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Honvang serpentinite body of the Song Ma fault zone, Northern Vietnam: A remnant of oceanic lithosphere within the Indochina–South China suture

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Abstract

The Honvang serpentinite body in the Song Ma fault zone consists mainly of massive serpentinite, altered gabbro and rare chromitite. The serpentinite preserves relict chromian spinel with rare olivine inclusions. The compositional relationship between the Fo content of olivine (Fo_{90-92}) and Y_{Cr} [atomic ratio $Cr/(Cr+Al)=0.43-0.44$] of chromian spinel suggests that the original peridotite was spinel-bearing lherzolitic harzburgite. Chromitite is typically a high-Al type, consisting of chromian spinel with $Y_{Cr}=0.43-0.44$. Saussuritized fine-grained gabbros display nearly flat rare earth element patterns, suggesting MORB-like affinity. Considering this petrotectonic information, we suggest that the serpentinite body of the Song Ma fault zone represents a remnant of paleo-oceanic lithosphere between the Indochina and South China blocks. The lherzolitic harzburgite may have formed in an environment with low degrees of melt depletion in a slow-spreading setting similar to some Tethyan paleo-oceanic lithospheres.

Keywords: Serpentinite; Chromian spinel; Suture zone; Song Ma fault zone; Vietnam

1. Introduction

The amalgamation of various Gondwana-derived continental blocks during the Phanerozoic growth of the Asian continent produced numerous suture zones (e.g., Hutchison, 1975; Maruyama et al., 1989; Sengör and Natal'in, 1996; Metcalfe, 1996a,b). In particular, Mesozoic suturing along the Indochina–Yangtze boundary was one of the most crucial events, and has been defined as the Indosinian Orogeny. This orogeny has been explained by a variety of mechanisms that include multiple subduction and collision of micro-continental blocks, igneous activity, subsequent metamorphism and deformation (e.g., Lepvrier et al., 1997, 2004; Nam et al., 1998; Carter et al., 2000; Osanai et al., 2004a,b; Nakano et al., 2004). Moreover, the geotectonic history of the Indochina–South China (Yangtze) boundary was complicated by southeastward movement of the Indochina block and subsequent regional left-lateral shearing during the Oligo-Miocene as a consequence of the Indo-Asian collision (e.g., Tapponnier et al., 1990; Gilley et al., 2003).

In northern Vietnam, several serpentinite bodies aligned along the Song Ma fault zone (SMFZ) have been considered to be fragments of oceanic lithosphere between the Indochina and South China blocks (e.g., Hutchison, 1975; Findlay and Trinh, 1997; Findlay, 1999). However, whether the ultramafic rocks represent a remnant of paleo-oceanic lithosphere is still debated due to the absence of critical petrologic evidences. In this paper we are reporting a relict chromian spinel with olivine inclusions that has been found in a serpentinite sample of the Honvang serpentinite body (HSB). The relict minerals in the HSB are described, and the petrological characteristics of chromitite and gabbroic rocks associated with the HSB are given before discussing their tectonic implications. These data provide a strong basis for the interpretation of tectonic processes that occurred during the Indosinian Orogeny in the northern Vietnam.

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2. Geologic setting

The SMFZ is a part of the suture zone juxtaposing the Indochina and South China blocks (Hutchison, 1975; Tran et al., 1977; Bao and Luong, 1985; Chung et al., 1997; Lepvrier et al., 2004) (Fig. 1). Serpentinite bodies are sporadically exposed along the SMFZ of northern Vietnam. Northwestern extension of the SMFZ crosses a part of Laos and extends to the north of Dien Bien. To the south, the SMFZ is bounded by a fault and in contact with late Triassic undeformed granite. To the north, the SMFZ is separated from Paleozoic phyllites and amphibolite facies rocks by a high-angle fault. The HSB is an elongate body with an area of 2 × 4 km, consisting mainly of massive serpentinite and fine-grained gabbro with rare chromitite. The area is extensively covered by subtropical vegetation. Apart from podiform chromitites (ca. 4 × 10 m) (Trung and Itaya, 2004) the outcrops that are rarely exposed are severely weathered.

