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META-ULTRAMAFIC ROCK FROM THE AUSTKAMPANE AREA OF THE SØR RONDANE MOUNTAINS, EAST ANTARCTICA

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Abstract: In the Austkampane area of the Sør Rondane Mountains, East Antarctica, a meta-ultramafic rock occurs as a lenticular block enclosed within the host garnet-biotite gneiss of the granulite facies. The rock consists of olivine, orthopyroxene, amphibole, spinel, apatite, ilmenite, magnetite, chalcopyrite and pentlandite. The bulk rock analysis shows an ultramafic composition in a broad sense, but compared with mantle peridotites it is enriched in TiO_2, Al_2O_3, CaO, Nb and Zr, and has a slightly high ratio of FeO*/MgO. This suggests a slightly differentiated basaltic cumulate as its precursor. After the igneous generation, the rock was incorporated within the original rock of the host gneiss (sedimentary quartzo-feldspathic rock), probably in the form of block-in-matrix, and then both rocks underwent the granulite facies metamorphism. The olivine-spinel geothermometer and Al_2O_3 content of orthopyroxene indicate metamorphic temperatures of about 780–820°C and 750–800°C, respectively. Similar meta-ultramafic rocks have been reported from the Lützow-Holm Complex, suggesting that the similar association of original rocks such as oceanic lower crusts developed in these two granulite terrains.

key words: meta-ultramafic rock, chemistry, cumulate, Sør Rondane Mountains

1. Introduction

In the Austkampane area of the Sør Rondane Mountains, East Antarctica, various kinds of metamorphic and plutonic rocks such as basic gneiss, pelitic gneiss, psammitic gneiss, calc-silicate rock, sapphirine-bearing rock, granite and diorite occur (ISHIZUKA and KOJIMA, 1987; ISHIZUKA *et al.*, 1995). On the basis of the mineral assemblage of the pelitic gneiss, *e.g.*, sillimanite+garnet+biotite+K-feldspar +plagioclase+quartz, the peak metamorphic conditions are estimated to reach the granulite facies at about 750–850°C and 7–8.5 kbar (ASAMI *et al.*, 1992). Reaction textures observed in the sapphirine-bearing rock also suggest that the area may have suffered nearly isothermal decompression after the peak metamorphism (ISHIZUKA *et al.*, 1995). Furthermore, the appearance of andalusite and muscovite, both of which partially overprint the minerals of the granulite facies, is suggestive of retrograde metamorphism of about 530–580°C and 5.5 kbar (YOSHIKURA *et al.*, 1992).

From this area, a meta-ultramafic rock (No. 86010602B) was collected as a unique litho-facies by the summer party of the 27th Japanese Antarctic Research Expedition and has been described briefly (ISHIZUKA and KOJIMA, 1987). This report describes the detailed petrography of this meta-ultramafic rock, and discusses its significance with respect to the problem of the original rock association of the Sør Rondane Mountains. Meta-ultramafic rocks have been also reported from the Balchenfjella area of the eastern Sør Rondane Mountains (ASAMI *et al.*, 1989; MAKIMOTO *et al.*, 1990) and from the Lützow-Holm Complex (HIROI *et al.*, 1986; SUZUKI, 1986); a brief comparison among these meta-ultramafic rocks is also presented in relation to the original rock association of these areas.

2. Field Occurrence and Petrography

The Austkampane area is underlain by various kinds of metamorphic and plutonic rocks (Fig. 1). Among the metamorphic rocks, garnet-biotite gneiss is the dominant lithology, of which the foliation strikes NE-SW to E-W and gently (25–60°)

