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GEOCHEMICAL INVESTIGATION OF CHROMITITES IN ULTRAMAFIC ROCKS OF TAUNG-PI-LA AREA, KALAY TOWNSHIP, SAGAING REGION

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Abstract

Taung-Pi-La Area is situated about 3.84 miles (6.22 kilometers) west of Kalemyo, Sagaing Region. The principal rock types of the Taung-Pi-La Area include harzburgite, dunite and serpentinites which are formed during Late Jurassic to Early Cretaceous. Exposures of pyroxenite were observed in the research area. Seven chromitites occurred in the Taung-Pi-La ultramafic rocks. Chromitite are massive, nodular and disseminate types displaying pull-apart, cataclastic, net and clot textures. Among the chromite grains, the interstitital silicate of olivine, orthopyroxene and serpentine are found. X-ray diffraction (XRD) of chromitites of the Taung-Pi-La Area shows magnesiochromite ($MgCr_2O_4$) type. Chromitite composition is characterized by Cr_2O_3 ranging from 27.10 to 59.43 wt.%, Al_2O_3 from 7.36 to 26.60 wt.%, MgO 8.27 to 26.80 wt.%, and FeO ranges from 4.37 to 14.66 wt.%. The maximum Fe_2O_3 content is 2.45 wt% and TiO_2 is always below 0.18 wt%, as typical for podiform chromitites and ophiolitic chromitites. The high-Cr chromitites are typically hosted in highly depleted harzburgites. In the TiO_2 vs. Cr_2O_3, Mg#[Mg/(Mg+Fe^{2+})] versus Cr#[Cr/(Cr+Al)] and TiO_2 vs. Fe^{2+}/Mg diagrams, most of the chromitites belongs to the podiform chromitites. The trivalent ion plot (Cr-Al-Fe^{3+}) and Al_2O_3 vs Cr_2O_3 of chromitite compositions show that chromitites are derived from mantle source. According to the $TiO_2$and Al_2O_3 diagram, chromitites of the Taung-Pi-La Area are formed in the supra-subduction zone (SSZ).

Keywords: pull-apart and cataclastic textures, magnesiochromite, podiform chromitites, supra-subduction zone

Introduction

The research area is situated about 3.84 miles (6.22 kilometers) west of Kalemyo, Sagaing Region. The area is bounded by N latitude 23° 11' to 23° 12' 10" and E longitude 93° 58' 30" to 94° 00' 30". It lies in UTM map sheet No.2393 16 and 2394 04 composite. It extends about 1.36 miles (2.18 kilometers) from north to south and 2.12 miles (3.40 kilometers) from east to west, covers 2.88 square miles (7.41 square kilometers). The location map of the research area is shown in Fig. (1). S of the Bhopi Vum the WNW-SSE trending hill of Taung-Pi-La is situated within the alluvial plain. The aeromagnetic map shows a direct connection with the Bhopi Vum. The topography of this area is generally low-lying in the eastern part, but it is higher and fairly rugged in the middle part. It is the dismembered incomplete ophiolite belt with nickel and chromite mineralization. The purpose of this study is to outline the geochemistry of chromitites and associated ultramafic rocks, and also to give some constraints on the petrogenesis of chromitites in this area.

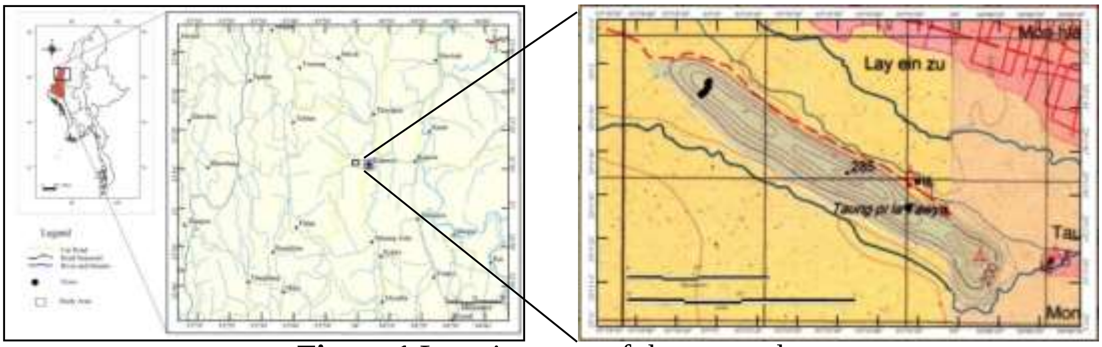

Figure 1 Location map of the research area.

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Materials and Methods

Identification of textural relationships of chromitites was investigated microscopically on polished thin sections under reflected light ore microscope. Six representative chromitite samples collected from the research area have been selected and analyzed by X-ray fluorescenes (XRF), X-ray Analytical Microscope (XGT 5200, HORIBA Scientific) and X-ray diffraction (XRD) at Mandalay University Research Center and Department of Research and Innovation (Naypyidaw).

General Geology

The Kalemyo ophiolite outcrops at the eastern margin of the Indo-Burma Range and consists of huge ultramafic massifs (Mwe Taung, Bhopi Vum and Webula) as well as small ultramafic massifs (Taung-Pi-La) but little mafic rocks. The principal rock types of the Taung-Pi-La Area include harzburgite, dunite, serpentinite and pyroxenite. Podiform chromitite (massive, nodular and disseminate) are observed in the research area. Chlorite schist are rare occur. Pyroxenites and chlorite schist are not mappable. Mitchell *et al*., 2015 argued that the ophiolites are best explained by the Late Jurassic or Early Cretaceous (ca.end-Jurassic) continental collision on a Medial Myanmar Suture Zone, prior to development of the west-facing Popa-Loimye arc system to the west. The geological map of the research area is shown in Fig. (2).

