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PETROGRAPHIC AND GEOCHEMICAL STUDIES OF THE SPINEL–BEARING PERIDOTITES EXPOSED IN SOUTHWEST OF MINDON TOWNSHIP, MAGWAY REGION

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Abstract

The ophiolite of the study area is a remnant of the Tethyan ophiolites preserved at the eastern margin of the Indo-Myanmar Orogenic Belt. Mineralogical features, textural relations and relative abundance of constituent minerals reveal that the samples are dominated by spinel lherzolite and spinel harzburgite with minor dunite, and characterized by olivine (>40 % volume) with varying amount of orthopyroxene and clinopyroxene. The samples display the preferred orientation of olivine, strain shadow, undulose extinction, kink bands of cleavage traces in pyroxenes, and are essentially spinel bearing suggesting derivation from deeper source in the mantle beyond the stability limit of plagioclase. Magnetite forms along fractures and rims of the spinel grains due to the result of cation exchange between spinels and coexisting silicates forming low pressure and low temperature metamorphic alteration. The samples have relatively homogeneous whole-rock compositions with Mg# values (90–92), and SiO_2 (43.6 – 44.8 wt%), Al_2O_3 (2.5–2.9 wt%) and CaO (2.3–2.5 wt%) contents and enriched in transition metals. The samples have negative correlations between SiO_2, Fe_2O_3, and CaO with MgO and are more similar to mid-oceanic ridge type. Correlating with the northern segment of the Western Ophiolite Belt it is likely suggest that the peridotite rock exposed in the northern and southern segment were formed in the mid-oceanic ridge setting and were accreted to the Indo-Myanmar Ranges from the downgoing Tethyan plate as part of subduction-accretion processes.

Keywords: The Western Ophiolite Belt, peridotite tectonite, spinel, deeper source, the mid-oceanic ridge setting

Introduction

Ophiolites are generally considered as the fragments of remnant oceanic lithosphere formed by seafloor spreading, which are of importance to plate reconstruction and understanding of orogeny (Dilek and Furnes, 2011). Ophiolites are widely distributed within Myanmar such as the Eastern Opiolite Belt, the Central Opiolite Belt and the Western Ophiolite Belt (Hla Htay et al., 2017). Among these belts, the Western Ophioite belt was regarded as the remnants of the Neo-Tethyan oceanic lithosphere (Sengupta et al., 1990; Mitchell, 1993) and as the southern continuation of the Neo-Tethyan ophiolites occurring along the Yarlung Zangbo suture zone in southern Tibet farther northwest (Mitchell, 1993; Fareeduddin and Dilek, 2015). This belt roughly follows the trend of the eastern Indo-Burma Range and geographically continues northward to ophiolites in the Naga Hills, e.g., the Manipur (Ghosh et al., 2014; Singh et al., 2013), and extends southward to the Andaman–Nicobar Island. The geological works in the Western Ranges and its environs were carried out by many authors, and the Kalaymyo ophiolite from the northern part of Western Belt was suggested to be formed during the Early Cretaceous (~125 Ma), and represents relics of the Neo-Tethys Ocean (Liu et al., 2016).

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The ophiolites along the Indo-Myanmar Ranges are poorly constrained. Some have interpreted them as segments of an island-arc system that were emplaced as nappes during the India-Burma collision (Sengupta et al., 1990; Mitchell, 1993). The origin and tectonic setting of the Manipur ophiolites, located in the northern part of the Indo-Myanmar Ranges suggested as an island-arc origin (Bhattacharjee, 1991) and as a mid-oceanic ridge origin (Singh, 2013; Khogenkumar et al., 2016), which underwent high-pressure metamorphism and deformation in a subduction channel and then was incorporated into an accretionary prism in the upper plate (Fareeduddin and Dilek, 2015). In the middle segment of the belt is the mantle peridotites of the Kalaymyo ophiolite which was also suggested to be mantle residues originated in a mid-oceanic ridge setting with no subduction zone influence in their magmatic evolution (Liu et al., 2016; Niu et al., 2017). In the present study we document the mineralogical features, occurrence of spinel and preliminary studies on the major and trace element geochemistry of the peridotites in the southwest of Mindon area in the central part of the Western Ophiolite Belt. The present study indicate that the spinel–bearing peridotite rocks are discontinuously exposed along the eastern margin of the Indo-Myanmar Ranges and comparing with the northern segment a mid-oceanic ridge origin are dominated in the northern and middle segment.

