The Characteristic of Serpentinised Ultramafic Rocks from South Sulawesi Indonesia: Constraint from Petrology and Geochemistry Data

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Abstract

Highly serpentinised ultramafic rocks occur in two separated basement complexes in the South Sulawesi, Bantimala and Barru blocks. The characteristics of the ultramafic are assessed using petrology and geochemistry data. The Bantimala ultramafic rocks consists mainly of serpentinised peridotite (harzburgite and dunite) and cumulates clinopyroxenite with locally podiform chromitite found enclosed in the peridotite bodies. They have been metamorphosed into greenschist facies. In contrast, the Barru ultramafic rocks are composed of strongly serpentinised and metamorphosed lherzolite and harzburgite peridotite and podiform chromitite. They suffered from amphibolite facies metamorphism overprint and later intruded by huge body of volcanic rocks. The absent of garnet indicates that the ultramafic rocks in both blocks were not experienced high-pressure condition.

Geochemical classification suggests that all the Bantimala and Barru ultramafics are different from each other. Based on trace element analysis including Nb and Ta anomalies as well as the Cr-spinel compositions suggests that the Barru lherzolite has had some melt extracted and is derived from suprasubduction zone (SSZ) environment, while the Bantimala dunite, harzburgite and clinopyroxenite are cumulates origin. Moreover, the Cr-spinel composition from the podiform chromitite in both blocks showed a very different characteristics, suggesting the different sources.

INTRODUCTION

Sulawesi Island is located in the central part of the Indonesian archipelago, which consists of four tectonic provinces namely (Kadarusman et al., 2004; Maulana, 2009) ; (1) the West and North Sulawesi Pluto-Volcanic Arc which occupies the south and north arm of the island, (2) the Central Sulawesi Metamorphic Belt which extends from central to south eastern arm part of the island, (3) the East Sulawesi Ophiolite Belt in the eastern arm and (4) the Banggai-Sula and Tukang Besi continental fragments.

Each of these provinces is characterized by the occurrences of pre-Tertiary rocks which contain metamorphic and mafic-ultramafic suites. Petrological and geochemical studies of the ultramafic suites from the Central Sulawesi Metamorphic Belt and the East Sulawesi Ophiolite Belt as well as the Banggai-Sula and Tukang Besi have been done in detail (Kadarusman et al., 2004; Kadarusman and Parkinson, 2000; Kadarusman et al., 2002; Smith and Silver, 1991). However, unlike those three provinces, no detail study has been conducted so far on the ultramafic suites from the Western Sulawesi Volcanic Arc, particularly from the south arm of Sulawesi except that from Sukamto (1982) and van Leeuween (1981) which only reported the general geology of the ultramafic sequences. As the occurrences of ultramafic suites may provide important information on the tectonic evolution of this region, detail study is needed to shed the light on their tectonic significances.

In this paper, characteristics of the ultramafic rocks including petrography and chemical data (major-trace elements including REE) which are found in two separated areas; Bantimala and Barru region, are firstly reported. These data are used to identify the origin of the ultramafic suites by comparing them with the previously reported ultramafic studies. The conclusion drawn are used to provide insight into the tectonic setting and geodynamic process associated with their generation.

REGIONAL GEOLOGY

Geology of this region consists of 5 (five) primary sequences; pre-Tertiary basement complex, Upper Cretaceous sediments, Paleogene volcanism, Eocene to Miocene sedimentation and Miocene to Recent volcanism and sedimentation (Maulana, 2009).

The first is the pre-Tertiary basement complex, which was formed by the metamorphic and ultramafic rock assemblages and can be found in two separated blocks, Bantimala and Barru block. The Bantimala block consists of HP metamorphic block (eclogite and blueschist) which was overprinted by either retrograde blueschist or greenschist facies assemblages whereas the Barru block is characterized by greenschist- to amphibolite-facies rocks assemblages with no trace of HP metamorphic rocks (Maulana et al., 2008). The ultramafic rock is dominated by serpentinised peridotite, which contains chromite lenses in some areas and is locally intruded by dacite and andesite (van Leeuwen, 1981).

The pre-Tertiary basement complex was covered with the Cretaceous sediments which can be classified into two group; Balangbaru and Marada Formation. The first is composed of interbedded sandstones and silty shales, with less important conglomerates, pebbly sandstones and conglomeratic breccias (Sukamto, 1982) whereas the later consists of a succession of alternating impure sandstones, siltstones and shales (van Leeuwen, 1981).