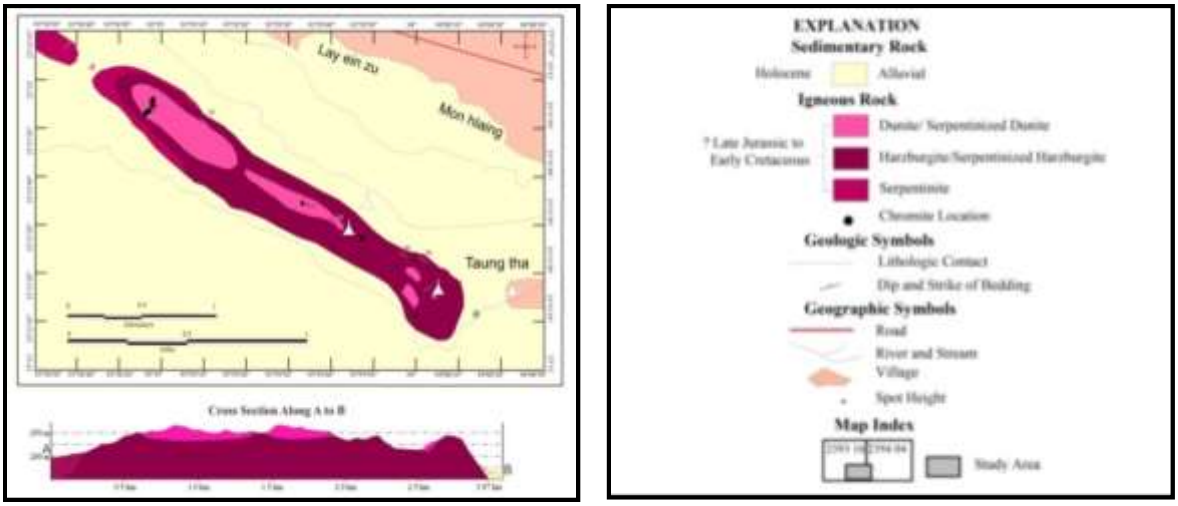

Figure 2 Geological map of the research area (Tun Tun Min *et al*., 2019).

Occurrences and Types of Chromitites

Seven chromitites were collected in the Taung-Pi-La Area (Fig. 2). The chromitites bodies are typically lens shaped, although many occur as tabular like bodies (Fig. 3A), but some occur as veins and stringers in dunite (Fig.3B).The chromite mineralization is concentrated along the western part of Taung-Pi-La. The boundaries of the chromitite pods with enclosing dunite are generally sharp (Fig.3C). Chromitites of the research area display massive, nodular (Fig. 3D) and disseminated types.

Petrography of Chromitites

Chromitites in the research area are composed of coarse-grained aggregates of chromite and silicate minerals (as in matrix). The chromite grains are subhedral to euhedral in shape and vary in size from 0.03 to 1 mm. It shows black colour with brownish and yellow tinge under ore microscope. The matrix is composed of olivine and serpentine group of minerals plus minor chlorite. Most of the chromite grains showed pull-apart and cataclastic texture (Fig.4A). In massive ores, the small interstitial chromite grains are found to be rounded and corroded (Fig.4B). Segregation of finer subhedral grains in the interspaces of coarsely granular chromite mosaic was described as clot texture by Mukherjee (1969) (Fig.4C). Chromites intercumulus chromite grains are joined together to form net-texture (Fig.3D).

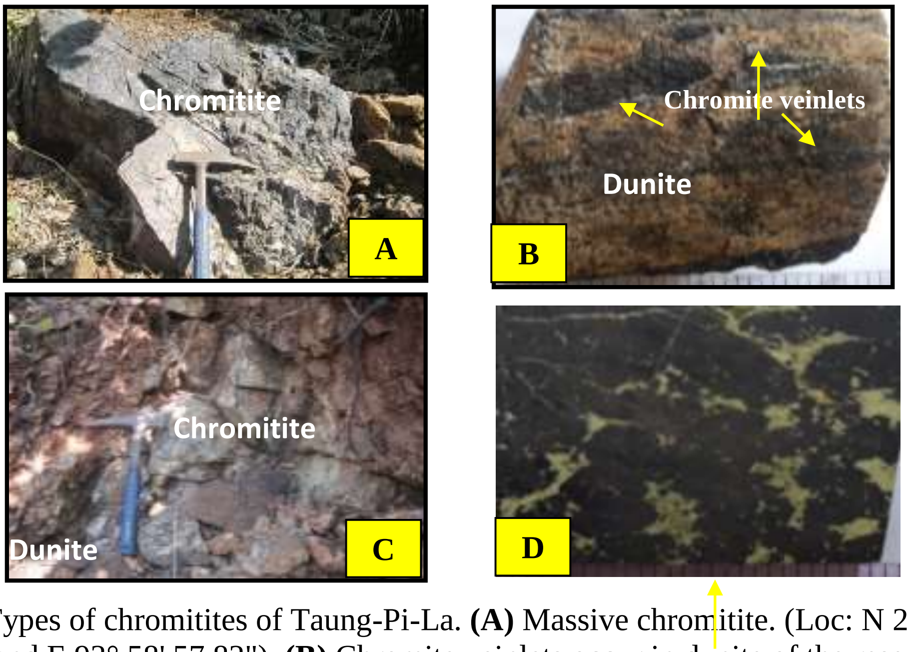

Figure 3 Types of chromitites of Taung-Pi-La. **(A)** Massive chromitite. (Loc: N 23° 11' 54.72" and E 93° 58' 57.82"). **(B)** Chromite veinlets occur in dunite of the research area. **(C)** Field photograph of chromitite enveloped dunite in Taung-Pi-La ultramafic body. **(D)** Nodular chromitite show net textured chromites.