Regional Geologic Setting

Opiolitic rock associations occur in three belts trending nearly north-south parallel with each other, and from west to east these belts are the Western Ophiolite Belt (WOB), the Central Ophiolite Belt (COB) and the Eastern Ophiolite Belt (EOB) (Hla Htay et al., 2017). The narrow Western Ophiolite Belt (WOB) forms the longest belt, extending from north to southern part of Myanmar. The Western Ophiolite Belt lying along the Indo-Myanmar Ranges extends from the Naga hills in the north through the Chin hills to the Rakhine Yoma and to Andaman and Nicobar islands in the south. It forms a narrow linear belt about 1300 km long and about 50 km wide. Throughout the belt dismembered ophiolitic rocks are represented by ultramafic and mafic rocks associated with oceanic pelagic sediments.

The study area which occupies as a part of the Western Ophiolite Belt is sited at the the eastern part of the Indo-Myanmar Ranges, and appear between Tertiary molasses sediments of the Inner-Myanmar Tertiary Basin and the Indo-Myanmar Flysch sediments (Figure. 1). The ophiolitic rocks occur along large Kabaw fault zone, which dissects the Indo-Myanmar Ranges and are restricted to the eastern parts of the Indo-Myanmar Ranges in association with metamorphic rocks (Figure. 1). The ophiolitic rocks mostly occur as small and elongated tectonized serpentinite bodies within low-grade metamorphic rocks or slightly tectonized serpentinite occurring within volcanic rocks of mafic to intermediate composition (Hla Htay et al., 2017). The present area is placed in the southwestern part of Mindon area and consists mainly of Kanpelet schists, ophiolitic rocks and Paleocene to Middle Eocene clastic sediments (Figure. 1).

The peridotite exposures in the study area vary in mineralogical composition from harzburgite, lherzolite to minor wherlite and dunite. They occur as tectonized and cumulate types, and form as massive, foliated, fractured and highly jointed nature near their contact with the overlying sediments at Hlwar Chaung near Ywathit area (Figure. 2a and d). They also occur as isolated blocks (Figure. 2b) associated with low-grade metamorphic rocks and Thanbaya Formation, and show grayish green to dark green-colored. Olivine and pyroxene grains in most of the exposures show slightly to strong serpentinization (Figure. 2a, c and d). Veinlets of serpentine are commonly present in these rocks (Figure. 2c). Some exposures display lenses or disseminations of chromite. Dolerite dike are exposed as large sheeted blocks forming hill at Shwe daung maung at the eastern margin of Rakhine Yoma. Dark grey vesicular basalts occur as a float at associated with peridotites.

Among the spinel–bearing peridotite samples, YU301 and YU03 samples are plotted in harzburgite field and YU01, YU06 and SU15 samples in lherzolite field based on their relative mineral proportion, and are shown in Figureure 3. Abbreviations for minerals and end-members used in text and figures are after Whitney and Evans (2010).