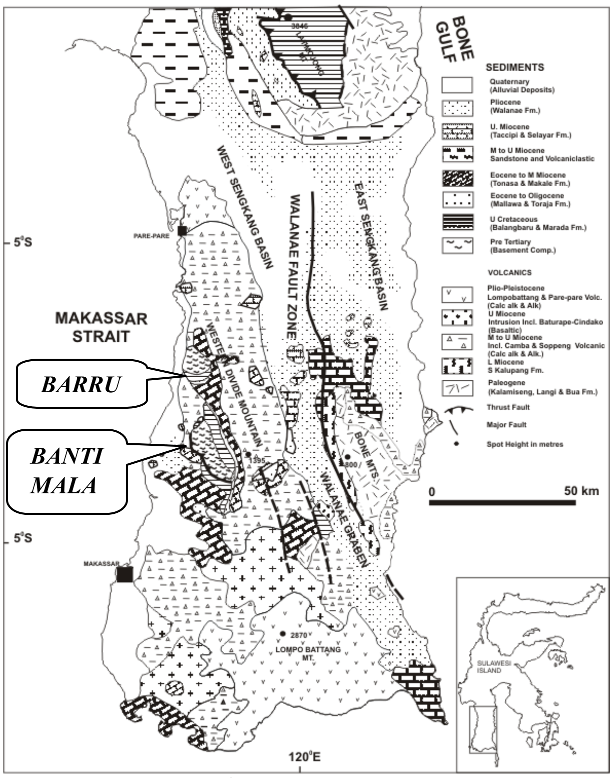


Fig.1. Regional geology of South Sulawesi (Maulana, 2009)

The sandstones are mostly feldspathic greywacke which are locally calcareous, composed of subangular to angular grains of quartz, plagioclase and orthoclase with subordinate biotite, muscovite and angular lithic fragments embedded in a matrix of clay minerals, chlorite and sericite.

Paleogene volcanism in the region is represented by the Kalamiseng, Langi and Bua Volcanics. The volcanics consist of lavas and pyroclastic deposits of andesitic to trachy-andesitic composition, with rare intercalations of limestone and shale towards the top of the sequence and show a strongly fractured, poorly bedded texture (Sukamto, 1982; van Leeuwen, 1981).

Eocene to Miocene sediments can be grouped into two: Mallawa Formation and Tonasa Formation. The first are composed of arkosic sandstones, siltstones, claystone, marls and conglomerates, intercalated with layers or lenses of coal and limestone whereas the latter consists of carbonate facies rock which can be classified into four members labelled A,B,C and D from the bottom to top (Wilson and Bosence, 1996).

Miocene to Recent volcanism and sedimentation in this region consists of various formations, including, in order of decreasing age, the Upper Camba Formation, Baturape–Cindako Volcanics, Soppeng Volcanics, Pare-pare Volcanics, Lemo Volcanics, and the Lompobattang Volcanics.

ANALYTICAL METHODS

Optical petrography was undertaken manually by using a Nikon petrographic microscope with 10× eyepieces and 5×, 10×, 20× and 40× objective lenses, equipped with a Nikon E4500 camera attached to the trinocular port for micrography.

Whole-rock major elements were analysed by X-ray fluorescence analyses (XRF), trace element were analysed by laser ablation inductively-coupled plasma mass spectrometry (LA-ICP-MS). Major elements Na, Mg, Al, Si, P, S, K, Ca, Ti, Mn, Fe, F and Cl were assessed by XRF with a Phillips (now Panalytical) PW2400 wavelength-dispersive X-ray fluorescence spectrometer. The major elements were calibrated against a set of 28 international standard rock powders and all the units are in wt%. All analyses were conducted at the Research School of Earth Sciences, ANU. The LA ICP-MS employs an ArF^+ (193 nm) excimer laser and a Hewlett Packard Agilent 7500 ICP-MS. The counting time was 20 seconds for the background and 60 seconds for sample analyses. The external standard for calibration was NIST 612 glass, using the standard reference values of Pearce et al. (1979). All the units for the trace element are in ppm. Si was employed as the internal standard, employing the SiO_2 concentration previously measured by XRF.

Loss-on-ignition (LOI) values were calculated from the mass differences in approximately 2 grams of powdered sample after heating to 1010 °C in the furnace for one hour.

RESULT

Petrography

Summaries of the field and petrographic characteristics of representative ultramafic rocks from the South Sulawesi Basement Complexes are listed in Table 1.