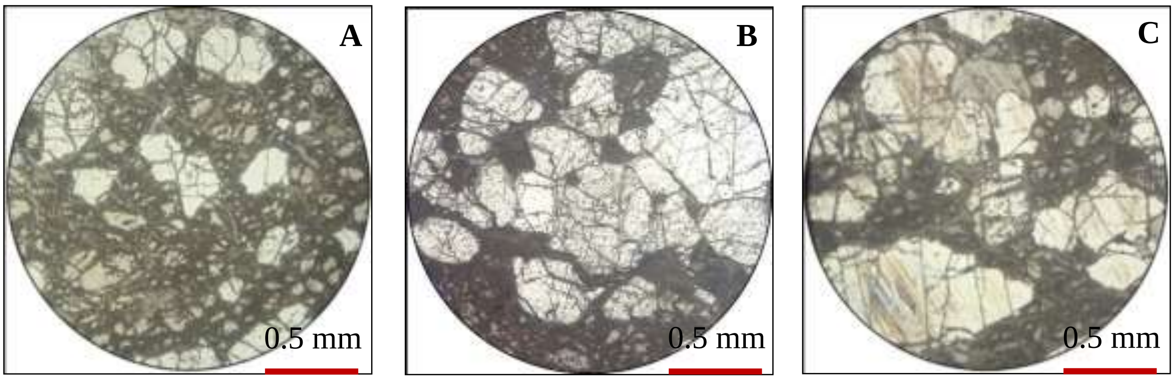

Figure 4 Textures of chromitites. **(A)** cataclasic textured chromites. **(B)** Resorbed grains of chromite. **(C)** Clot texture of chromite (under ore microscope).

Results

Geochemistry of Chromitites

The results of XRF analyses of chromitite were presented in Table 1. Chromitite composition is characterized by Cr_2O_3 ranging from 27.10 to 59.43 wt.%, Al_2O_3 from 7.36 to 26.60 wt.%, MgO 8.27 to 26.80 wt.%, and FeO ranges from 4.37 to 14.66 wt.%. X-ray powder diffraction (XRD) analysis indicates that the studied chromitites are of magnesiochromite

($MgCr_2O_4$) (Fig. 5A). In the Mg# vs. Cr# diagram (Dick and Bullen 1984) (Fig. 5B), most of the chromitites belongs to the magnesiochromite type except one sample.

Table 1 Chemical data of chromitites of Taung-Pi-La Area.

ore	**Massive chromitites**			**Nodular chromitites**		
Samp: No.	**1**	**2**	**3**	**4**	**5**	**6 (xgt)**
SiO_2	11.70	11.10	12.20	22.60	20.6	3.63
TiO_2	0.17	0.15	0.14	0.13	0.15	0.18
Al_2O_3	26.10	26.60	25.50	18.20	17.80	7.36
Fe_2O_3	2.37	2.45	2.43	2.11	2.08	6.98
FeO	4.98	5.15	5.11	4.42	4.37	14.66
Cr_2O_3	29.40	30.70	29.60	27.10	27.50	59.43
MgO	24.20	22.80	24.60	24.30	26.80	8.27
CaO	0.32	1.14	0.35	1.26	0.76	0.00
Na_2O	0.58	0.00	0.00	0.00	0.00	0.00
K_2O	0.06	0.07	0.06	0.00	0.06	0.00
NiO	0.08	0.08	0.08	0.09	0.09	0.19
V_2O_5	0.08	0.06	0.08	0.05	0.05	0.00
Co_2O_3	0.02	0.02	0.02	0.02	0.00	0.00
ZnO	0.02	0.03	0.02	0.02	0.023	0.11
WO_3	0.05	0.05	0.03	0.02	0.00	0.00
Total	100	100	100	100	100	101
Si	5.50	5.20	5.70	11.00	9.60	1.70
Mg	15.00	14.00	15.00	15.00	16.00	5.00
Al	6.90	7.00	6.70	4.80	4.70	1.90
Cr	10.00	11.00	10.00	9.30	9.40	20.00
Fe^{2+}	3.87	4.00	3.97	3.44	3.40	11.4
Ti	0.10	0.10	0.10	0.10	0.10	0.10
Ni	0.10	0.10	0.10	0.10	0.10	0.10
$Mg/(Mg+Fe^{2+})$	0.77	0.75	0.77	0.79	0.81	0.28
Cr/(Cr+Al)	0.60	0.60	0.60	0.66	0.67	0.91

Under XGT microscopic study, aerial analysis of X-ray mapping of Mg, Si, Fe, Al, Ti, Cr, Mn, Ni, Pm, Zn and Bi in nodular chromitites are shown in Fig (6). FeO, Cr_2O_3 and Al_2O_3 content of the massive chromitites have higher composition than nodular chromitites. Massive chromitites contain lower SiO_2 than nodular chromitites. Mg, Fe and Si in nodular chromitites contain mostly indicates that olivine or serpentine (Fig 6).