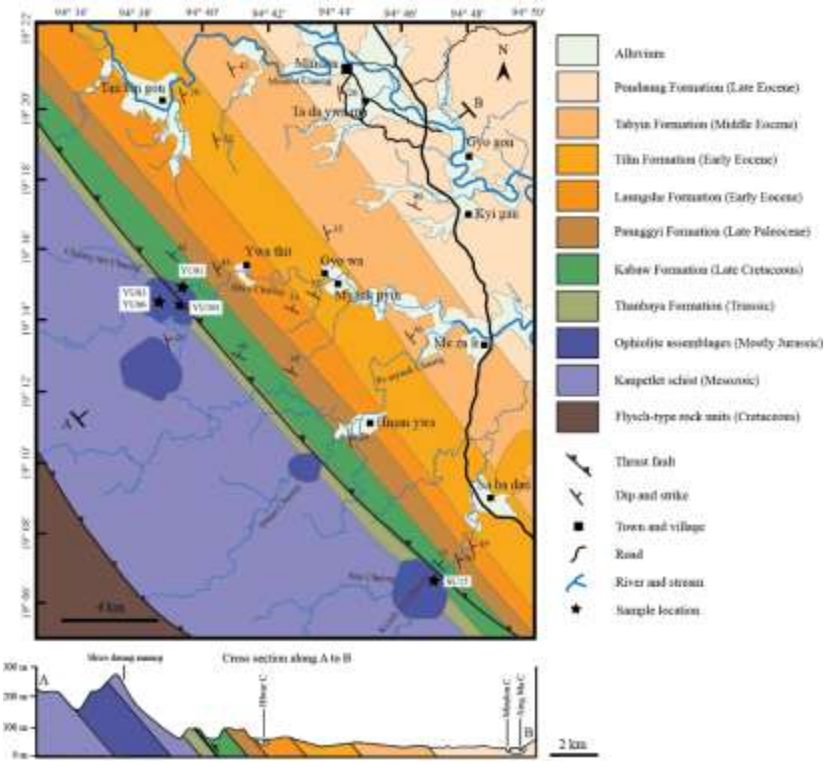

Figure 1. Geological map of the sampling area (combined with the data of thrust faults and flysch–type rock units from Geological Map of Myanmar of Myanmar of Geosciences Society, 2014 and with structural data of the northern part from Htet Aung Thu, 2015).

Figure 2 (a) peridotite exposure in contact with Thanbaya Formation, (b) isolate harzburgite block at Hlwar Chaung southwest of Ywathit area, (c) serpentinization in peridotite and (d) massive serpentinized peridotite at Kyaukkyi Chanung southwest of Sabadan area.

Petrographic Features

Spinel-bearing lherzolites were collected from longitude 94° 39' 26" E and latitude 19° 14' 55" N for YU01 sample, 94° 38' 47" E and 19° 14' 38" N for YU06 sample and 94° 38' 47" E and 19° 14' 38" N for SU15 sample. Spinel-bearing harzburgite samples YU03 and YU301 were collected from 94° 38' 47" E, 19° 14' 38" N and 94° 39' 07" E, 19° 14' 26" N, respectively (Figure 1).

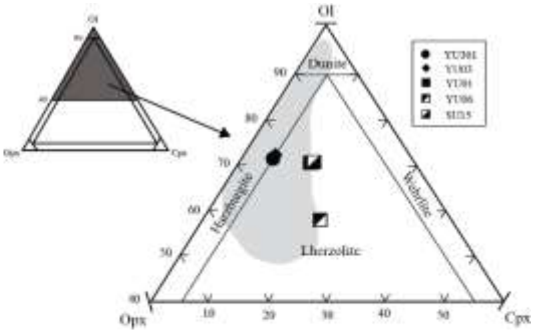

Figure 3. Classification diagram for spinel–bearing peridotite samples plotted based on primary mineral phases. The light grey shaded area denotes the most common types of peridotites in the upper part of the mantle (Bodinier and Godard, 2007).