Table 1. Mineral assemblages of ultramafic rocks

Sample	Mineral assemblages	Retrograde assemblages	Locality	Rock
Bantimala block				
MOR01	$Ol^R+Cpx^R+Opx^R$	Srp+Chl+Spl	1	Dunite
MOR02B	$Ol+Cpx^R+Opx^R$	Srp+Chl+Spl	1	Harzburgite
MOR 2A	Ol+Cpx+Ccp+Brn++Pn+Cr-spl	Srp+Chl+Ilm+Fe-Cr+Mag	1	Olivine clinopyroxenite
MOR4A	Ol+Cpx+Cr-spl	Srp+Chl+Mag	1	Olivine clinopyroxenite
MOR3A	$Ol+Cpx^R+Opx^R$	Srp+Chl	1	Harzburgite
MOR3B	Cr-spl	Chl+Srp	1	Podiform chromitite
BGR 02	–	Tr+Chl	2	Tremolite schist
BGR 01	–	Srp+Chl+Spl	2	Serpentinite
Barru block				
AM16	$Ol+Opx+Cpx^X+Cr\text{-}spl^X+Pn$	Hbl+Tr+Srp	3	Spinel lherzolite
DNG01	Ol+Opx+Cpx+Cr-spl	Hbl+Tr+Srp	4	
BR01	$Ol^R+Opx^R+Cpx^R+Cr\text{-}spl$	Srp+Chl	5	Harzburgite
BR02	$Ol^R+Opx^R+Cpx^R+Cr\text{-}spl$	Srp+Chl	5	
BR03	Cr-spl	Chl+Srp	3	Podiform chromitite

1. Moreno Hill. 2. Batugarencing Hill.3. Sabangnairi Hill. 4. Lasitae Mountain. 5. Kamara Village. R = relict, X = exsolution

Bantimala Block

The ultramafic rocks in the Bantimala block occur as olivine clinopyroxenite and serpentinised peridotite (harzburgite and dunite). Podiform chromitite occurs as lens shaped blocks or nodules within the clinopyroxenite and enveloped by dunite. Mostly, all the peridotites have been strongly serpentinised as shown by the high degree of serpentinisation in the rocks. In fact, some of them have been totally altered into serpentinite. Locally, greenschist-facies metamorphism occurred which is evidenced by the occurrence of tremolitic schist.

The olivine clinopyroxenite (sample MOR02 and MOR04A) is predominantly cumulate-textured clinopyroxene and olivine as shown in Fig. 2a. All the samples also contain serpentine as an alteration product of these two minerals. Olivine has modal abundance 30 – 40%, and forms euhedral to subhedral grains with irregular fractures filled by serpentine. In some cases, it is almost completely replaced by serpentine.

Harzburgites (MOR02B and MOR03A) have been strongly serpentinised. They consist of olivine (40 – 50%), relict orthopyroxene (20 – 25%), small amounts of clinopyroxene (0 – 5%) and amphibole (5 – 15%) (Fig.2b). Olivine varies in size, usually 0.4 – 1.2 mm, but sometimes up to 3 mm. Most olivines are altered, with serpentine veins cutting the olivine. Orthopyroxene occurs as subhedral – anhedral crystals of size 0.5 – 1.5 mm, sometimes up to 4 mm, and often replaced by amphibole, which is usually found in the contact between orthopyroxene and olivine, and is sometimes altered into serpentine.

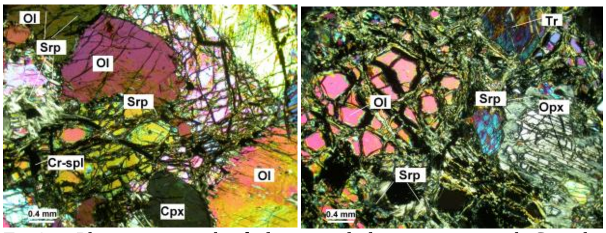


Fig.2 a. Photomicrograph of olivine and clinopyroxene with Cr-rich spinel (Cr-spl) in clinopyroxenite (MOR02A) with crossed polars. Olivine has been partially replaced by serpentine (Srp). b. Photomicrograph of harzburgite (MOR02B) with crossed-polarised light showing olivine (Ol), orthopyroxene (Opx), serpentine (Srp) and tremolite (Tr). Note that rim of Opx is altered into serpentine

A dunite (MOR01) associated with the harzburgites was strongly serpentinised (ca. 85% replacement), but olivine relicts can still be identified. Olivine would have originally made up 90 – 95% of the rock. Spinel abundance is 3 – 5%; it usually forms small grains 0.2 – 1 mm in size.

Podiform chromitite commonly occurs as lenses within olivine clinopyroxenite, and sometimes enveloped by dunite. In some places, they were found as discontinuous tabular bodies. Most of the chromitite was massive in structure, typically coarse grained and composed up to 90 vol % of chromite. Anhedral individual grains of chromite range from 0.5 to 3 mm and are closely packed, but often with films of silicate between the grains.

Tremolite schist (BGR02) and serpentinite were found on the Batugarencing Hill.

Barru Block

Generally, the ultramafic rocks of the Barru Block have been strongly serpentinised (70 – 90%) and metamorphosed to low temperature (greenschist) or moderately high temperature (amphibolite) facies. The ultramafic rocks are of spinel lherzolite and harzburgite composition. Podiform chromitite sometimes occurs as lenses or nodules within peridotite at Sabangnairi Hill and Kamara Village.