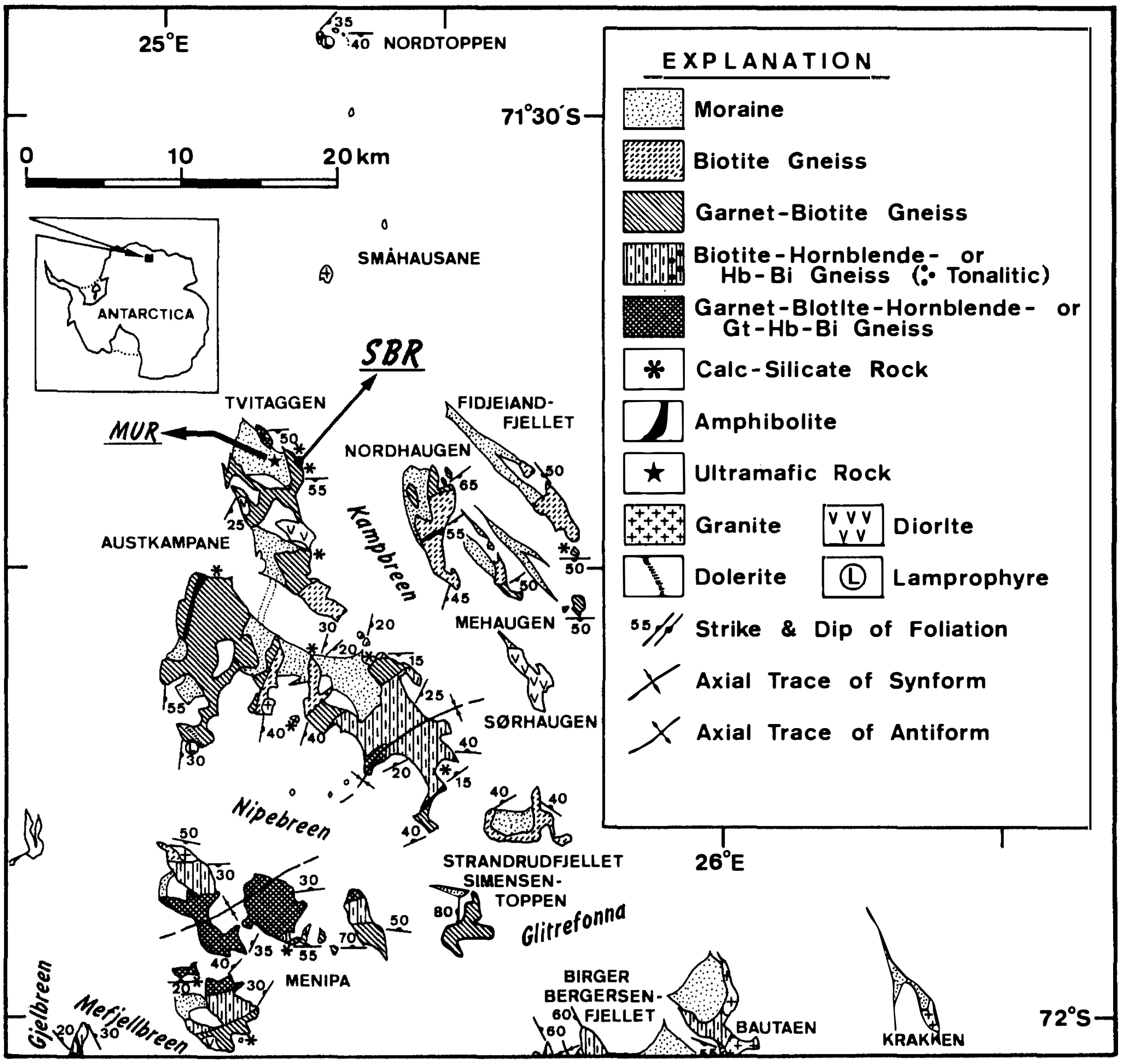

Fig. 1. Geological map of the Austkampane area, Sør Rondane Mountains (after ISHIZUKA *and* KOJIMA, *1987), in which the localities of the meta-ultramafic rock (MUR) and sapphirine-bearing rock (SBR) are shown.*