These samples display mainly porphyroclastic texture. Their primary mineral assemblages of lherzolite samples are characterized by olivine (55–67 vol. %), orthopyroxene (16–21 vol. %), clinopyroxene (11–19 vol. %) and spinel and opaque minerals (5–9 vol. %), those of harzburgite are olivine (66–67 vol. %), orthopyroxene (20–22 vol. %), clinopyroxene (about 5 vol. %) and spinel and opaque minerals (up to 7 vol. %). Olivine and orthopryoxene show strain shadow, kink bands of cleavage traces, undulose extinction, shearing and recrystallization suggesting plastic deformation of upper mantle peridotites. In these samples, SU15 sample is fairly serpentinized and most silicate minerals are obliterated. Olivine grains display large porphyroclastic grains (>3 mm) (Figure. 4) and fine-grained neoblasts (<3 mm) (Figure. 4b). The olivine porphyroclasts are mostly elongated (Figure. 4g) and curved or tapered, and some grains show equigranular (Figure. 4d). The neoblasts show uniform extinction. Brecciated grains occur traversed by secondary serpentine (Figures. 4b and c). Smaller olivine grains (0.1– 0.2 mm) occur as inclusion in orthopyroxene (Figure. 4b) and spinel, implying that these mineral form after olivine. Some olivine grains are altered to serpentine. Orthopyroxene shows porphyroclastic and subhedral to anhedral grains with an average of 0.2–1.5 mm in diameter (Figures. 4a–f and h) and some grains exhibit exsolution lamellae of clinpyroxene. Some orthopyroxene grain are surrounded and partly replaced by neoblastic olivine (Figure. 4b). Clinopyroxene grains occur as porphyroclastic, subhedral to anhedral grains and range in size of 0.3–1.7 mm (Figure. 4) and some occur as exsolution phase in orthopyroxene. Bent cleveage traces and strain shadow are observed in some grains (Figure. 4e). Spinel grains occur as subhedral to anhedral, blocky, skeletal, and irregularly rounded grains and range in size up to 0.7 mm (Figures. 4). Most of the crack and rim of spinel grain are replaced by secondary magnetite (Figures. 4c and h). Secondary phases include serpentine, chlorite, chromite and magnetite. Magnetite mostly occurs as alteration product after spinel grain along the crack and marginal rim (Figures. 4c and h) and are associated with secondary serpentine.

Metamorphic Condition of Spinel–bearing Peridotites Samples

The spinel composition is characterized by solid solution between chromite ($Fe^{2+}Cr_2O_4$) and spinel sensu stricto ($MgAl_2O_4$). The compositional heterogeneity of the Cr-spinel is a function of the fluid-rock interaction and metamorphic grade (Barnes, 2000; Farahat, 2008). Along grain boundaries and through cracks, magnetite was formed at lower temperature because of the readily exchange of Fe from host peridotite silicates e.g., olivine during serpentinisation (Gahlan et al., 2006). During metamorphism Cr-spinel changes to magnetite and/or ferritchromite along grain margins and fractures, as these are the only sites for metamorphic fluid interaction. Due to the lack of chemical data obtained from electron probe micro analyzer (EPMA), it is difficult to distinguish among opaque minerals and chemical composition of spinel and coexisting silicate minerals. Interpretation was made based on textural relationship, and implication on previous published works. In studied samples ferritchromite could not be identified, and instead magnetite forms along fractures and rims (Figures. 4c and h).

Based on the schematic illustration of chemical changes in primary Cr-spinel grains during metamorphism with element exchange (Bhat et al., 2019), the chemical modifications in primary Cr-spinel grains of the peridotite samples during secondary alteration and metamorphism are employed here and shown in figure 5. Olivine and pyroxene minerals are magnesian–bearing minerals, and magnetite were formed along cracks and grain boundaries due to the result of Mg^{2+} and Fe^{2+} cation exchange between spinel and coexisting silicates with limited amounts of Fe on their hydration (Figure. 5). Fe with minor Mn is incorporated into the Cr-spinel substituting for Al, Mg and Cr of the Cr-spinel, which show outward diffusion during metamorphism. This results in a decrease in $Mg/(Mg + Fe^{2+})$ and an increase in $Cr/(Cr + Al)$ of the magnetite compared to the unaltered Cr-spinel core (Bhat et al., 2019). The ionic potential of Mn is relatively low and hence it is more liable to leakage by weakly acidic solutions (Economou-Elipoulos, 2003).