The spinel lherzolite (samples AM 16 and DNG01) consist of subhedral to euhedral clinopyroxene (20 – 30%) and orthopyroxene (0 – 15%) together with anhedral olivine (40 – 60%) and subordinate amphibole (15 – 20%). Cr-rich spinel occurs as an accessory (2 – 10%). Small amounts of sulfide and chromite also occur as accessory minerals. In some samples, the modal proportion of the olivine was lower than indicated above. Olivine was often pseudomorphed by serpentine (Fig.3a). Some relict olivine grains exhibited undulating and mosaic extinction. Clinopyroxene varied in size (0.4 – 1.2 mm); orthopyroxene was usually smaller. They were both often replaced by amphibole, but sometimes relicts remained. Decomposition of primary orthopyroxene solid solution produced exsolution lamellae of clinopyroxene and rarely Cr-rich spinel. Another feature of the rocks is the presence of multiple generations of amphibole identified as hornblende (earlier, coarser, more pleochroic) to tremolite (less so), which partially replace pyroxene and are in turn altered into serpentine. The extensive development of tremolite, hornblende and Fe^{3+}-rich chromite strongly suggest medium-temperature (< 550°C) metamorphism (amphibolite facies).

Highly serpentinised harzburgite includes samples BR01 and BR02. Generally, they show mesh-textured serpentine pseudomorphs, and also contain chlorite. Relict grains of olivine and pyroxene rimmed by serpentine are sometimes still found, but most grains of these minerals have been completely replaced. The rock consists of serpentine pseudomorphs after olivine (50 – 60 %) and clinopyroxene and orthopyroxene (10 – 25%) with some relicts of all the primary minerals observed, chlorite (20 – 30%), Cr-rich spinel (5 – 8%) and magnetite as an accessory mineral (Fig.3b). The olivine pseudomorphs show a mesh texture as described by O'Hanley (1996), with serpentine in the mesh rims and olivine relicts in the mesh centres. Serpentine also occurs as thin veins. Cr-rich spinel in the matrix varies in size (usually 0.2 – 0.7 mm), and is sometimes replaced by Fe^{3+}-rich chromite. Iron oxides, usually magnetite, occur as accessory minerals in the matrix.

Podiform chromitite was found as coarse-grained (1 – 5 mm) layers containing up to 95 vol% anhedral chromite grains cemented by serpentine. Interlayering with dunite or peridotite was sometimes observed in the field.

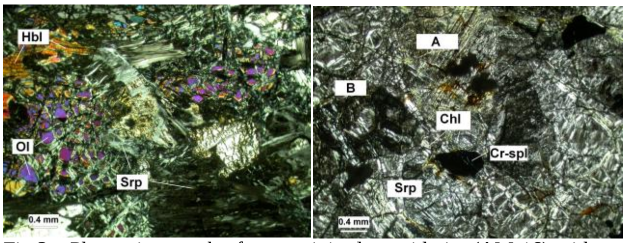


Fig.3a. Photomicrograph of serpentinised peridotite (AM 16) with crossed polars. The rock exhibit a pseudomorphic texture in which olivine has been altered into serpentine and pyroxene has been replaced by hornblende. b.Photomicrograph of harzburgite spinel that has been strongly serpentinised (BR02) in crossed polars. The rock shows pseudomorphic (A) and meshes (B) textures formed by serpentine after olivine. Chlorite (Chl) occurs in some areas and Cr-rich spinel is found as accessory mineral.

Geochemistry

The whole-rock composition and trace element composition are listed in Table 2.

Table 2. Whole rocks and trace elements compositions of the ultramafic rocks from the Bantimala and Barru Blocks