3. Petrography

3.1. Serpentinite

Serpentinite of the HSB consists mainly of chrysotile–lizardite serpentine with minor amounts of magnetite and relict chromian spinel. Mesh textured pseudomorphs after olivine and rare bastite pseudomorphs after orthopyroxene are observed. Chromian spinel occurs as irregular shaped crystals. One chromian spinel grain contains rounded olivine inclusions. Rounded serpentine inclusions in chromian spinel are interpreted to be serpentinized olivine inclusions (Fig. 2A).

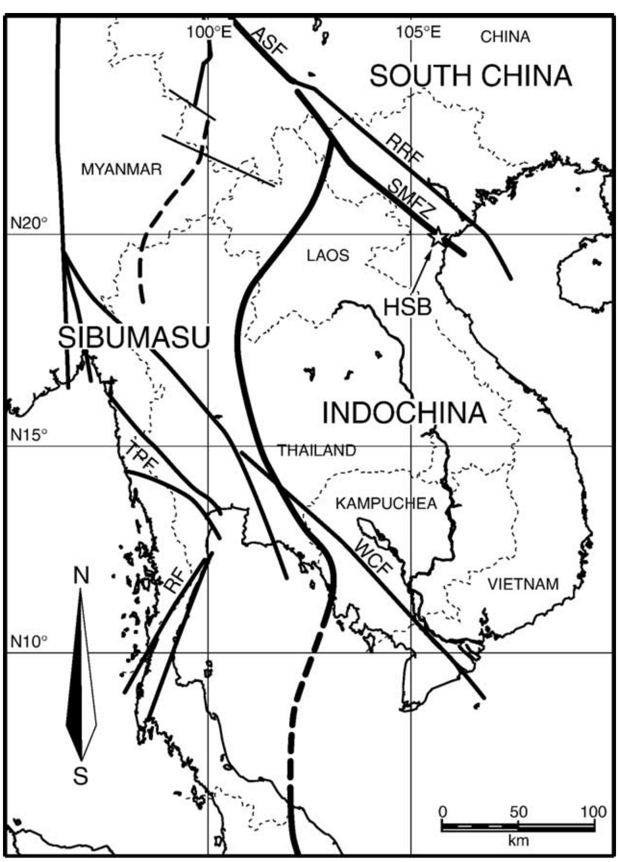

Fig. 1. Tectonic sketch showing the position of the Honvang serpentinite body. Major fault and continental blocks are based on Lepvrier et al. (2004). ASF: Ailao Shan fault; RF: Ranong fault; RRF: Red River fault; TPF: Three Pagodas fault; WCF: Wang Chao fault.