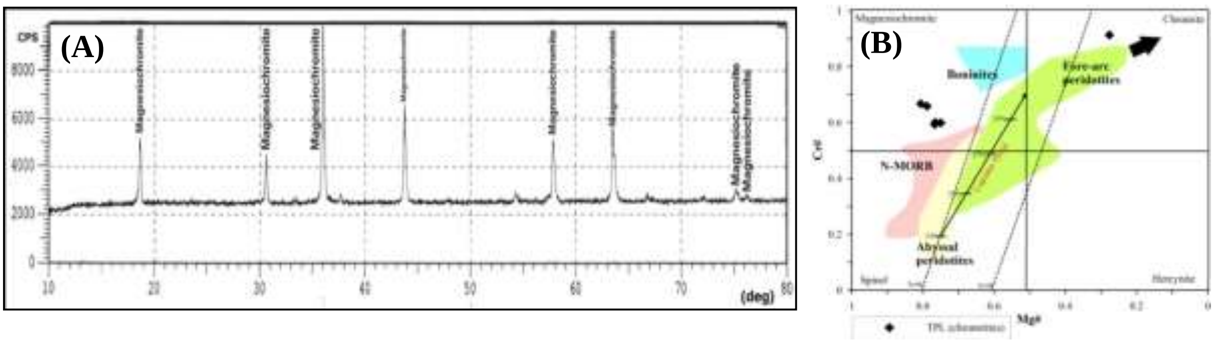

Figure 5 (A) X-ray diffractograms of chromitite from the research area. **(B)** Chromitites from the Taung-Pi-La Area plotted on the Cr# [Cr/(Cr + Al)] versus Mg# [Mg/(Mg + Fe^{2+})] diagram. Fields are collected from Dick and Bullen, 1984.

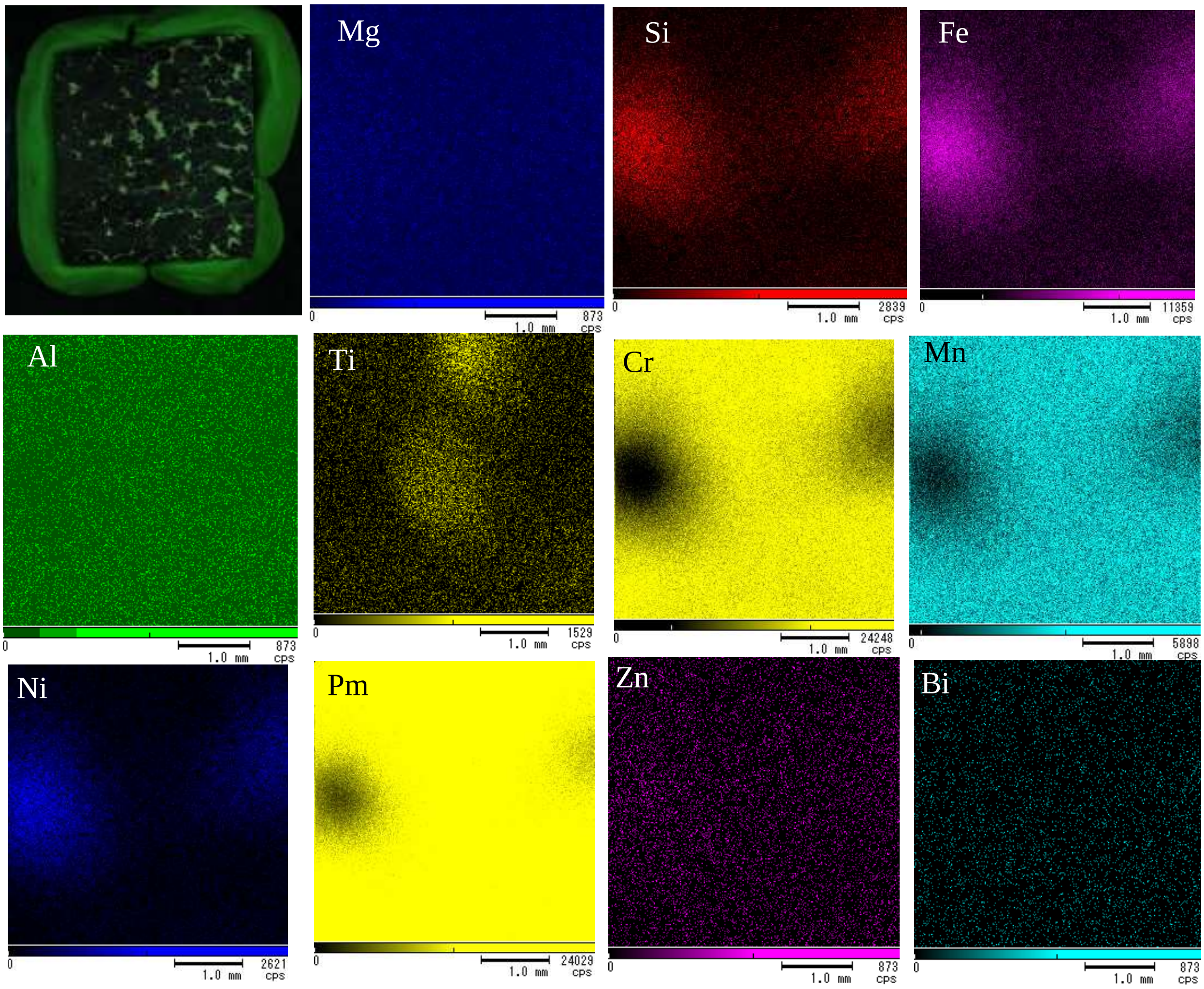

Figure 6 X-ray maps of the elements Mg, Si, Fe, Al, Ti, Cr, Mn, Ni, Pm, Zn and Bi of nodular chromitite sample under X-ray analytical microscope.