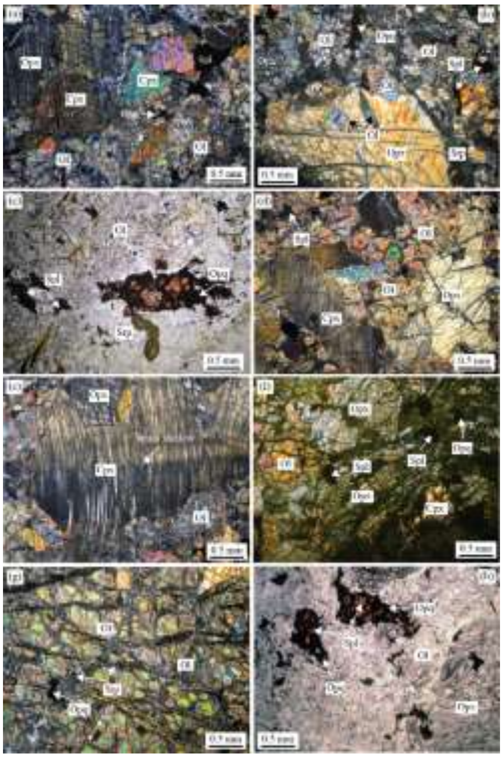

Figure 4. spinel-bearing peridotite samples showing (a) assemblages of olivine, orthopyroxene and clinopyroxene (YU01 sample), (b) orthopyroxene with inclusions of olivine grains and olivine neoblasts (YU01 sample), (c) reddish brown spinel grains replaced by magnetite along crack and rim (YU01 sample), (d) equigranular olivine with orthopyroxene and clinopyroxene (YU06 sample), (e) clinopyroxene showing strain shadow (YU06 sample), (f) assemblages of olivine, orthopyroxene and clinopyroxene, (g) preferentially oriented olivine porphyroclasts traversed by serpentine and opaque minerals (YU301 sample) and (h) spinel grains replaced by magnetite along crack and rim. All photomicrographs are under crossed polars except (c) and (h), which are under plane polarized light.

Based on the magnetite formation around the Cr-spinel this textural relationship suggests the host peridotite experienced at least greenschist facies metamorphism. Cr-spinel in studied samples was not completely replaced by maganetite composition (Figure. 5) suggesting these samples have not been achieved the higher metamorphic conditions (Farahat, 2008). Magnetite growth with limited Cr solubility form well below 500 ºC in mantle peridotites (Barnes, 2000) and the studied samples have likely undergone low temperature metamorphism.

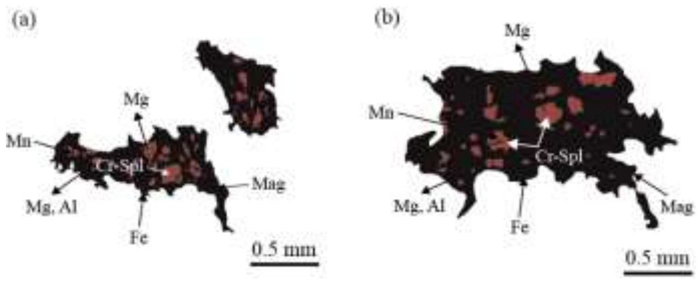

Figure 5. (a) and (b) Cr–spinel with arrow showing possible cation exchange with constituent silicate minerals using illustration for chemical variation of Bhat et al., 2019.

Geochemistry

Analytical Procedures

Samples were made for the detailed study of the constituent mineral assemblages under polarizing microscope. Samples were selected for geochemical analysis and made fine powder using tungsten bolt in jablab pulverizer and dried in the oven to dry out the water in the sample. Dried samples were weighed and placed in the microfurnance setting 950 °C for 5 hours. Whole-rock compositions used for the geochemical analysis were determined by an X-ray fluorescence spectrometer (WDXRF; Rigaku supermini 200) installed in Chemistry Laboratory, Department of Chemistry at Yadanabon University. Whole rock chemical analyses of studied samples are listed in table 1.

Whole rock major and trace Elements

Whole rock major element compositions of the peridotites are listed in table 1. The peridotites in the study area are variably altered to serpentine. The analyzed sample shows a range of SiO_2 (43.6 – 44.8 wt%), Al_2O_3 (2.5–2.9 wt%), MgO (38.7–41.3 wt%), Fe_2O_3 (8.3–9.6 wt%), CaO (2.3–2.5 wt%), Na_2O (0.1–0.2 wt%) and K_2O (< 0.1 wt%) (Table 1). The samples are rich in silica, titanium, aluminum and iron contents compared with the Kalaymyo peridotite, but poor in those compared with mantle peridotite. Most of the peridotites are enriched in the transition elements that are compatible in ultramafic rocks (Ni = 2040–3120 ppm, Cr = 2350–3660 ppm) compared to the Kalaymyo peridotite (Ni = 1860 ppm, Cr = 2520 ppm; Niu et al., 2017) and the primitive mantle (Ni = 1860 ppm, Cr = 2520 ppm; Palme and O'Neill, 2003). The samples have similar whole-rock Mg# [=100 x Mg/(Mg + Fe)] values (90–92), although the spinel bearing harzburgites contain higher concentrations of MgO (39.30–41.30 wt%) than the spinel bearing lherzolite (38.70–39.80 wt%). These concentrations can be used as an indicator of the degree of depletion. An increased depletion can be correlated with an increase in MgO value, which in turn increase in olivine abundance. The most applicable approach to evaluate the chemical changes in the studied samples is to compare the concentrations of elements of interest with MgO concentrations. The samples have negative correlations between SiO_2, Fe_2O_3, and CaO with MgO (Figure. 6).