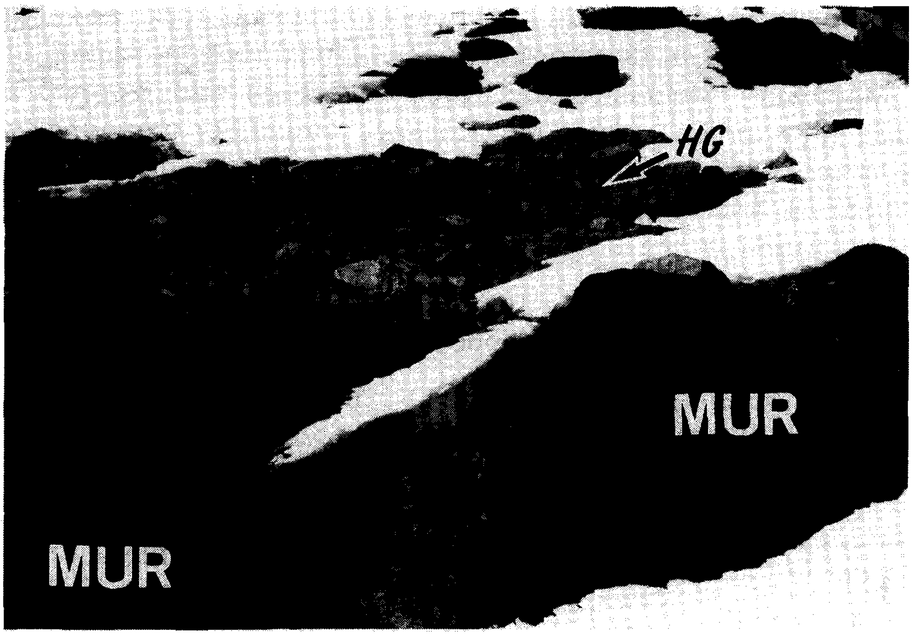

Fig. 2. Field occurrence of the meta-ultramafic rock (MUR). Note that the rock is enclosed within the host gneiss (HG).