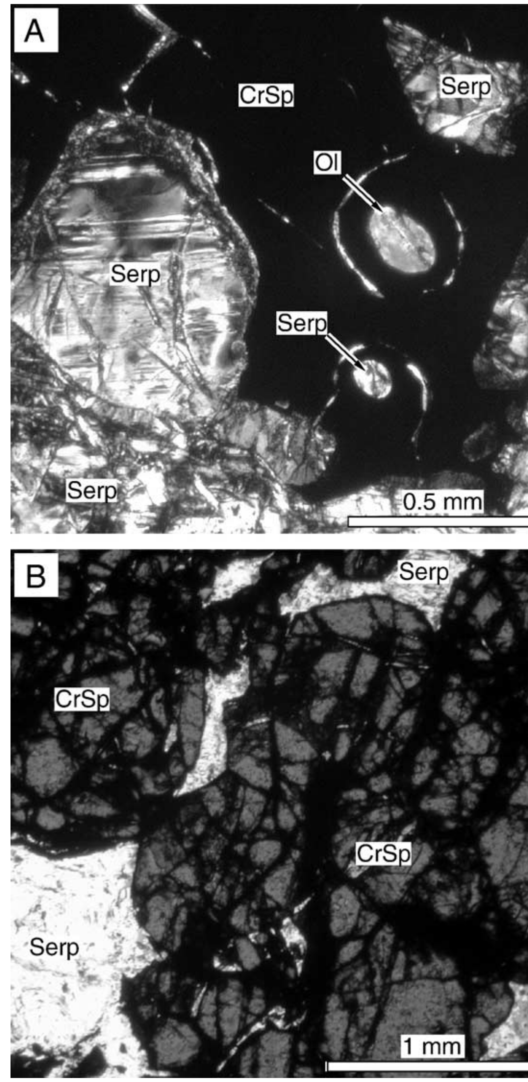

Fig. 2. Photomicrographs of serpentinite and chromitite from the HSB. (A) Crossed polarized light view of relict chromian spinel (CrSp) in serpentinite (Serp). Olivine (Ol) preserved as inclusion within chromian spinel. (B) Plane polarized light view of chromitite (abbreviations are same as A).

3.2. Chromitite

The chromitite studied in the HSB is composed of anhedral to subhedral chromian spinel (more than 95 vol.%) with serpentine and chlorite pseudomorphs after olivine (Fig. 2B). Grain sizes of the chromian spinel range from 0.5 to 1.5 mm. Chromian spinels are replaced by magnetite along internal cracks.

3.3. Gabbro

The gabbro is fine-grained and altered. It consists mainly of saussuritized plagioclase, relict clinopyroxenes and titanite

Table 1
Bulk-rock chemistry of serpentinites in HSB

	KTSM-SLC1	KTSM-SLC2	KTSM-SLC3	TH102/1a	TH102/1b
(wt.%)					
SiO_2	38.64	39.30	39.62	41.00	40.54
TiO_2	0.29	0.18	0.27	0.21	0.21
Al_2O_3	1.15	1.16	0.93	1.03	1.09
Fe_2O_3	6.74	6.53	6.54	6.36	6.03
FeO	2.13	2.03	1.88	2.11	2.15
MnO	0.16	0.15	0.16	0.16	0.15
MgO	36.18	36.08	35.94	36.24	36.85
CaO	0.35	0.95	0.09	0.29	0.15
Na_2O	0.01	0.01	0.01	0.11	0.09
K_2O	0.03	0.02	0.02	0.13	0.11
Total	85.68	86.41	85.46	87.64	87.37
(mg)	0.97	0.97	0.97	0.97	0.97

mg = MgO/(MgO + FeO) mole ratio.

Table 2
Major, trace and rare earth elements of gabbroic rocks in HSB

	HV.42	HV.84	HV.91	HV.209	HV.2097/1
Major oxides (wt.%)					
SiO_2	49.10	51.12	47.88	52.36	50.26
TiO_2	1.10	0.80	0.60	1.00	1.10
Al_2O_3	15.06	13.29	16.82	15.47	8.48
Fe_2O_3	4.57	2.92	3.60	0.95	1.80
FeO	5.46	5.50	4.74	6.90	7.80
MnO	0.17	0.17	0.17	0.13	0.16
MgO	8.45	9.06	8.65	7.56	11.36
CaO	10.05	11.47	12.18	7.57	13.21
Na_2O	2.79	3.04	2.50	2.08	2.50
K_2O	0.31	0.42	0.21	0.68	0.58
P_2O_5	0.16	0.16	0.08	0.69	0.31
Total	97.22	97.95	97.43	95.39	97.56
Trace elements (ppm)					
La	2.7	6.9	2.1	38	28
Ce	7.3	13	5.2	68	46
Pr	2.3	2.3	0.7	11	9
Nd	8.7	11	6.4	33	23
Sm	2.6	3.1	1.9	7.1	5.7
Eu	0.9	0.9	0.8	1.4	1.3
Gd	3.7	4.4	2.5	6.6	6.3
Tb	0.9	0.7	0.4	1.1	1.4
Dy	3.9	4.2	2.3	4.6	5.0
Er	2.7	2.9	1.7	2.7	3.2
Tm	0.4	0.4	0.3	0.4	0.5
Yb	2.4	2.6	1.3	2.2	2.3
Lu	0.4	0.4	0.2	0.3	0.4
Sr	233	822	463	155	287
Rb	30	24	7	38	21
Ba	206	134	30	225	227
Th	2.3	4.2	0.2	8.9	3.8
Ta	1.7	1.2	0.2	1.1	1.4
Nb	18	14	4	14	16
Zr	84	135	49	136	119
Hf	1.2	2.8	0.5	2.8	2.5
Y	20	23	11	22	24
Yb	2.4	2.6	1.3	2.2	2.3
mg	0.73	0.75	0.76	0.66	0.72
Zr/Y	4.3	5.9	4.3	6.3	5.0
Nb/Y	0.9	0.6	0.4	0.6	0.7
Ti/Y	338	210	316	278	275

mg = MgO/(MgO + FeO) mole ratio.

