Geochemical Characteristics of Basaltic Rocks from Kyaukphyu-Webaung Ophiolite, Thabeikkyin and Mongmit Townships: Implications for Tectonic Settings

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Abstract

This paper presents a systematic study of geochemical characterization of the basaltic rocks from the Kyaukphyu-Webaung area. The study area occupies in the Thabeikkyin and Mongmit Townships, about 30 km NE of Thabeikkyin. The basaltic rocks samples were analyzed for geochemical studies from several locations in this area. They are mainly comprised olivine, plagioclase , pyroxene and minor amount of chrome spinel and opaque minerals. Based on the major elements data, they plot in foidite, tephrite, trachy basalt, basalt, basaltic andesite, andesite and dacite. They are in tholeiitic series of calc-alkaline affinity. The multi-element N-MORB and chondrite normalized plot of the spider pattern exhibit positive spikes generally on Rb and Ba and with marked negative Nb anomalies further strongly confirm their island arc signatures and the basaltic lavas are originated from variable partial melting degrees of subduction-related mantle source and island arc nature. The trace element analyses of the basaltic rock samples indicate that these are having characteristics of either island arc tholeiitic or transitional between mid-oceanic ridge basalt and island arc tholeiitic. Therefore, they have formed in supra-subduction zone tectonic setting.

Keywords: chrome spinel, calc-alkaline, mid-oceanic ridge basalt, island arc tholeiitic, supra-subduction zone

Introduction

The Kyaukphyu-Webaung area lies within latitudes 23° 04′ N to 23° 15′ N and longitudes 96°06′ E and 96° 17′ E. It falls in the UTM map sheet No. 2396-04 and 2396-08, one-inch Topographic map 93-A/4 and 93-A/8. It is situated between the southwestern corner of Tagaung-Myitkyina Belt (TMB) and the northwestern part of Mogok Metamorphic Belt (MMB). The study area occupies in the Thabeikkyin Township and Mongmit Township, about 30 km NE of Thabeikkyin. It extends 20 km in east-west direction and 22 km in north-south direction, covers approximately 440 square kilometers.

Regional Geologic Setting

Tectonically, Myanmar territory is consisted of at least two north-south trending paleo-continental blocks. They are the Shan-Thai Block (STB) (Bunopas and Vella, 1983) to the east, and the whole West Burma Block or West Myanmar Block (WMB) including its accreted terranes as Western Ranges (WR) and Rakhine Coastal Belt (RCB) to the west. These two blocks are separated from each other at present by a younger active dextral slip Sagaing Fault (Win Swe, 1981 and 2010, 2013).

Three metamorphic belts such as the Jade Mines Belt, Katha-Gangaw Belt and the Tagaung-Myitkyina Belt splay off from the Sagaing fault in the northern Myanmar (Searle *et. al,* 2007). The study area is located in the southwest corner of the Tagaung-Myitkyina Belt of the Upper Ayeyarwaddy Province (Mitchell *et. al*, 1975). This belt narrows northward between the converging Mogok Belt and Kumon Range.

The west of the study area is bounded by a regional north-south lineament (the Sagaing Transform Fault) which follows the course of the Ayeyarwaddy. The present area is

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truncated by northeast-southwest diagonal fault (Nansein Strike-slip Fault) that bifurcates from the Sagaing Fault. Therefore, the area is a highly deformed zone surrounded by the major tectonic domains. West of the Sagaing Fault is the N-S trending range known as the Minwun Range. This range is made-up of Eocene sediments and pre-Tertiary inliers.

The Twinnge-Momeik Fault (TMF) passes through the study area and divided into highly mountainous track of Shwe-U-daung Taung in the southern part, which is made up of metamorphic rocks of Mogok Series. To the northeast is occupied by Eastern Highland, which is built up by medium- to high-grade metamorphic rocks of the Mogok Series.

Mogok Series is consisting of the Precambrian to Upper Cretaceous succession lying unconformably on the Proterozoic turbidites which extend northward into Yunan.