Block	Bantimala					Barru		
Sample	MOR 4	MOR 2A	MOR 01	MOR 02B	MOR 3A	AM 16	DNG 01	BR 02
Rock type	Ol clinopyroxenite		Dunite	Harzburgite	Harzburgite	Lherzolite	Lherzolite	Lherzolite
Whole rock (wt%)								
SiO2	49.04	48.65	40.55	40.18	39.62	38.85	40.53	39.47
TiO2	0.14	0.14	0.03	0.03	0.06	0.03	0.09	0.05
Al2O3	2.20	2.15	0.95	1.36	0.84	1.27	2.75	1.70
FeOt	5.77	5.83	6.93	8.46	8.02	7.59	8.18	7.47
MnO	0.10	0.10	0.11	0.11	0.13	0.09	0.17	0.08
MgO	21.51	21.86	36.54	37.84	36.74	36.06	34.23	35.62
CaO	18.23	17.83	0.05	1.26	0.03	0.23	2.13	0.10
Na2O	0.17	0.19	0.00	0.00	0.00	0.06	0.08	0.00
K2O	0.01	0.01	0.01	0.02	0.01	0.02	0.02	0.00
P2O5	0.00	0.00	0.01	0.01	0.01	0.01	0.01	0.01
LOI	3.36	3.29	14.35	10.42	14.02	16.19	12.27	15.13
Total	51.49	100.04	99.53	99.70	99.47	100.40	100.45	99.62
Mg#	86.90	87.00	90.40	88.90	89.10	89.40	88.20	89.50
Trace elements (ppm)								
Cr	1085.45	1084.23	3783.50	3219.98	2572.75	2339.31	2572.91	2730.86
Ni	391.31	361.74	2074.29	2136.79	1040.00	2173.93	2118.32	2070.88
Rb	0.00	0.02	0.24	0.38	0.12	0.30	0.17	0.08
Ba	2.11	1.16	0.68	2.98	4.67	16.86	22.81	1.20
Th	0.03	0.01	0.01	0.03	0.04	0.02	0.01	0.02
U	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.01
Nb	0.10	0.09	0.02	0.03	0.06	0.03	0.04	0.02
Ta	0.05	0.04	0.03	0.11	0.00	0.08	0.02	0.00
La	0.09	0.08	0.06	0.12	0.18	0.22	0.24	0.26
Ce	0.16	0.17	0.07	0.24	0.55	0.18	0.17	0.13
Pr	0.05	0.01	0.00	0.05	0.07	0.03	0.03	0.03
Sr	18.74	19.72	0.47	9.15	0.69	5.66	5.36	1.77
Nd	0.33	0.23	0.08	0.21	0.39	0.31	0.27	0.10
Zr	0.35	0.40	0.37	0.94	1.09	1.87	0.95	0.28
Hf	0.30	0.20	0.10	0.31	0.08	0.68	0.20	0.04
Sm	0.20	0.08	0.02	0.15	0.10	0.12	0.15	0.00
Eu	0.08	0.06	0.02	0.04	0.06	0.06	0.05	0.03
Ti	1370.00	1350.00	330.00	330.00	560.00	270.00	900.00	480.00
Gd	0.34	0.37	0.07	0.08	0.25	0.22	0.27	0.08
Tb	0.06	0.06	0.00	0.01	0.04	0.06	0.04	0.02
Dy	0.42	0.34	0.13	0.01	0.23	0.41	0.49	0.16
Y	2.19	2.00	0.68	0.84	1.22	2.47	2.27	0.82
Ho	0.09	0.07	0.03	0.05	0.03	0.10	0.10	0.03
Er	0.24	0.23	0.12	0.09	0.11	0.34	0.24	0.08
Tm	0.05	0.04	0.03	0.03	0.01	0.04	0.04	0.00
Yb	0.17	0.15	0.11	0.08	0.10	0.39	0.28	0.16
Lu	0.02	0.02	0.02	0.02	0.02	0.06	0.05	0.03
Eu	0.92	0.98	2.00	1.25	1.21	1.61	0.82	12.04
La_N/Yb_N	0.37	0.39	0.38	1.13	1.34	0.40	0.61	1.17

Whole rock composition

The Mg# of the clinopyroxenite is relatively lower (Mg# = 86.9) than peridotite (Mg# = 89 - 90). The whole-rock compositions of the ultramafic samples from the Bantimala and Barru blocks clearly show that they have been hydrated. The compatible minor elements Ni and Cr decrease markedly from high values in the peridotites (Ni = 1040 - 2170 ppm and Cr = 2340 - 3783 ppm) to much lower values in the clinopyroxenite (Ni = 361 - 361 ppm and Cr = 1084 ppm), consistent with the fractionation of olivine, spinel and clinopyroxene.

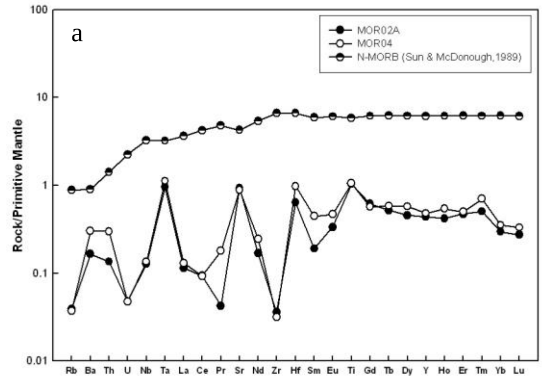
Trace elements

The ultramafic rocks show a large variation in trace element distribution. Primitive mantle-normalised trace elements of peridotite rocks show highly spiked distribution of LILE and variation in HFSE with some samples having distinctive negative anomaly of Nb. In general, the composition of peridotite samples are characteristic of refractory residues, shown by the lower concentration of most elements than primitive mantle, especially in LILE.