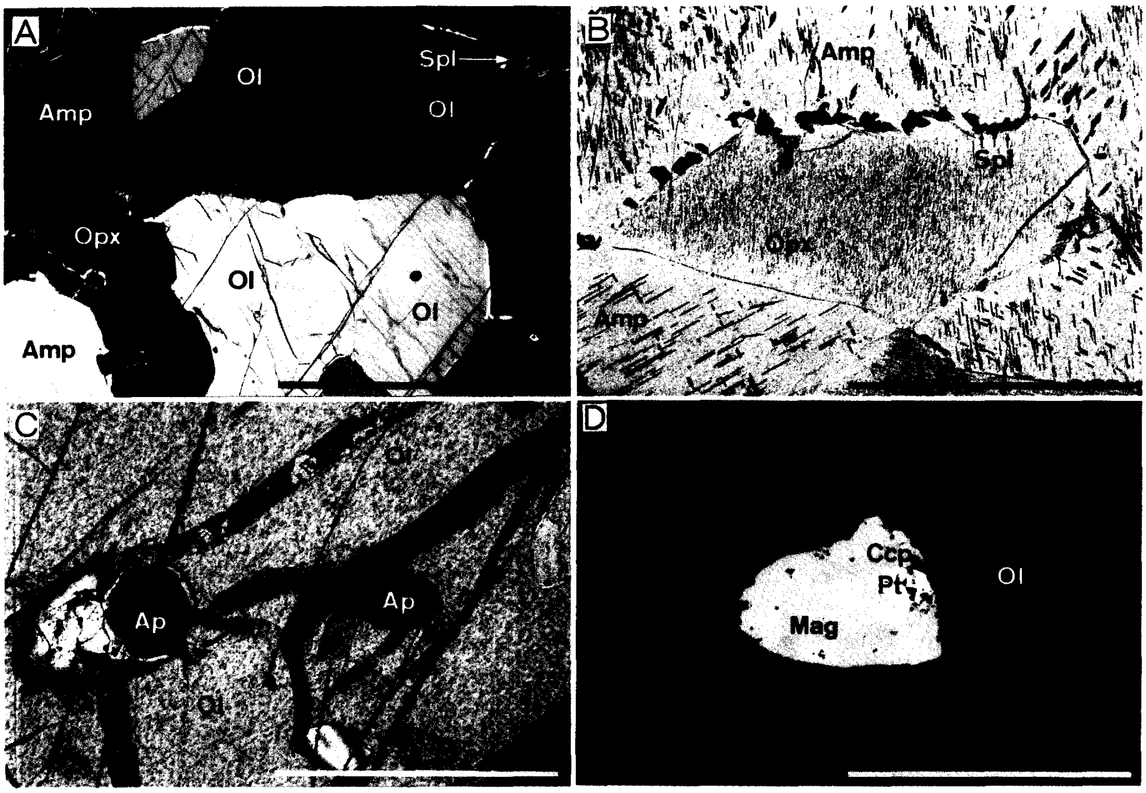

Fig. 3. Photomicrographs of the meta-ultramafic rock. A: Granular texture composed of Ol, Opx and Amp. Scale bar=2 mm. B: Vermicules of Spl occurring along the margin of Amp. Note that lamellae of Ilm develop within Amp. Scale bar=1 mm. C: Euhedral Ap included in Ol. Scale bar=0.2 mm. D: Composite grain of Mag+Ccp+Pt. Scale bar=0.2 mm.

dips southward. The calc-silicate rocks occur as small lenses or blocks in the garnet-biotite gneiss. Plutonic rocks such as granite and diorite intrude into the gneisses, of which the latter includes, very rarely, a block of the sapphirine-bearing rock.

The meta-ultramafic rock in question was sampled from the northern region of the Austkampane area. It occurs as a lenticular block (about 10 m in diameter of long-axis) enclosed within the host garnet-biotite gneiss (Fig. 2), similar to the block-in-matrix type of the field occurrence in mélange. The foliation of the host gneiss is concordant with the margin of the block. A dark-grayish reaction zone (several centimeters in width) composed of fibrous mica and/or amphibole minerals develops along the contact between the block and host gneiss.

The rock is massive with a medium- to coarse-grained granular texture; representative photomicrographs are shown in Fig. 3. This contrasts with the surrounding rocks that display well-developed metamorphic foliation. The constituent minerals include olivine (Ol), orthopyroxene (Opx), amphibole (Amp), spinel (Spl), apatite (Ap), ilmenite (Ilm), magnetite (Mag), chalcopyrite (Ccp), and pentlandite (Pt). The modal proportion is presented in Table 1. There is no trace of serpentinization in the rock. Neither plagioclase (Pl) nor garnet (Grt) occurs in the rock, indicating that the rock belongs to spinel-amphibole peridotite in the sense of JENKINS (1983).

The majority of Ol occurs as granular crystals (Fig. 3A), but small amounts of Ol have tiny irregular-shaped forms that exist characteristically along the boundary between Opx and Amp. Opx is also granular in form, and displays a weak pleocroism from pale red to pale green, in which fine-scaled cleavages commonly develop. Small and irregular-shaped grains of Opx sometimes occur along the boundary between Amp and Ol. Amp occurs only as granular crystal, and has a pale blue-greenish color. Spl with translucent green color shows various modes of occurrence (Fig. 3B): granular crystal, vermicule or bleb along the margin of Amp, and irregular-shaped

Table 1. Modal proportion and bulk rock chemistry of meta-ultramafic rock (No. 86010602B).

Modal proportion		Bulk rock chemistry			
	(%)		(wt%)		(ppm)
Olivine	16.9	SiO_2	40.40	Co	124.3
Orthopyroxene	33.1	TiO_2	0.74	Cr	103.6
Hornblende	46.9	Al_2O_3	9.32	Nb	14.2
Spinel	2.8	FeO*	18.45	Ni	456.0
Others**	0.3	MnO	0.23	Rb	3.6
		MgO	23.78	Sr	67.4
**Includes apatite,		CaO	5.08	V	135.2
ilmenite, magnetite,		Na_2O	0.41	Y	9.1
chalcopyrite,		K_2O	0.31	Zn	130.0
and pentlandite.		P_2O_5	0.10	Zr	53.8

FeO* means total iron as FeO.

crystal along the boundary between Ol and Opx. Other minerals (Ap, Ilm, Mag, Ccp and Pt) are scattered as accessories, of which Ap is commonly euhedral and restricted to inclusion within Ol (Fig. 3C), Ilm often forms lamellae within Amp (Fig. 3B), and Mag+Ccp or Mag+Ccp+Pt occurs as composite grain (Fig. 3D).