pseudomorphs after ilmenite. Minor amounts of secondary minerals such as chlorite, epidote and rare actinolite are also observed. This secondary mineral assemblage indicates a low greenschist facies metamorphism.

4. Bulk-rock chemistry

Bulk-rock major element compositions of representative serpentinites and gabbros were analyzed with an Atomic Absorption Spectrophotometer Shimadzu UV-1201V and Jenway PFP7 at the Center for Geological Analysis and Experiment of Vietnam (CGAEV). The trace element compositions of the gabbros were analyzed with an Inductively Coupled Plasma Spectrometer JY38S at CGAEV. The results are given in Tables 1 and 2. The Ni and Co contents of chromitite were analyzed with an Atomic Absorption Spectrophotometer Unicam SP9-Pye at CGAEV.

The analyzed serpentinites are characterized by low Al_2O_3 + CaO contents of 1.2–2.4 wt.% to the normalized total of 100%. The MgO/(MgO + FeO) mole ratios are 0.97. Since serpentinization may have modified the original bulk-rock composition, in particular, by the metasomatism, it is impossible to estimate the original composition before serpentinization.

The analyzed chromitites contain 96–104 ppm Co and 2072–2317 ppm Ni.

The analyzed fine-grained gabbros are basic (47.9–52.4 wt.% SiO_2). Except for samples HV.209 and HV.209 7/1, they are characterized by high Al_2O_3 (13.3–15.5 wt.%), moderate CaO (10.1–12.2 wt.%), Na_2O (2.5–3.0 wt.%), TiO_2 (0.6–1.1 wt.%), low MnO (0.17 wt.%) and P_2O_5 (0.08–0.16 wt.%). The MgO/(MgO + FeO) mole ratios ranges from 0.73 to 0.76. Nearly flat REE patterns (Fig. 3) and relationships of Zr (49–135)–Zr/Y (4.3–5.9) and Nb/Y (0.4–0.9)–Ti/Y (210–338) suggest MORB-like affinity (Pearce, 1982, 1983). In contrast, intensely altered samples HV.209 and HV.209 7/1 are characterized by higher K_2O (0.58–0.68 wt.%), P_2O_5 (0.31–0.69 wt.%) and Ba (225–227 ppm). They are enriched in La, Ce, Pr, Nd and Sm, and

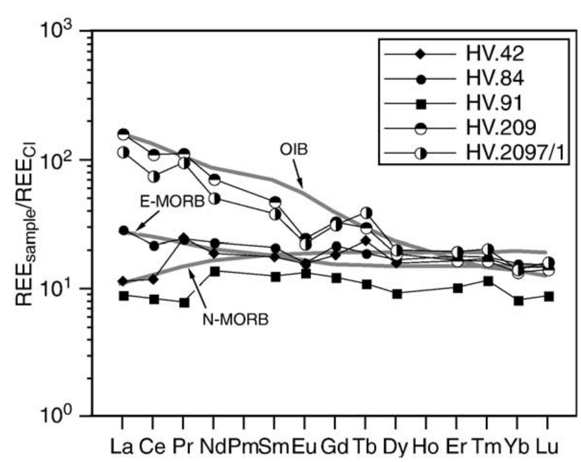

Fig. 3. CI chondrite-normalized rare earth element (REE) patterns for fine-grained gabbros from the HSB. Normalizing values are from Sun and McDonough (1989).