The Bantimala clinopyroxenites are depleted in all elements compared to primitive mantle or N-MORB (Fig.4a). The chondrite-normalised pattern of REE from the clinopyroxenite also shows lower values of all elements relative to N-MORB with depleted LREE (generally 0.5 to 1x chondrite) and relatively similar HREE (1 - 2 x chondrite) (Fig.4b). Apparent anomalies in unusual REE (such as that in Pr in this figure) are likely due to analytical error, given the very low concentrations of these elements.

Harzburgite and dunite from the Bantimala block are characterised by depleted trace elements as well as REE compared to primitive mantle and chondrite respectively, with irregular variation across the pattern (Fig.5a and b).

Depletion relative to primitive mantle due to partial melt extraction is also seen for Barru ultramafics analysed, namely lherzolite and harzburgite (Fig. 6a and b). The lherzolite HREE are slightly closer to the primitive mantles values than those of the harzburgite and dunite from the Bantimala ultramafics.



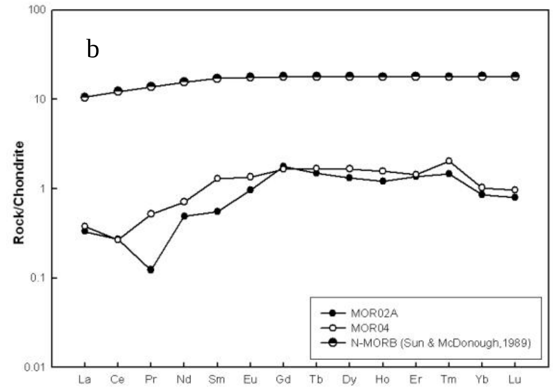
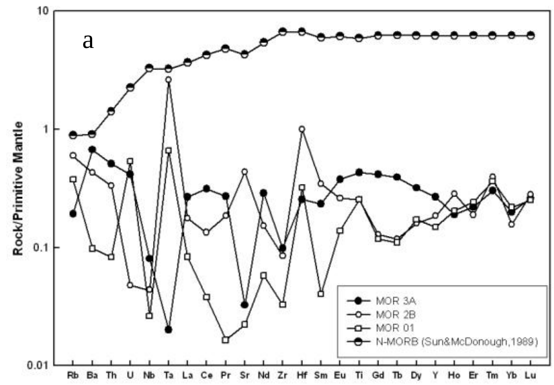


Fig.4a Primitive Mantle -normalised (Sun and McDonough, 1989) trace element patterns of clinopyroxenite from the Bantimala Block. N-MORB pattern is shown as comparison. b. Chondrite-normalised (Sun and McDonough, 1989) REE patterns of clinopyroxenite from the Bantimala Block. N-MORB from Sun & McDonough (1989) is shown as comparison.



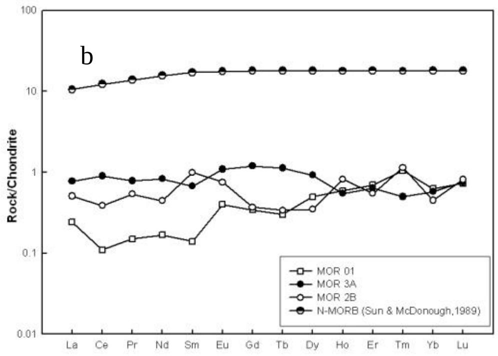


Fig. 5 a. Primitive-mantle normalised (Sun and McDonough, 1989) trace element patterns of peridotite from the Bantimala Block. N-MORB from Sun & McDonough (1989) is shown as comparison. b. Chondrite-normalised (Sun and McDonough, 1989) REE patterns of peridotite from the Bantimala Block. Note the depletion relative to N-MORB pattern from Sun & McDonough (1989).