3. Bulk Rock and Mineral Chemistries

The bulk rock analysis of the meta-ultramafic rock was performed by using an X-ray fluorescence analyzer Rigaku RIX3000 at the National Institute of Polar Research. The analytical procedure followed the methods of MOTOYOSHI and SHIRAISHI (1995) and MOTOYOSHI *et al.* (1996). The results are listed in Table 1. Chemical compositions of constituent minerals were analyzed by using an electron probe microanalyzer JEOL JXA-8600S/M at Kochi University. Representative mineral analyses are listed in Table 2 and plotted in the system $CaO-(FeO+MgO)-Al_2O_3-SiO_2$ of Fig. 4. In the following discussion, the ratio of $Fe^*/(Fe^*+Mg)$ is abbreviated to XFe*, in which Fe* means total iron as Fe^{2+}.

The bulk compositions of the meta-ultramafic rock are characterized by high MgO, FeO*, Co, Cr and Ni contents and low SiO_2 content, being consistent with ultramafic composition. However, the rock is also enriched in TiO_2, Al_2O_3 and CaO, and includes considerable amounts of Nb and Zr. The FeO*/MgO ratio is about 0.78. As many major and minor elements, especially large ion lithophile elements such as K, Rb and Sr, are mobile during medium- to high-grade metamorphism (*e.g.*,

Table 2. Representative mineral analyses of meta-ultramafic rock (No. 86010602B).

Mineral	Ol-C	Ol-R	Ol-IS	Opx-C	Opx-R	Opx-IS	Amp	Spl-G	Spl-V	Spl-IS
SiO_2	37.38	36.59	36.62	53.58	52.52	52.24	43.06	0.01	0.01	0.02
TiO_2	0.01	0.01	0.00	0.05	0.08	0.11	1.49	0.05	0.04	0.04
Al_2O_3	0.00	0.00	0.00	4.17	2.66	2.80	14.75	61.73	61.77	61.13
Fe_2O_3	–	–	–	–	–	–	–	3.71	2.36	2.49
Cr_2O_3	0.00	0.01	0.00	0.03	0.00	0.05	0.00	0.20	0.12	0.14
FeO*	28.54	32.19	31.47	15.93	18.14	18.45	9.87	22.88	22.80	22.79
MnO	0.42	0.38	0.35	0.43	0.33	0.38	0.08	0.19	0.13	0.10
MgO	33.80	31.24	31.76	26.10	25.72	25.61	14.30	12.39	12.07	11.96
NiO	0.17	0.04	0.09	0.04	0.04	0.00	0.07	0.21	0.25	0.19
CaO	0.01	0.02	0.01	0.25	0.26	0.26	12.08	0.01	0.04	0.01
Na_2O	0.00	0.01	0.05	0.00	0.01	0.00	1.24	0.00	0.00	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.00	0.62	0.00	0.00	0.00
P_2O_5	0.01	0.01	0.00	0.01	0.00	0.00	0.02	0.00	0.02	0.00
Total	100.34	100.50	100.35	100.59	99.76	99.90	97.58	101.38	99.61	98.87
XFe*	0.32	0.37	0.36	0.26	0.28	0.29	0.28	0.51	0.51	0.52

Ol-C and Ol-R: core and rim of zoned crystal, Ol-IS: irregular-shaped crystal, Opx-C and Opx-R: core and rim of zoned crystal, Opx-IS: irregular-shaped crystal, Amp: homogeneous granular crystal, Spl-G: homogeneous granular crystal, Spl-V: vermicular crystal, Spl-IS: irregular-shaped crystal, XFe*: $Fe^*/(Fe^*+Mg)$. FeO* means total iron as FeO, except for Spl for which Fe_2O_3 and FeO were calculated from total iron assuming ideal spinel formula.