North of the metamorphic belt is distributed sequence of sandstones, mudrocks (with *lalobia*), limestones (bearing *Orbitolina*), pyroclastic rocks, pillow basalt and bedded chert (carrying Jurassic-Cretaceous radiolarians). It passes into the rocks of green-schist facies and meets an untrabasic complex along a fault at Tagaung Taung area (Clegg, 1942; Laja, 1983; Aung Kyaw Thin, 2006). The schists stretch northward into the Gangaw and Kumon ranges.

Serpentinites and basaltic rocks are leaking out (escape form) in many places through the Sagaing Fault. The serpentinites of the study area belong to the Eastern Ophiolite Belt of Hla Htay (2002) which is a belt of incomplete, dismembered ophiolites.

Analytical Techniques

Twenty-one representative samples which are mostly fresh were selected for geochemical analysis. The samples were broken into small chips. The rocks were crushed, and then pulverized using grinder. Major oxides and selected trace element analysis were carried out on powder pellets by X-ray Fluorescence Spetrometer (XRF) in the URC (University Research Center) of Mandalay University and Kyusu University of Japan.

Geochemical Characteristics

Basalts show low SiO_2 content (38.8-62.16 wt %) and moderate Al_2O_3 (9.64-19.00 wt %), CaO (1.33-30.5 wt %), MgO (2.39-8.45 wt %), total FeO (2.64-14.99 wt %), TiO_2 (0.4-1.39 wt %) and Na_2O+ K_2O (1.44-6.33 wt %) concentrations (Table 1).

Classification

All the volcanic rock samples are plotted in SiO_2 vs. alkali (wt %) diagram (Fig. 1) of Middlemost (1994). In this diagram, one each sample plots in foidite field and tephrite field, one sample straddles in the tephrite and trachy basalt fields, four in basalt field, ten in basaltic andesite field, and two each in the andesite and dacite fields.

The superposition of a dashed line demarcates the alkaline and subalkaline (Irvine and Baragar, 1971). The three samples such as no. 21, 22 and 25 plot in the alkaline field and the other all samples fall in the sub-alkaline/tholeiitic field. Since alkali elements (Na_2O+ K_2O) are susceptible to mobilization in response to alteration, metasomatism, metamorphism; classification scheme based on high-field strength element is used for verification (Siddiqui *et. al.,* 2007).