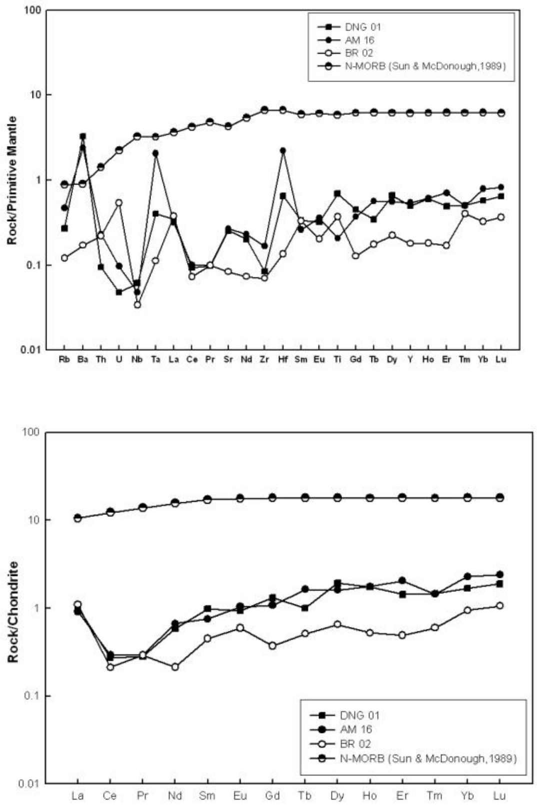


Fig. 6a. Primitive mantle-normalised (Sun and McDonough, 1989) trace element patterns of lherzolite (AM16 & DNG01) and harzburgite (BR02) from the Barru block. b. Chondrite-normalised (Sun and McDonough, 1989) REE patterns of lherzolite (AM16 & DNG01) and harzburgite (BR02) from the Barru block.

DISCUSSION AND CONCLUSION

The absences of gabbro, pillow basalt, sheeted dykes and other characteristic components of ophiolites, such as volcanoclastic sediments and lava in these areas, suggest that the ultramafic suites in both blocks are at best fragments of highly tectonised, dismembered ophiolite sequences.

Fast and slow spreading centres, produce ophiolites with different characteristics (Pearce et al., 1984; Poli and Schmidt, 2002). Those formed at fast spreading centres are characterised by depleted harzburgites (little to no clinopyroxene) and dunite and typically have a complete ophiolite section, whereas those from slow spreading centres generally show lherzolite and relatively enriched harzburgite and often show dismembered sections. The occurrences of olivine clinopyroxenite in Bantimala and lherzolite in Barru indicates that the ultramafic suites in both blocks formed in slow spreading centres. This is also supported by the high degree of serpentinisation.

From geochemical charactersitics, it appears that the ultramafic suites in the Bantimala represent cumulates whereas Barru ultramafic represents SSZ-derived ultramafic suites, probably from marginal or back-arc basins, which were emplaced onto the proto-Sulawesi arc and juxtaposed with the metamorphic rock assemblages to form the basement complexes within two blocks.

Unless there has been large differential rotation between the blocks, the Barru ultramafics were emplaced approximately from the North, but the Bantimala ultramafics from the East. Thus, they represent closure of two different small basins in different directions, although differential rotation of blocks like these is possible, so close to the Walanae fault system (Charlton, 2000). Small and young marginal basins which correlate with the ophiolite distribution pattern are commonly found as products of multiple convergence and collision in the Southeast Asia region including in Sulawesi region (Harris, 2003).

The Bantimala and Barru ultramafics show geochemical differences from the nearby ultramafic rocks of the East Sulawesi Ophiolite series (Kadarusman et al., 2004; Monnier et al., 2002), suggesting that they did not form in the same tectonic setting. This is expected, since Eastern Sulawesi would have been quite distant at the time of accretion of the Bantimala and Barru complexes (Hall, 2002). Note that Kadarusman et al. (2004) proposed a Pacific plume origin for the East Sulawesi Ophiolite, whereas Monnier et al. (2002) preferred origin from collision of the Australian and Eurasian plates. More likely to correlate with either Barru or Bantimala is the Meratus Complex in Kalimantan, which would have been geographically close in the Cretaceous, but for which geochemical data is currently lacking.

The absence of garnet may indicate that both the Bantimala and Barru ultramafic were formed in lower pressure condition. The Bantimala ultramafic were later metamorphosed into greenschist-facies metamorphism whereas the Barru block was experienced higher (amphibolite-facies metamorphism) during uplift.

Stratigraphic position later suggests that the Bantimala ultramafic emplaced onto the Bantimala block from the spreading of oceanic crust at the eastern to northeastern part of the block. At the same time, those from the Barru block obducted from the back arc basin setting at the western to northwestern part of the blocks. The ultramafic suites from these two blocks then are juxtaposed with metamorphic assemblages which later intruded by younger volcanic, particularly in the Barru block.

The main tectonic implication is that the Bantimala and Barru obduction events were not caused directly by the westward thrust of Australian microcontinent or Pacific oceanic plate on the Eurasian margin (Hamilton, 1979; Katili, 1978; Parkinson, 1998; Wakita et al., 1996) or by southward obduction of the Celebes Sea over the east Sulawesi basement as suggested for the emplacement of East Sulawesi Ophiolite by Monnier et al. (2002).

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REFERENCES

Charlton, T.R, *Tertiary evolution of the Eastern Indonesia Collision Complex*, Journal of Asia Earth Sciences, 18: 603 -631 (2000).

Hall, R. Cenozoic geological and plate tectonic of SE Asia and the SW Pacific: Computer-based reconstructions, model and animations. *Journal of Asia Earth Sciences*, **20**, 353-431(2002).