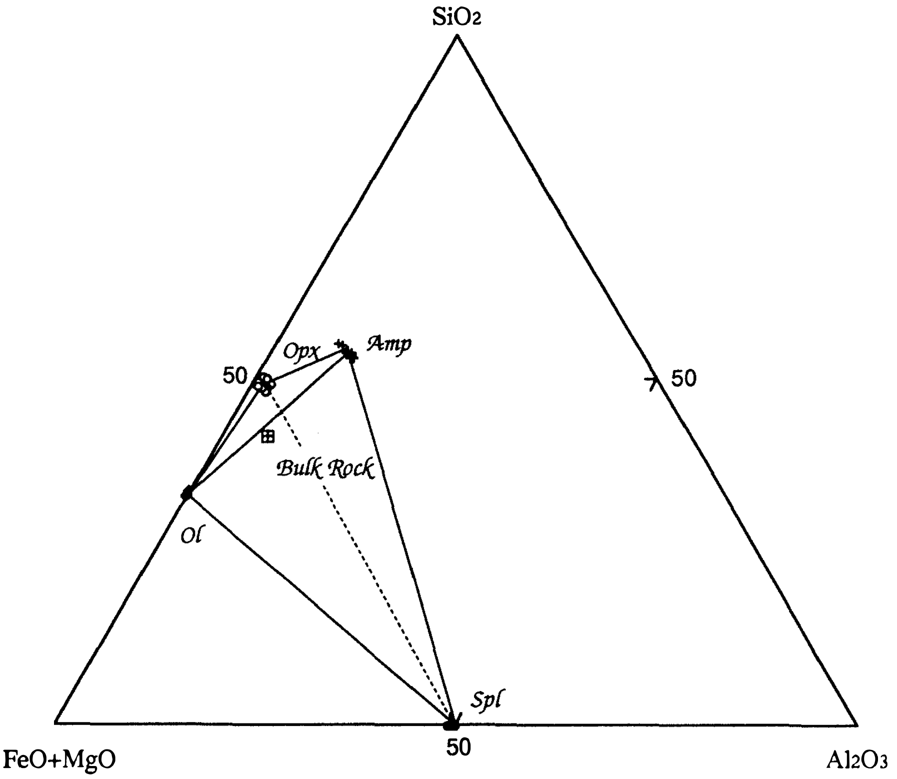

Fig. 4. Projection of mineral and bulk rock compositions from the CaO component on to the (FeO+MgO)–Al_2O_3–SiO_2 plane. Note that the bulk rock composition lies just within the tetrahedron of Ol+Opx+Amp+Spl, and it is consistent with this 4-phase mineral assemblage.

CONDIE, 1981), the primary composition of the meta-ultramafic rock may have been masked. However, it is commonly assumed that Ti, Co, Cr, Ni, Nb and Zr are resistant to such secondary processes (*e.g.*, CONDIE, 1981), and then the chemical features of the meta-ultramafic rock described above may represent its original chemical affinity. On the other hand, the bulk rock composition is also plotted in the system CaO–(FeO+MgO)–Al_2O_3-SiO_2 of Fig. 4, showing that the data lies just within the tetrahedron of Ol-Opx-Amp-Spl, and then it is very consistent with this 4-phase mineral assemblage.

Granular Ol is compositionally zoned, and its XFe* ranges from 0.32 in the core to 0.37 at the rim. Irregular-shaped Ol has XFe* of 0.35–0.37, similar to those of the rim of zoned granular Ol. The NiO and MnO contents are 0.02–0.18 wt% and 0.35–0.48 wt%, respectively.

Granular Opx is also compositionally zoned with XFe* ranging from 0.26 in the core to 0.29 at the rim. Irregular-shaped grains of Opx have XFe* of 0.28–0.29. The Al_2O_3 and CaO contents of granular Opx range from 4.1 wt% in the core to 1.1 wt% at the rim and from 1.83 wt% in the core to 0.24 wt% at the rim, respectively, whereas these elements are very low in irregular-shaped Opx, being up to 1.7 wt% Al_2O_3 and 0.28 wt% CaO. It is then clear that the compositions of irregularly-shaped Opx are similar to those of the rim of zoned granular Opx.

Amp is generally homogeneous, and has compositions ranging from Mg-hornblende to tschermakitic hornblende in the sense of Leake (1978). Minor elements include up to 1.5 wt% TiO_2, 1.3 wt% Na_2O, and 0.55 wt% K_2O.