Table 3
Representative electron microprobe analyses

	Serpentinite		Chromitite	Gabbro
	CrSp	Ol-Inc	CrSp	Cpx
SiO_2		40.56		52.61
TiO_2	0.05	0.02	0.19	0.35
Al_2O_3	31.74	0.04	32.53	1.97
Cr_2O_3	37.02	0.25	36.11	0.10
FeO*	14.77	8.06	12.75	6.04
MnO	0.33	0.15	0.25	0.18
MgO	16.34	50.95	18.11	15.39
CaO		0.04		22.38
Na_2O		0.01		0.10
K_2O		0.00		0.00
NiO		0.46		
Total	100.24	100.06	99.94	99.12
O=	4	4	4	6
Si		0.985		1.954
Ti	0.001	0.000	0.004	0.010
Al	1.082	0.001	1.096	0.086
Cr	0.847	0.005	0.816	0.003
Fe^{3+}	0.069		0.081	
Fe^{2+}	0.288	0.164	0.224	0.188
Mn	0.008	0.003	0.006	0.006
Mg	0.705	1.844	0.772	0.852
Ca		0.001		0.890
Na		0.000		0.007
K		0.000		0.000
Ni		0.009		
Total	3.000	3.003	2.999	3.995
X_{Mg}	0.71	0.92	0.78	0.82
Y_{Cr}	0.44		0.43	

FeO* = total Fe as FeO. X_{Mg} = Mg/(Mg + Fe^{2+}).
Inc = inclusion in CrSp.

show a weak negative Eu anomaly. Some of these geochemical features may be related to alteration as evidenced by abundant secondary epidote and kaolinite.

5. Mineral compositions

Electron microprobe analyses of the main rock-forming minerals were carried out with a JEOL JXA-8900R at Okayama University of Science. The analyses were performed with 15 kV accelerating voltage, 12 nA beam current and 5 μm beam size. Natural and synthetic silicates and oxides were used as standards for calibration. The ZAF (oxide basis) method was employed for matrix corrections. Representative analyses of chromian spinel, olivine and clinopyroxene are listed in Table 3.

5.1. Chromian spinel

Chromian spinels in the serpentinite are characterized by low Y_{Cr} [Cr/(Cr + Al) atomic ratio] of 0.43–0.44 and low Ti content (<0.1 wt.% TiO_2). The X_{Mg} [Mg/(Mg + Fe^{2+}) atomic ratio] ranges from 0.70 to 0.73. Chromian spinels in chromitite also have similar Y_{Cr} compositions (0.43–0.44) but they are characterized by slightly higher X_{Mg} (0.77–0.80) and Ti content (0.19–0.23 wt.% TiO_2) (Fig. 4A). The analyzed chromian spinels are comparable with those chromian spinels from Alpine type and abyssal peridotites (Evans and Frost, 1975; Dick and Bullen, 1984; Dick, 1989; Arai, 1987, 1994).

5.2. Olivine

Olivine inclusions in the chromian spinel of the serpentinite have a composition of 91.9 mol.% forsterite (Fo) with 0.46 wt.% NiO, 0.04 wt.% Cr_2O_3 and 0.15 wt.% MnO. These values are similar to typical mantle olivine (e.g., Takahashi et al., 1987). The olivine inclusions are volumetrically smaller than the host chromian spinel. Hence the X_{Mg} value of the