Table (1). Major Oxides of Igneous Rocks in Ophiolite Suite

Sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P2O5	H_2O	Total
◇ 5	62.16	0.69	13.75		9.16	0.20	5.46	2.26	1.98	0.12	0.09	4.04	99.91
▽ 6	61.98	1.09	13.77		8.79	0.19	5.24	1.51	3.49	0.39	0.24	3.22	99.90
⊠ 7	61.70	0.40	19.00	2.76	2.64	0.15	2.56	4.19	4.67	1.55	0.24	0	99.86
✳ 8	58.38	1.44	15.19	4.31	4.69	0.38	6.67	1.33	2.19	0.73	0.54	4.1	99.96
⊕ 9	52.76	1.39	14.57	5.83	7.45	0.30	8.40	4.17	1.96	0.06	0.13	2.8	99.82
✦ 10	52.50	0.86	16.86		8.84	0.19	4.87	6.02	3.00	1.07	0.13	5.33	99.67
✡ 11	51.98	1.02	15.73		11.57	0.30	4.49	5.88	2.17	0.82	0.15	5.76	99.87
⊞ 12	51.80	0.76	17.30		9.73	0.29	4.82	5.59	2.39	1.53	0.19	5.48	99.88
⌘ 13	51.38	1.04	15.65		11.69	0.31	4.71	6.24	2.02	0.79	0.16	5.89	99.87
⊠ 14	51.05	1.22	13.95		12.76	0.26	7.70	4.30	2.01	0.06	0.12	6.41	99.85
■ 15	50.89	1.31	13.74		14.99	0.31	4.98	7.10	2.97	0.41	0.14	2.62	99.46
● 16	50.59	0.71	16.17	4.04	5.60	0.26	5.87	6.67	2.30	1.26	0.10	0.17	93.74
▲ 17	50.57	0.86	16.46		9.16	0.26	5.64	5.48	2.90	1.19	0.20	7.17	99.88
• 18	50.12	1.25	14.29		13.41	0.28	8.04	4.16	1.93	0.05	0.12	6.17	99.82
◆ 19	50.10	1.15	17.10	6.44	8.86	0.27	8.00	5.12	2.33	0.12	0.12	0	99.61
• 20	47.79	1.27	14.26	4.69	7.07	0.32	5.76	8.32	2.72	0.6	0.21	6.84	99.85
○ 21	46.70	0.46	21.40	4.69	7.31	0.41	7.25	5.52	5.47	0.53	0.15	0	99.89
□ 22	46.40	0.54	20.90	4.14	6.46	0.38	7.20	7.44	5.94	0.39	0.13	0	99.92
◇ 23	45.75	0.57	9.64	2.64	4.15	0.14	2.39	25.41	0.43	0.01	0.09	8.62	99.84
△ 24	43.74	0.60	14.88		9.09	0.22	8.45	9.77	1.62	0.65	0.06	10.8	99.89
▽ 25	38.80	0.63	12.50	2.88	5.81	0.30	4.11	30.5	3.90	0.13	0.25	0	99.81

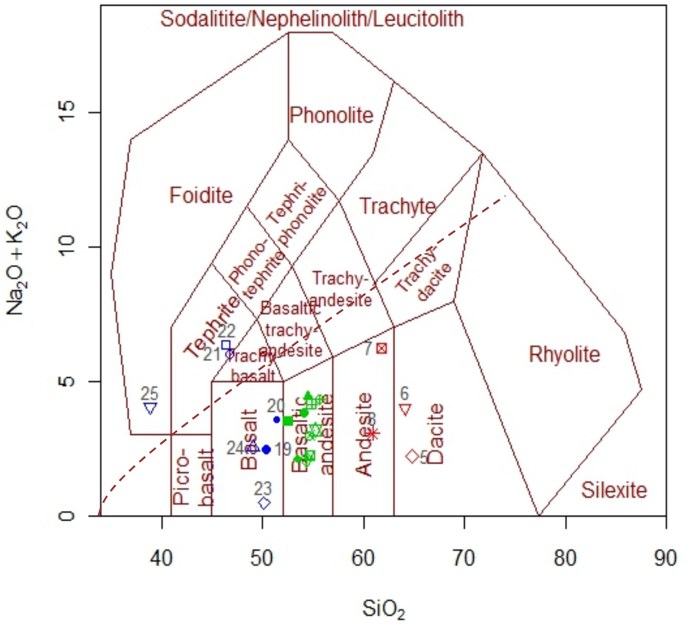

Figure (1). The total alkali versus silica (TAS) diagram of Middlemost (1994)

When these rocks are plotted in Al_2O_3- FeO(T)+TiO_2 –MgO diagram (Jensen, 1976), six samples fall in normal basaltic field, two in andesite, one in dacite and the other plots in high Fe-Mg tholeiitic basalt field (Fig. 2).

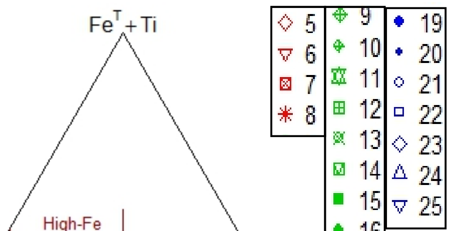

Figure (2). The Al- Fe^T + Ti -Mg diagram of Jensen (1976), showing the classification of volcanic rocks

Geochemical characteristics of Major elements

In the AFM diagram of Irvine and Baragar, (1971), the studied basaltic rocks exhibit a deviation in magma type ranging from the typical tholeiitic to calc-alkaline series. Sample no. 6, 7, 10, 17, 21, 22 and 25 fall in the calc-alkaline series but the others are in tholeiitic series (Fig. 3 A). In tholeiitic vs. calc-alkaline discrimination plot of Miyashiro (1974), the sample no. 5 to 8 fall in calc-alkaline series and others lie in the thoellitic series (Fig. 3 B) except sample no. 9 which straddles calc-alkaline and tholeiite series.