Chromitites from Taung-Pi-La Area show a wide range of composition, with Cr-numbers varying from 0.60 to 0.91 and Mg numbers (0.28-0.81) (Table 1). In the chromitites, FeO contents of chromitites are negatively correlated with MgO (Fig. 7B), whereas Cr_2O_3 contents are negatively correlated with MgO (Fig. 7D). The Al_2O_3 (7.36-26.60 wt.%) abundance in podiform chromitite depends on the melt of peridotite composition which is a function of pressure, temperature and the degree of partial melting (Kamentesky *et al*., 2001).

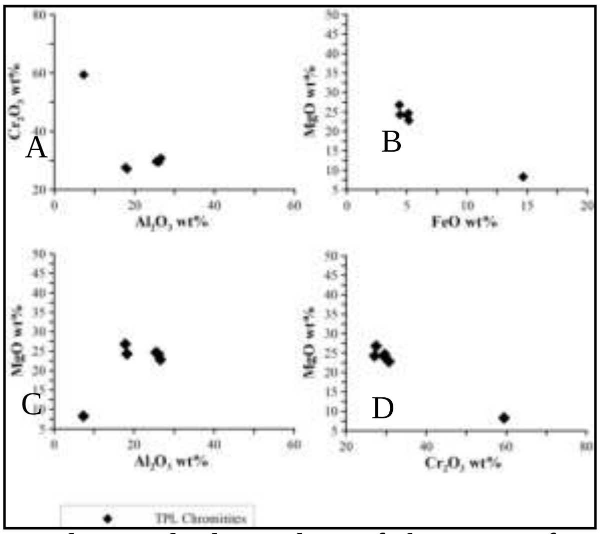

Figure 7 (A-D) Interelemental relationships of chromitites from Taung-Pi-La Area.

The samples studied in this work yield Cr_2O_3 contents of (27.10 - 59.43 wt.%), with a correspondingly high Cr# [Cr/(Cr + Al) atomic ratio; 0. 6-0.9] and Mg# [(Mg/Mg+ Fe^{2+}) atomic ratio;0.28-0.81] the studied samples are plotted in the high Cr type (Fig.8). In the Cr# vs. Ti and Cr# vs. Ni diagrams, these samples are displayed to belong to Cr-rich chromitites (Fig.9).

High Cr-rich chromitites (Cr#> 0.6) might have formed initial liquid after higher degree of partial melting. In the diagram Cr#[Cr/(Cr+Al)] versus Mg#[Mg/(Mg+Fe^{2+})], the composition of these chromitites plotted in or near the field of podiform (ophiolite) chromitites (Fig. 10A). Nickel content (0.08-0.19 wt %) of chromitites in ophiolites are similar to those of chromitites in typical podiform chromitites (Ahmed, 1984). In the Cr# vs. TiO_2 discriminant diagrams (Barnes and Roeder, 2001), chromitites from the Taung-Pi-La Area are displayed at the ophiolitic chromitites (Fig. 10B). In Cr-Al- Fe^{3+} (atomic element) ternary diagram (Proenza *et al*.,2007), the studied samples overlaps the compositional field for typical podiform (ophiolitic) chromitites (Fig.11A). In Cr# vs. Fe_2O_3 diagram, high-Cr chromitites plotted in the podiform chromitites fields (Fig.11B).

The compositional characteristics of the Taung-Pi-La chromitites, i.e. Cr, Al, Mg, Fe^{3+} and Ti concentrations, are in accordance with those from typical podiform chromitites hosted in the mantle section of ophiolites. In the TiO_2 vs. Cr_2O_3 diagram (Fig.12A), most of the chromitite samples belong to the podiform chromitites. The maximum Fe_2O_3 content is 2.45 wt% and TiO_2 is always below 0.18 wt%, as typical for podiform chromitites and ophiolitic chromitites. The low TiO_2 contents of studied samples (0.13-0.17 wt %) also indicate its characteristics as podiform chromitites.

In the Fe^{2+}/Mg vs. TiO_2diagram (Fig.12B), chromitites are situated at the podiform chromitites field. The chromitites have a low Fe/Mg ratio indicating low Fe/Mg ratio of the magma from which they have crystallized. Fe-Mg exchange temperatures (Ballhaus *et al*., 1991) of chromite from massive chromitite and olivine from coexisting silicate mantle dunite or harzburgite are between 915 and 1200°C, which suggest magmatic origin of chromite.