Although Spl compositions slightly vary irrespective of mode of occurrence, they are generally characterized by a high $Al/(Al+Cr+Fe^{3+})$ ratio ranging from 0.95 to 0.99. The Cr_2O_3 and Fe_2O_3 contents are up to 0.22 wt% and 4.44 wt%, respectively. XFe* ranges from 0.50 to 0.53.

4. Discussion

Most importantly, the bulk rock composition indicates that the meta-ultramafic rock described here may have been derived from a basaltic cumulate rather than a mantle peridotite, even though the rock has been completely modified by metamorphic deformation and shows no sign of igneous cumulate texture. Furthermore, the relatively high FeO*/MgO ratio (=0.78) suggests the rock to be crystallized from a slightly differentiated magma. On the basis of bulk rock compositions, Osanai *et al.* (1992) divided the basic rocks from the central Sør Rondane Mountains into five Units (I–V). The area studied here belongs to Unit-I that has chemical affinity with mid-ocean ridge basalt (MORB). It is, therefore, most likely that the meta-ultramafic rock represents a slightly differentiated cumulate phase evolved from a MORB-like magma.

After generation as a igneous cumulate, this precursor and related basic rock were incorporated as blocks into the matrix of quartzo-feldspathic rock (now represented by garnet-biotite gneiss), probably related to the sedimentary process modeled for the formation of mélange, and then they underwent the metamorphism together with the host rock. As there is no chemical reaction texture preserved in the rock, the conditions of metamorphism are only estimated by mineral compositions. In this connection, the Ol-Spl geothermometer of Fabriés (1979) was applied to the granular Ol and Spl. The results range from 750°C to 800°C. Another estimation of temperature was done by using the Al_2O_3 solubility of Opx coexisting with Ol and Spl (Gasparik, 1987). This thermometer is well known to be highly temperature sensitive, and yields 780–820°C for the granular Opx with XFe*=0.26–0.29. These calculated temperatures are consistent with those (750–850°C) of the peak metamorphism in the Sør Rondane Mountains as estimated by the mineral assemblage of the pelitic gneisses (Asami *et al.*, 1992).

From the Balchenfjella area of the eastern Sør Rondane Mountains, Asami *et al.* (1989) and Makimoto *et al.* (1990) have also described meta-ultramafic rocks such as harzburgite, orthopyroxenite and garnet amphibolite. Of these, the harzburgite that is characterized by the assemblage of Ol+Opx with minor Cpx, Spl and Amp has similar field occurrence and mineral assemblage to those of the meta-ultramafic rock described here, but in a strict sense the mineral compositions are different from each other. The harzburgite of Balchenfjella has magnesian Ol (XFe*=0.1) and Opx (XFe*=0.1), and is interpreted to have been derived from a mantle peridotite. Therefore, there may be two types of ultramafic rocks with respect to original rocks in the Sør Rondane Mountains, that is, a basaltic cumulate and mantle peridotite.

Furthermore, in the Austkampane area, there is sapphirine-bearing rock that was derived from a troctolitic rock (Ishizuka *et al.*, 1995). This is another type of original rocks. These facts suggest that various kinds of precursors existed in the Sør Rondane Mountains, and then, they suffered the granulite facies metamorphism together with the surrounding pelitic rocks.

Several types of meta-ultramafic rocks have also been reported from the Lützow-Holm Complex, of which some were analyzed for the bulk rock compositions of major elements (Hiroi *et al.*, 1986; Suzuki, 1986). Some types of meta-ultramafic rocks of the Lützow-Holm Complex are Ol-bearing but Pl-free, and have similar field occurrence, mineral assemblage and major element compositions to those of the meta-ultramafic rock described here. Hiroi *et al.* (1986) also interpreted these rocks as cumulate gabbros derived from MORB-like magma. It follows that the similar association of original rocks such as oceanic lower crusts developed both in the Sør Rondane Mountains and Lützow-Holm Complex; a comparative study of these rocks may play an important role in evaluating the geologic evolution in East Antarctica.

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