Hamilton, W., *Tectonics of the Indonesian region*, U.S. Geol. Surv. Prof. Pap, 1078: 345 (1979).

Harris, R., *Geodynamic patterns of ophiolites and marginal basins in the Indonesia and New Guinea regions*, In: Y. Dilek and P.T. Robinson (Editors), Ophiolite in Earth History. Geological Society Special Publication, London, pp. 481-505 (2003).

Kadarusman, A., Miyashita, S., Maruyama, S., Parkinson, C.D. and Ishikawa, A., *Petrology, geochemistry and paleogeographic reconstruction of the East Sulawesi Ophiolite, Indonesia*. Tectonophysic, 392: 55-83(2004).

Kadarusman, A. and Parkinson, C.D., *Petrology and P-T evolution of garnet peridotites from central Sulawesi, Indonesia, In: J.G. Liou, D.A Carswell (editors)*, Journal of Metamorphic Geology: special issue on Garnet Peridotites and Ultradeep Minerals 18: 193-209 (2000).

Kadarusman, A., Sopaheluwakan, J. and van Leeuwen, T.M., *Eclogite, garnet peridotite, granulite and associated high-grade rocks from the Palu-Koro region, Central Sulawesi, Indonesia: An example of mantle and crust interactions in young orogenic belt*, EOS, Transactions, American Geophysical Union Geol.Res.Dev.Centre, Bandung, Indonesia, pp. 277-304 (1981).

Wakita, K., Sopaheluwakan, J., Miyazaki, K. and Munasri. Tectonic evolution of the Bantimala Complex, South Sulawesi, Indonesia. In: R. Hall and D.J. Blundell (Editors), Tectonic Evolution of Southeast Asia. Geological Society of London Special Publication 106, pp. 353-364 (1996).

Wilson, M.E.J. and Bosence, D.J.W. The Tertiary Evolution of South Sulawesi; A record in Redeposited (abstract), 83(48): F. 1182 (2002).

Katili, J.A., *Past and present geotectonic position of Sulawesi, Indonesia*. Tectonophysics, 45: 289-322 (1978).

Maulana, A., Christy, A.G. and Ellis, D.J. *The petrology of Eclogite from Bantimala Complex, South Sulawesi*, Indonesia. Indonesian Geologist Association Annual Convention Proceeding 2008, 37: 40 - 63 (2008).

Maulana, A. Petrology, Geochemistry and Metamorphic Evolution of The South Sulawesi Basement Complexes, Indonesia, M.Phil. Thesis. The Australian National University, Canberra, 188 pp (2009).

Monnier, C., Girardeaue, J., Maury, C.R. and Cotten, J, Back-arc basin origin for the East Sulawesi ophiolite (eastern Indonesia). Geology, 23(9): 851-854 (2002).

O'Hanley, D.S., Serpentinites: Records of Tectonic and Petrological History. Oxford Monograph on Geology and Geophysics No.34. Oxford University Press, 277 pp (1996).

Parkinson, C.D. An outline of the petrology, structure and age of the Pompangano Schist Complex of central Sulawesi, Indonesia. The Island Arc, 7: 231-245 (2008).

Pearce, J.A., Lippard, S.J. and Roberts, S. Characteristic and tectonic significance of supra-subduction zone ophiolites. In: B.P. Kokelaar and M.F. Howell (Editors), Marginal Basin Geology. Geological Society Special Publication No.15. Blackwell Scientific Publication, Oxford, pp. 77-94 (1984).

Poli, S. and Schmidt, M.W. Petrology of subducted slabs. Annu. Rev. Earth Planet. Sci, 30: 207-235 (2002).

Smith, R.B. and Silver, E.A. Geology of a Miocene Collision, Buton, eastern Indonesia. Geology Society of America Bulletin, 103: 660-678 (1991).

Sukamto, R. The geology of the Pangkajene and Western part of Watampone, South Sulawesi, scale 1 : 250.000. Geological Research and Development Centre, Bandung (1982).

Sun, S. S. & McDonough, W. F, Chemical and isotopic systematics of oceanic basalts: implications for mantle composition and processes. In: *Magmatism in Ocean Basins* (eds Saunders, A. D. & Norry, M. J.), pp. 313-345, Geol. Soc. London Spec. Publ.(1989).

van Leeuwen, T.M. The geology of south-west Sulawesi with special reference to the Biru area. In: A.J. Barber and S. Wiryosujono (Editors), Geology and Tectonic of Eastern Indonesia Spec.Publs. 2.

Carbonates of the Tonas Limestone Formation. In: R. Hall and D.J. Blundell (Editors), Tectonic Evolution of Southeast Asia. Geological Society of London Special Publication 106, pp. 365-390 (1996).