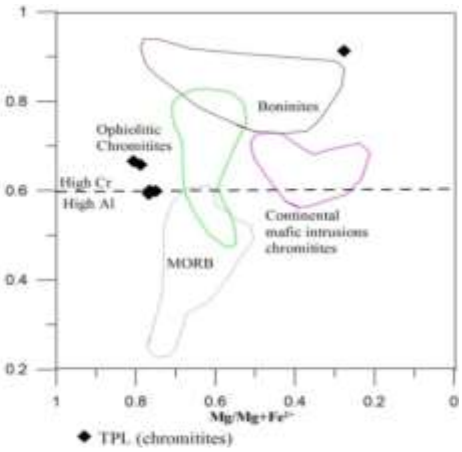

Figure 8 Cr# [(Cr/Cr + Al) atomic ratio] versus Mg# [(Mg/Mg+ Fe^{2+}) atomic ratio] of chromitites. (Field from Proenza *et al.*, 2007).

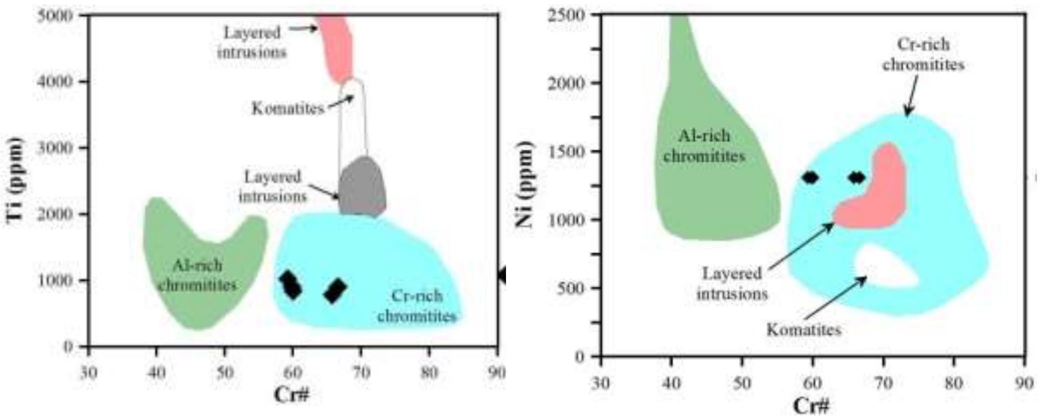

Figure 9 Compositional variations of Cr# vs. Ti and Ni of the chromitites. Data sources for the high-Al and high-Cr ophiolitic chromitites are collected from Zhou *et al*., 2014.

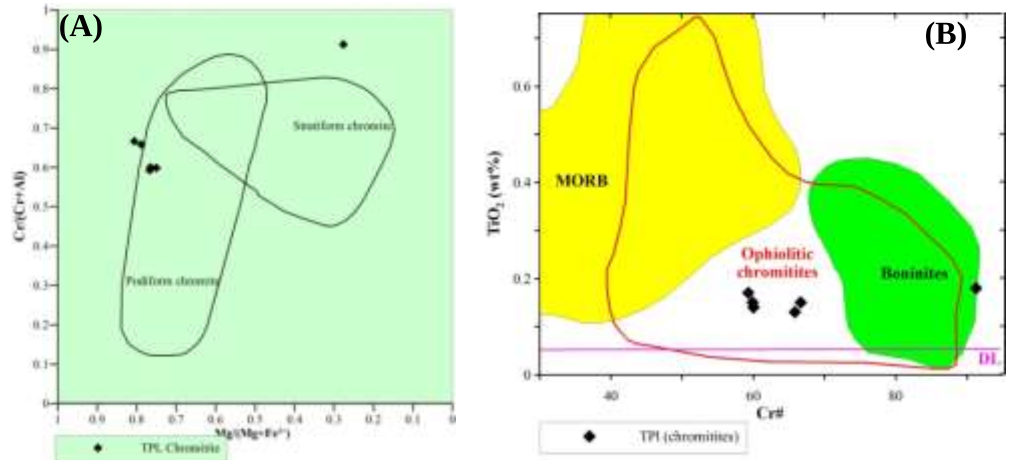

Figure 10 (**A**) Chromitites are plotted on the Cr# [Cr/Cr+Al] versus Mg# [Mg/Mg+ Fe^{2+}] diagram. Compositional fields of podiform and stratiform chromitites are collected from Leblanc and Nicolas (1992) and Irvine (1967) (in Mirza, T.A, 2008), respectively. **(B)** Composition of chromitites from the research area are plotted on the Cr# vs. TiO_2 (wt%) diagram. Compositional fields are from Barnes and Roeder (2001).