Table 1 Analysis of the major and some trace elements of the peridotite samples from Ywathit and Sabadan areas.

Sample	YU301	YU03	YU01	YU06	SU15
Major elements (Wt%)					
SiO_2	43.60	44.1	44.60	44.30	44.08
TiO_2	0.11	0.11	0.10	0.11	0.09
Al_2O_3	2.50	2.71	2.89	2.71	2.60
Fe_2O_3*	8.30	9.40	9.60	8.90	9.30
MnO	0.17	0.21	0.21	0.18	0.26
MgO	41.30	39.30	38.80	39.80	38.70
CaO	2.33	2.57	2.43	2.31	2.53
Na_2O	0.12	0.15	0.12	0.16	0.17
K_2O	0.08	0.08	0.08	0.09	0.08

Sample	YU301	YU03	YU01	YU06	SU15
P_2O_5	0.03	0.02	0.03	0.03	0.03
Total	98.54	98.65	98.86	98.59	98.56
Trace elements (ppm)					
Cr	2400	2350	3320	2610	3660
Ni	2040	2790	2460	2750	3120
Zn	118	110	122	132	104
Co	247	210	230	220	235

* Fe2O3 as total Fe

Figure 6 compares the peridotite samples with abyssal (or mid-oceanic ridge type) of Niu et al. (1997) and suprasubduction zone (SSZ) type peridotites of Parkinson and Pearce (1998). The studied peridotites are more similar to mid-oceanic ridge type than SSZ type, similar to the compositions of peridotites from the Kalaymyo peridotit (Niu et al., 2017) in the northern segment of the Western Ophiolite belt. ACM (Al_2O_3–CaO–MgO) and AFM ((Na_2O + K_2O)–FeO–MgO) ternary diagrams show that the peridotite samples correspond to metamorphic peridotites (Fig. 7). The samples represent the basal parts of ophiolite sequences, which are depleted or residual mantle rocks (Coleman, 1971). The samples are also enriched in transition metals such as (Ni = 2040–3120 ppm, Cr = 2350–3660 ppm, Co (210–247 ppm), reflecting their mantle origin.