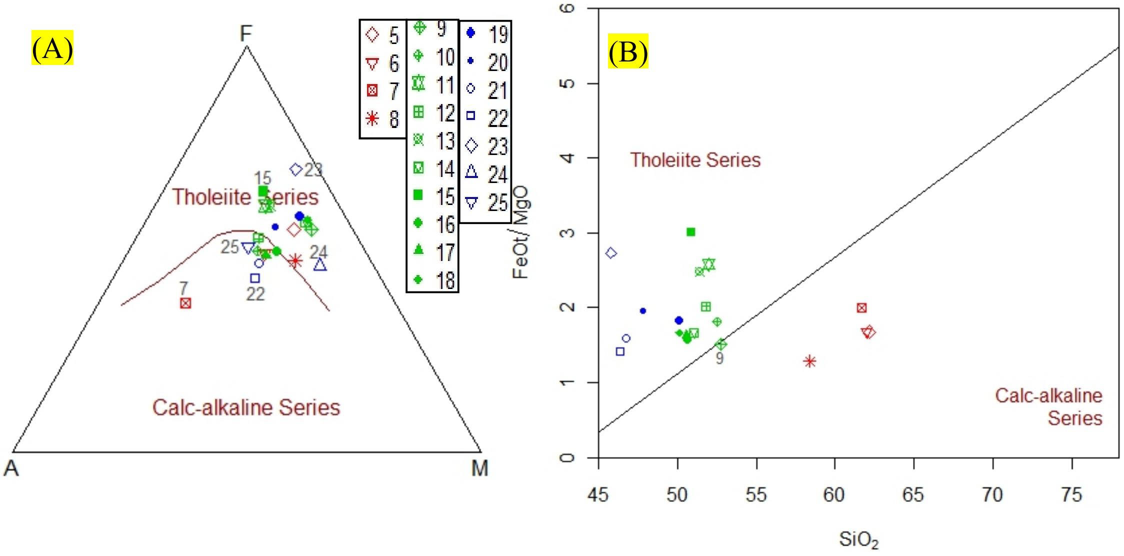

Figure (3). (A). AFM plot of Irvine and Baragar, (1971), (B) SiO_2- FeOt/MgO plot Miyashiro (1974) showing the types of basaltic rocks

Moreover, the projection of analyzed basaltic rock compositions on SiO_2 vs. K_2O plot (Peccerillo and Taylor, 1976) suggests tholeiitic and calc-alkaline character for the parental basaltic magma (Fig. 4). Sample no. 7, 10, 11, 13, 16, 17, 20, 21 and 22 lie in the calc-alkaline series whereas sample no. 5, 6, 8, 9, 14, 18, 19 and 23 plot in the tholeiitic series. Sample no. 12 straddles calc-alkaline and high-K calc-alkaline series and sample no. 19 also straddles tholeiitic and calc-alkaline series.