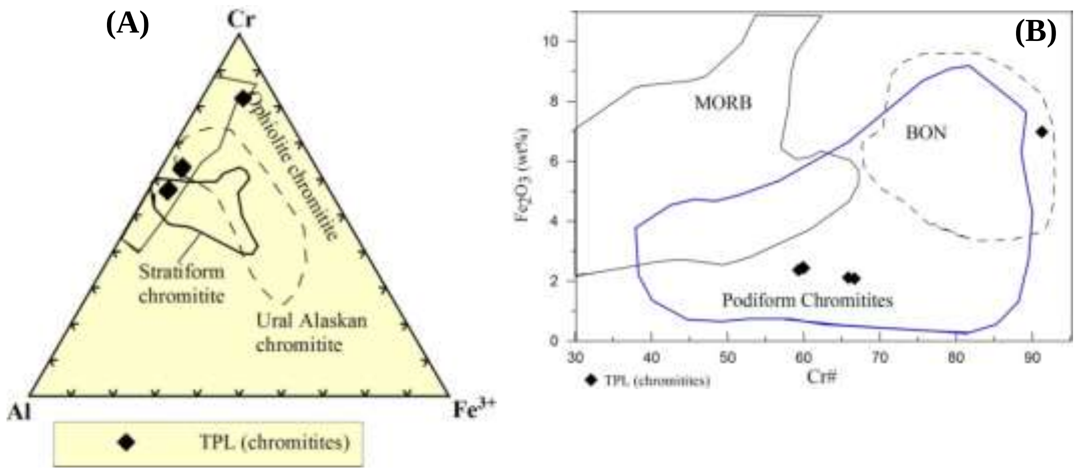

Figure 11 (A) Cr-Al- Fe^{3+} (atomic element) ternary diagram. Data sources for chromitites of different tectonic settings are from Proenza *et al*., 2007. **(B)** Fe_2O_3 vs. Cr# for chromitites from the Taung-Pi-La. The field of podiform chromitites is compiled from Dare (2008).

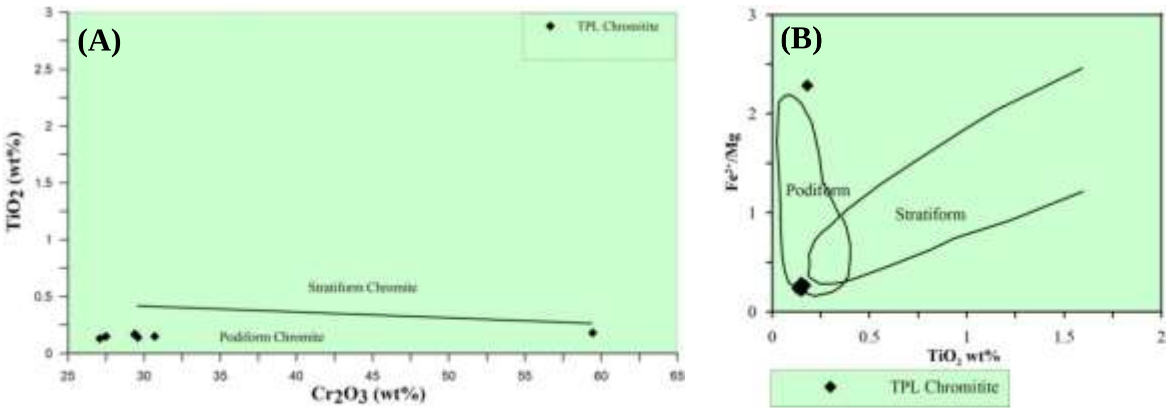

Figure 12 (A) Chemical compositions of chromitites compared with stratiform and podiform chromitites on TiO_2 wt% vs Cr_2O_3 wt% diagram. Fields are from Musallam *et al*. (1981) and Arai *et al*. (2004) (in Mirza, T.A, 2008). **(B)** Chromitites of the studied area are plotted in the Fe^{2+}/Mg vs. TiO_2 podiform and stratiform chromitite diagram.

Petrogenesis of Chromitites

Such chromitites hosted in depleted peridotites, crystallized from mantle melts (Coleman, 1977). Chromitites commonly have dunite envelopes grading outward into harzburgite which were explained by additional partial melting of harzburgite (Thayer, 1963). Chromitites and adjacent peridotites should yield insights into the melt-rock interaction process and the mechanism of chromitite formation in the upper mantle. The podiform chromitite is usually associated with dunite; it occurs as pod-like bodies with dunite envelopes of mantle origin (Nicolas, 1989). The trivalent ion plot (Cr-Al- Fe^{3+}) and Cr_2O_3 vs Al_2O_3 of chromitite compositions show their mantle origin (Fig.12A &12B). The TiO_2 and Al_2O_3 contents of chromitite from genetically- related peridotite, dunite and chromitite samples aids the interpretation of the tectonic setting in which they formed. On the tectonic discrimination diagrams, chromitites of the Taung-Pi-La Area are plotted in the supra-subduction zone (SSZ) field (Fig. 12C).

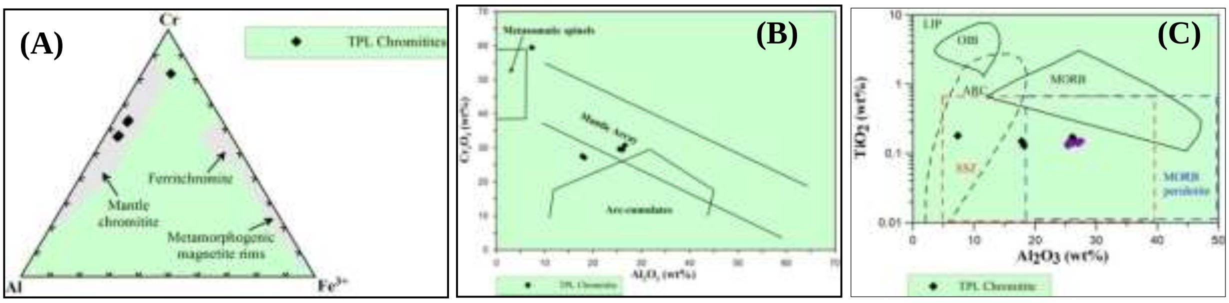

Figure 13 (A) Trivalent ion plot (Cr-Al-Fe^{3+}) of chromitite compositions. Mantle chromitite, Ferritchromite and metamorphogenic magnetite field (Arai and Yurimoto, 1994) are shown for comparison. **(B)** Cr_2O_3 versus Al_2O_3 plot of the chromitite of the present study. Fields are collected from Franz and Wirth (2000). **(C)** Plot of TiO_2 versus Al_2O_3 in chromitite from Taung-Pi-La ophiolite complex. Fields are after Kamenetsky *et al*. (2001). SSZ; Supra-subduction zone; LIP, large igneous province; MORB, mid-ocean ridge basalt; OIB, ocean island basalt. ARC = arc related volcanic rocks.