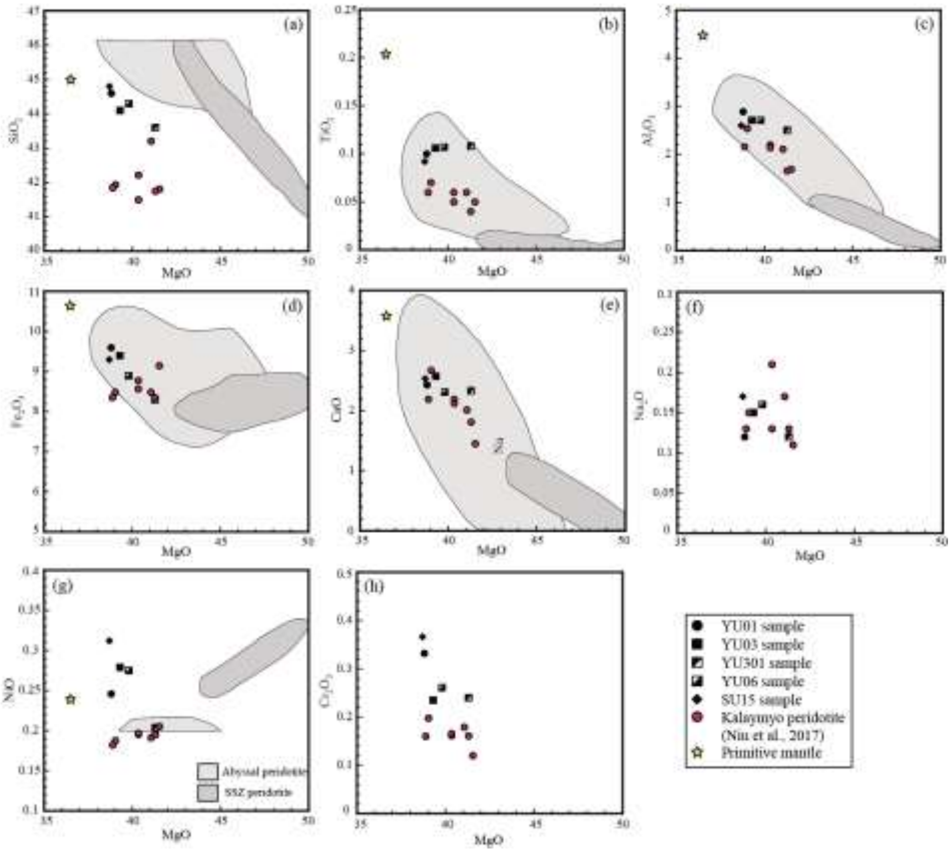

Figure 6. Variations diagrams of major element concentrations relative to MgO. The abyssal and suprasubduction zone (SSZ) peridotite fields are from Niu et al. (1997) and Parkinson and Pearce (1998), respectively, and data for other Kalaymyo peridotites are from Niu et al., 2017.

Comparison with the northern segment of the Western Ophiolite Belt

Ophiolitic rocks were emplaced along the eastern margins of the Indian plate during the northward movement of the Indian plate and the collision of the Indian continental block with the Asian continental block (Mitchell, 1993). The Western Ophiolite Belt roughly follows the trend of the eastern Indo-Burma Range (Figure. 8), and continues northward to ophiolites in the Chin Hill including Kalaymyo peridotite and Naga Hills including the Manipur (Ghosh et al., 2014; Singh, 2013; Singh et al., 2013). The peridotites from the Manipur ophiolite occurring in the northern part of the Indo-Myanmar Ranges mainly consist of lherzolites and clinopyroxene-bearing harzburgites (Ningthoujam et al., 2012; Singh, 2013), and are compositionally similar to abyssal peridotites, with negligible subduction-related modification (Ningthoujam et al., 2012; Singh, 2013), suggesting that the Manipur ophiolite was formed in the mid-ocean ridge (MOR) setting.

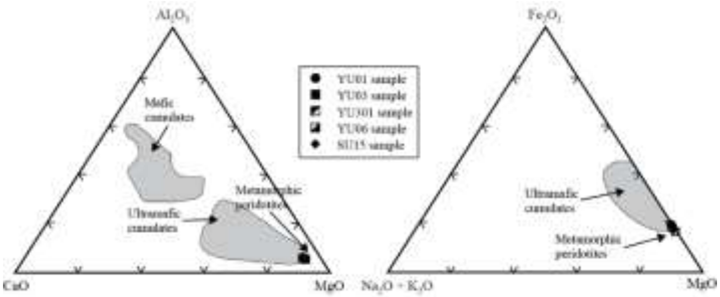

Figure 7. ACM (Al_2O_3–CaO–MgO) and AFM ((Na_2O + K_2O)–FeO–MgO) ternary diagrams. Fields of mafic cumulates, ultramafic cumulates, and metamorphic peridotites are after Coleman (1971).

In addition, the Kalaymyo peridotites are characterized by harzburgite with the mineral assemblage of olivine, spinel, orthopyroxene, and clinopyroxene. They display fertile compositions and have been subjected to anhydrous melting and represent residual upper mantle peridotites after low to moderate degrees (Liu et al., 2016; Niu et al., 2017). Whole-rock chemical compositions resemble those of abyssal peridotites.