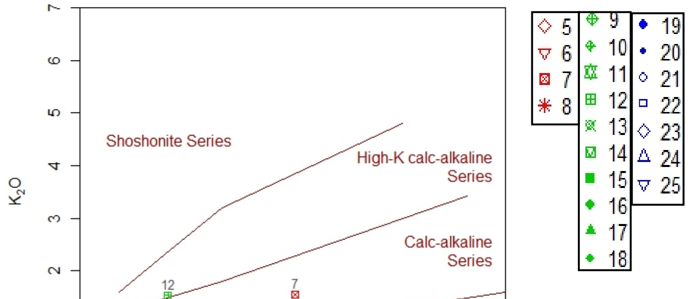

Figure (4). SiO_2 vs. K_2O plot showing the various series of basaltic rocks (Peccerillo and Taylor, 1976)

A plot of the basaltic rocks of the present area on the A/CNK-A/NK diagram (Shand, 1943), shows that they fall in peraluminous and metaluminous (Fig. 5 A). Furthermore, the projection of analyzed alumina composition on Na_2O-K_2O-CaO plot of Green and Poldervaort (1958) distinctly reflects the sodic field although all are nearly rich in calcium (Fig. 5 B).

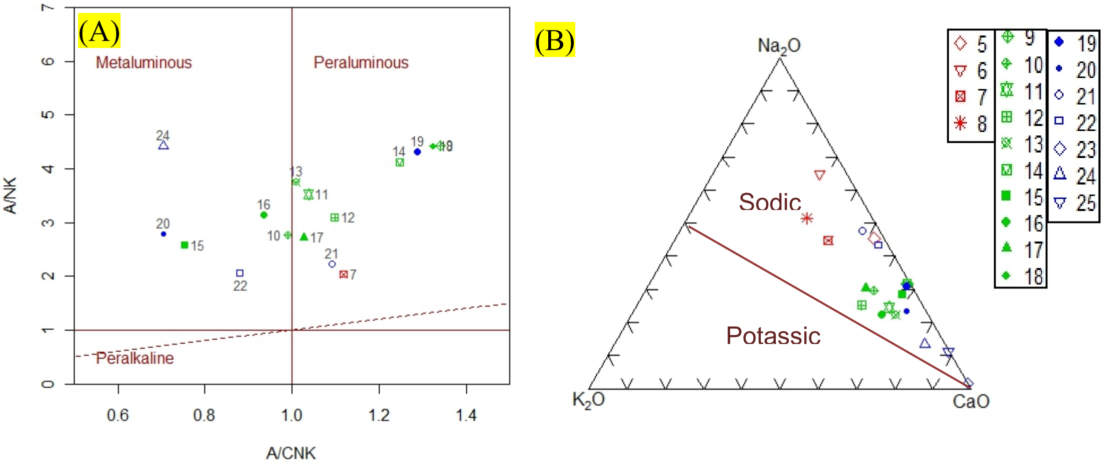

Figure (5). (A). A/CNK-A/NK diagram of Shand (1943) showing the alumina situation and (B) K_2O-Na_2O-CaO showing the alkali series of basaltic rocks (Green & Poldervaort, 1958)

Major Element Variation

According to the Harker variation diagram, most of the major oxide of the volcanic rocks against with MgO show as cluster variation with minor variability (Fig. 6). SiO_2 shows scattered negative correlation with MgO, probably due to the fractionation of pyroxene, plagioclase, magnetite, ilmenite and sphene (Siddiqui *et. al.*, 2007). The TiO_2 and Al_2O_3 content of the volcanic rock samples exhibit positive correlation with MgO, suggesting magmatic differentiation, whereas the Na_2O, CaO and P_2O_5 plot of the volcanic rocks show distinct clusters, which may be due to cumulate nature. The Fe_2O_3 and K_2O content of the studied sample does not show any correlation with MgO (Dey *et. al.*, 2018).