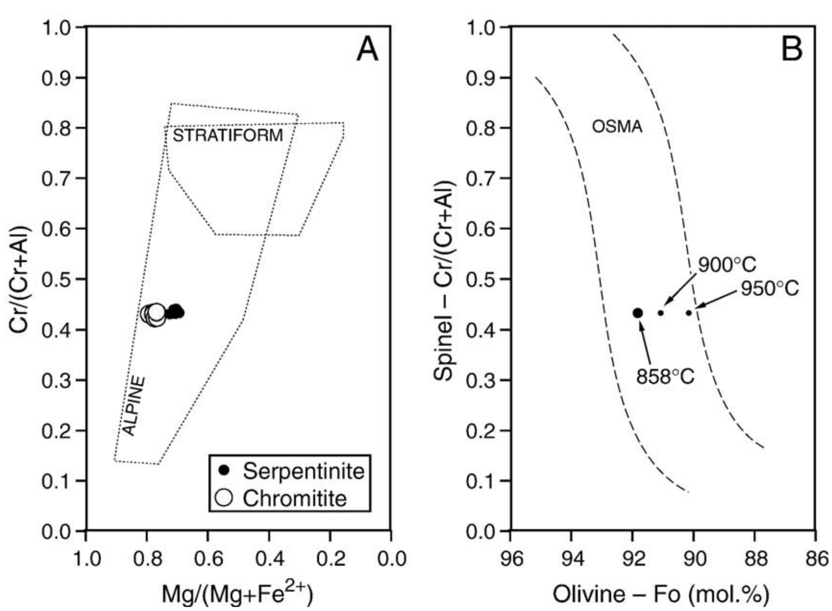

Fig. 4. Compositional plots of analyzed chromian spinel in serpentinite and chromitite from the HSB. (A) Cr/(Cr + Al) versus Mg/(Mg + Fe^{2+}) diagram. The generalized compositional ranges of Alpine and stratiform peridotites are from Evans and Frost (1975). (B) Compositional relationship between chromian spinel and coexisting olivine inclusion. Apparent Mg–Fe^{2+} temperature and calculated olivine Fo contents at 900 and 950 °C are also shown. OSMA represents olivine–spinel mantle array proposed by Arai (1987).

olivine inclusions may have been affected by subsolidus $Mg-Fe^{2+}$ redistribution between the olivine and the host chromian spinel. The apparent $Mg-Fe^{2+}$ partitioning constant (K_D) between the olivine inclusion (Fo_{92}) and host chromian spinel is 4.2, indicating a re-equilibration temperature of about 860 °C (Fabries, 1979). The calculated Fo component in olivine equilibrated with host chromian spinel at 900–950 °C has a slightly Fe-richer composition (Fo_{90-91}). However, the relationship between the Fo content of the olivine (Fo_{90-92}) and chromian spinel (Y_{Cr}=0.43–0.44) suggests a spinel-bearing less-depleted (lherzolitic) harzburgite as the original peridotite (e.g., Arai, 1994).

5.3. Clinopyroxene

Clinopyroxene in the gabbro has a diopsidic composition, containing 1.6–2.5 wt.% Al_2O_3, 0.3–0.6 wt.% TiO_2, 0.05–0.18 wt.% Cr_2O_3 and 0.04–0.17 wt.% Na_2O. The X_{Mg} ranges from 0.81 to 0.83.

6. Tectonic implications

What do the serpentinite bodies in the SMFZ mean? The finding of relict chromian spinel with olivine inclusions in the HSB is significant in terms of origin and the tectonic setting of the serpentinite. The petrological work has defined some of the compositional characteristics of primary minerals in ultramafic rocks from the SMFZ. The inferred original peridotite, with chromian spinel of Y_{Cr}=0.43–44, is lherzolitic harzburgite of the type that formed in an environment with a low degree of melt depletion in slow-spreading or rift settings (e.g., Arai, 1987, 1994; Dick, 1989; Matsukage and Kubo, 2003). In the north of the SMFZ, Permian–Triassic komatiites of the Emeishan continental flood basalt province occur as a narrow belt in the Song Da zone. It has been considered that komatiites and related mafic–ultramafic volcanic rocks were formed in a continental rift environment (e.g., Glotov et al., 2001; Hanski et al., 2004), but their petrologic characteristics do not match with those of the SMFZ. Although the HSB does not have ophiolitic traits, the inferred original peridotite, with chromian spinel of Y_{Cr}=0.43–44, may be comparable with a mantle section of some Tethyan lherzolitic ophiolites (e.g., Nicolas and Duouy, 1984; Ishiwatari, 1985). The presence of high Al-type chromitite also supports the oceanic setting (Arai, 1997). Moreover, the less altered fine-grained gabbro associated with the HSB has MORB-like geochemical features. Therefore, it is suggested that the HSB represents a remnant of paleo-oceanic lithosphere between the Indochina and South China blocks. This would be consistent with a model that interprets the SMFZ as a suture.

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