The present study area occurr in the southern part of the Indo-Myanmar Ranges (Figure. 8) and mainly comprise of spinel–bearing lherzolites and spinel–bearing harzburgites. Compared with the Kalaymyo peridotite the samples show higher SiO_2, TiO_2, Fe_2O_3, NiO and Cr_2O_3 content. Most major elements compositionally fall within the field of the abyssal peridotite (Figs. 6a–e and g) and suggest that the peridotite rock exposed in the northern and southern segment (Figure. 8) were formed in the mid-oceanic ridge setting. The peridotites and their crustal rocks were accreted to the Indo-Myanmar Ranges from the downgoing Tethyan plate as part of subduction-accretion processes (Fareeduddin and Dilek, 2015). Further studies are still needed to understand the melt evolution, melt-rock interaction and tectonic characterization.

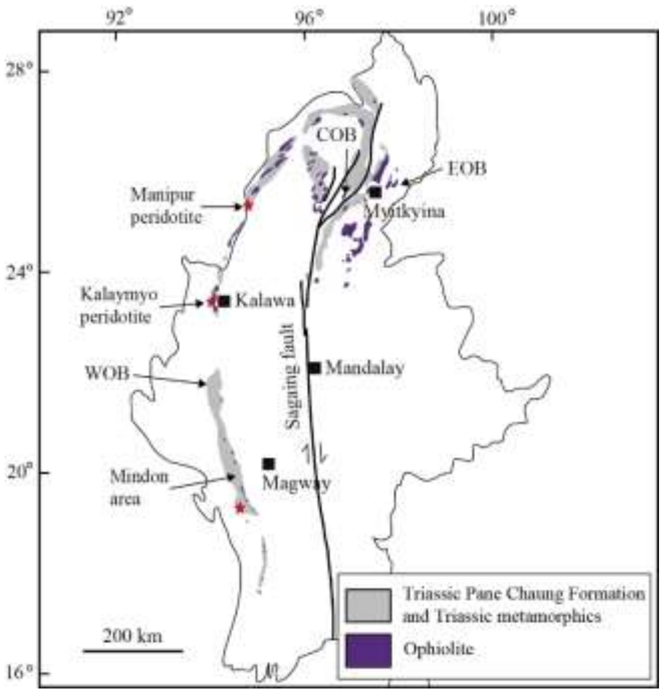

Figure 8. Map showing the main ophiolite occurrences in Myanmar and Triassic-age rocks association (after Searle et al., 2017). Red stars represent sampling areas.

Conclusion

The ophiolite of the study area is a remnant of the Tethyan ophiolites preserved at the eastern margin of the NNE–SSW trending Indo-Myanmar Orogenic Belt. The exposed ophiolite rocks are characterized by the occurrence of big massifs of peridotite tectonite, serpentinite, peridotite cumulate, dolerite dyke, basalt, pyroclastic rock, and pelagic sediment. Mineralogical features, textural relations and relative abundance of constituent minerals reveal that the samples are dominated by spinel lherzolite and spinel harzburgite with minor dunite, and characterized by olivine (>40 volume %) with varying amount of orthopyroxene and clinopyroxene. The samples display the preferred orientation of olivine, strain shadow, undulose extinction, kink bands of cleavage traces in pyroxenes, and are essentially spinel bearing suggesting derivation from deeper source in the mantle beyond the stability limit of plagioclase. Magnetite forms along fractures and rims of the spinel grains in studied samples due to the result of cation exchange between spinels and coexisting silicates, and suggests the peridotites have experienced low pressure and temperature metamorphic alteration. The samples have relatively homogeneous whole-rock compositions with Mg# values (90–92), and SiO_2 (43.6 – 44.8 wt%), Al_2O_3 (2.5–2.9 wt%) and CaO (2.3–2.5 wt%) contents and enriched in transition metals. The samples have negative correlations between SiO_2, Fe_2O_3, and CaO with MgO and are more similar to mid-oceanic ridge type than SSZ type. Correlating with the northern segment of the Western Ophiolite Belt it is likely suggest that the peridotite rock exposed in the northern and southern segment were formed in the mid-oceanic ridge setting and were accreted to the Indo-Myanmar Ranges from the downgoing Tethyan plate as part of subduction-accretion processes.

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