Moreover, a diagram of TiO_2 versus Fe_2O_3 indicates that almost all samples from Taung-Pi-La plot within the field of SSZ ophiolites (Fig. 13A). The podiform chromitite must have formed under the uppermost mantle conditions in SSZ environments.Chromitites fall within a boninitic affinity (Fig. 13B). Chromites with high Cr# (>70) are commonly found in boninitic lavas and these are thought to have formed in SSZ environments. Podiform chromitites formed from hydrous boninitic magmas in a SSZ environment (Zhou *et al*., 1996).

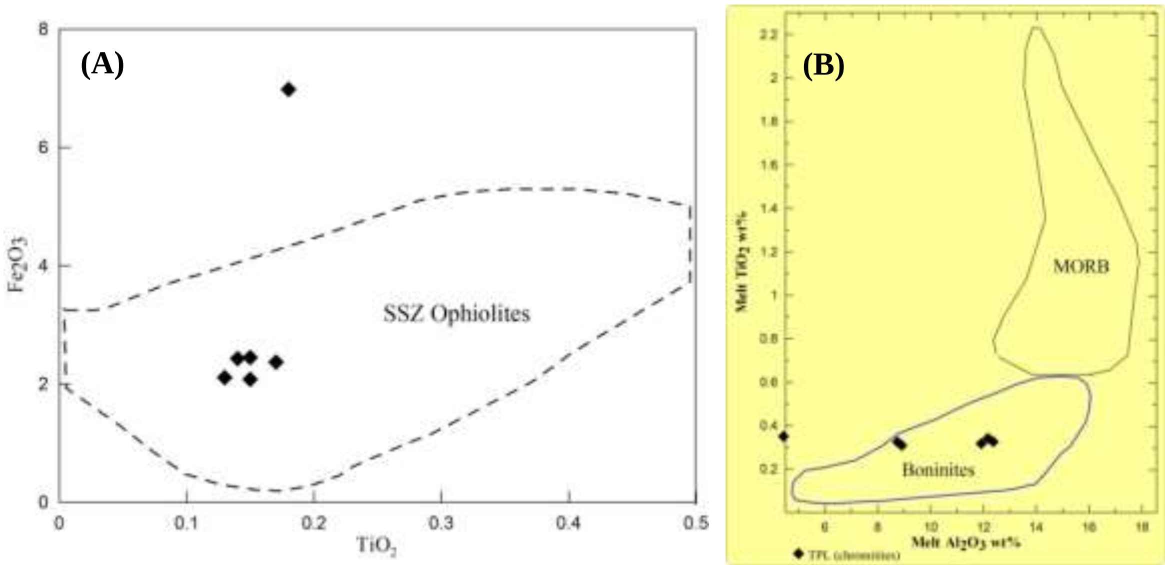

Figure 14 (A) Plots of TiO_2 vs. Fe_2O_3 of chromitites of the study area (fields after Bridges et al. 1995). **(B)** Composition of the parental melt in equilibrium with the studied chromitite in terms of TiO_2 versus Al_2O_3 (wt.%). Data sources for chromian spinel of different tectonic settings are from Pagé and Barnes (2009).

$$\ln (\text{wt \% } Al_2O_3 \text{ in melt}) = 0.41322 \times (\ln (\text{wt \% } Al_2O_3 \text{ in chromitite})) + 1.38529.$$

$$\ln (\text{wt \% } TiO_2 \text{ in melt}) = 0.82574 \times (\ln (\text{wt \% } TiO_2 \text{ in chromitite})) + 0.20203.$$

Conclusion

Podiform chromitites in Taung-Pi-La are enclosed in dunite which, in turn, is surrounded by harzburgite. Chromitites are presented by massive, nodular and disseminate types displaying pull-apart, cataclastic, net and clot textures. Among the chromite grains, the interstitital silicate of olivine, orthopyroxene, serpentine and chlorite are found. X-ray diffraction (XRD) of chromitites shows pattern of magnesiochromite ($MgCr_2O_4$). The TiO_2 vs. Cr_2O_3 diagram, Cr#[Cr/(Cr+Al)] versus Mg#[Mg/(Mg+Fe^{2+})] and TiO_2 vs. Fe^{2+}/Mg diagram indicate that most of the chromitite samples belongs to the podiform chromitites. The high-Cr chromitites (Cr#> 0.6) are typically hosted in highly depleted harzburgites and formed initial liquid after higher degree of partial melting. The trivalent ion plot (Cr-Al-Fe^{3+}) and Cr_2O_3 vs Al_2O_3 of chromitite compositions show their mantle origin. According to tectonic discrimination diagram, Taung-Pi-La chromitites must be generated from hydrous boninitic magmas in a SSZ environment. Chromitites and adjacent peridotites should yield insights into the melt-rock interaction process.

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