolite

complex are depleted in both LILE (Rb and Sr) and HFSE (Ti, P and Y) (Table 2). These chemical characteristics indicate that the Hantaishir sheeted dykes represent boninite-type HMA rather than sanukite-type HMA (Fig. 4b).

On the basis of Fo-Cr# relations, Arai (1994) estimated Cr# of spinel in mantle restite in equilibrium with primary magmas as follows: 0.2–0.6 for MORB, 0.4–0.5 for back-arc basin basalts, 0.2–0.5 for intraplate alkali basalts, 0.1–0.7 for Quaternary arc magmas of the Northeast Japan arc and >0.7 for high-Mg arc magmas. In general, boninites contain spinel with high Cr# relative to sanukite-type HMA (e.g., Arai, 1994; Shiraki, 1997). The high Cr# of spinel in the Hantaishir HMA, varying from 0.80 to 0.82, is consistent with the characteristics of boninite. HMA igneous activity plays a very important role in the evolution of continental crust (e.g., Kay, 1978; Kelemen, 1995). Boninites are generated by H_2O -fluxed, high-temperature melting of refractory mantle in intra-oceanic island arcs above subduction zones. The existence of boninites in the sheeted dykes of the Hantaishir ophiolite complex suggests that before assembly of the Gondwana supercontinent, the Altai region was positioned in an extensional environment with the combination of newly-formed oceanic lithosphere and subducting slab (e.g., Shiraki, 1988; Macpherson and Hall, 2001).

Summary and Conclusions

(1) The Hantaishir ophiolite complex contains two relatively large ultramafic massifs, the Taishir and Naran massifs. The massifs consist mainly of harzburgite and dunite, with a small amount of associated podiform chromitite.

(2) Cr# of chromian spinel from the Naran massif are 0.70–0.75 in harzburgite, 0.75–0.82 in dunite and 0.75–0.85 in chromitite, whereas Cr# of spinel from the mélange zone are 0.70–0.75 in harzburgite-dunite, and chromitites have spinel with high (0.80–0.85) and relatively low (0.70–0.75) Cr#. Cr# of chromian spinel from the massif and the mélange zone differ slightly. Fo contents of olivine in both dunite and harzburgite span a relatively narrow range (91.8–93.0).

(3) The sheeted dyke complex occurs over 4 km long continuously, with individual dykes between 5 cm and 2 m in width. Most of the sheeted dykes consist of boninite-type HMA. The sheeted dykes also have Cr-rich spinels (Cr# 0.80–0.82), characteristic of spinels in boninites.

(4) Both the mantle and the crustal members of the Hantaishir ophiolite complex have island-arc characteristics. The high Cr# of chromian spinels in the podiform chromitites may indicate a genetic link with

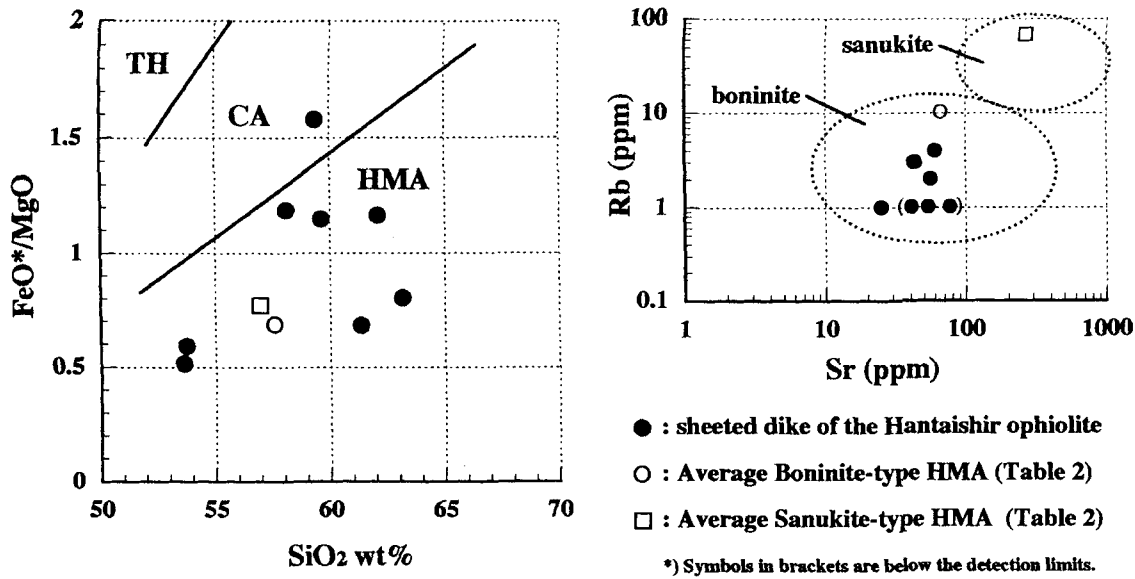


Fig. 4. Bulk rock chemical composition of Hantaishir high-Mg andesite. (a) FeO*/MgO vs SiO₂ wt%. Boundaries between tholeiites (TH), calc-alkaline rocks (CA) and high-Mg andesites (HMA) from Sato (1989). (b) Rb vs Sr. Fields of boninite-type and sanukite-type HMA are from Shiraki (1993).

boninites (e.g., Arai, 1994). Coexistence of podiform chromitite and boninite suggests that the Hantaishir ophiolite complex formed in an intra-oceanic subduction zone from a depleted mantle source.

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