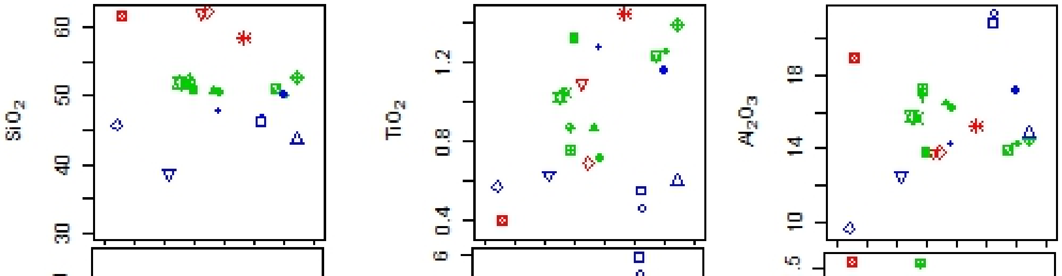

Figure (6). Harker's variation diagram showing the cluster variation with minor variability

Spider diagram

The multi-element N-MORB and chondrite normalized plot of the spider pattern (Fig. 7 A & B), which exhibit positive spikes generally on Rb and Ba and with marked negative Nb anomalies further strongly confirm their island arc signatures (Pearce, 1982; Wilson, 1989; Sounders and Tarney, 1991, in Siddiqui *et. al.*, 2007).

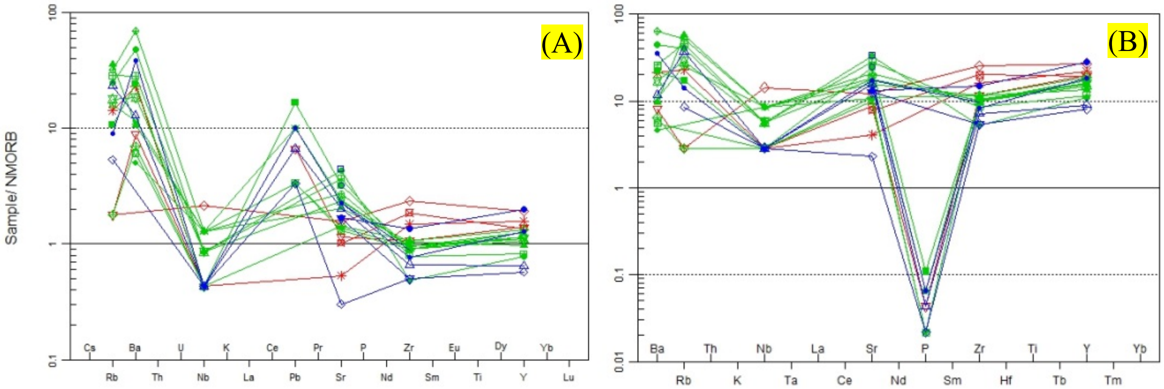

Figure (7). Spider diagrams of (A) NMORB normalized (Sun and Mc Donough, 1989), and (B) chondrites normalized (Thompson, 1982)

The marked negative Nb anomalies are explained by retention of this element in the residual phase during fractionation whereas the marked negative P anomalies are explained by reaction of this element in the residual phase during partial melting (Siddiqui *et. al.*, 2007). The positive spikes or enrichment of certain LIL elements (Rb, Ba, Sr and Pb) are generally considered to have formed by incorporation of these elements in the source from the subducting slab (Pearce, 1982; Wilson, 1989, in Siddiqui *et. al.*, 2007).

Petrogenesis of Basaltic Rocks

The geochemical characteristics of the ophiolite suite of rocks in general show certain amount of variations in terms of their major and trace elemental concentration, which could possibly due to mantle heterogeneity without any influence of crustal contamination (e.g. Pearce and Norry, 1979; Pearce, 1983, in Dey *et. al.,* 2018).

The basalts of the ophiolite suites are generally considered as part of paleo-oceanic crust formed through magma derived from depleted mantle (DM) (Dey *et. al.*, 2018). The enrichment in LIL elements in the volcanic rocks of the present study area can be due to modification of the depleted mantle by a subducted slab component or may be due to variable degree of mobilization during the alteration processes. However, the enrichment of Ba and depletion of Nb (Fig. 8) relative to other incompatible elements are considered to represent the addition of subduction zone component (in Kakar, 2012).

Further the spider diagram of basalt confirm above factor that the enrichment of LILEs (Rb, Ba, Sr, & Pb) may be due to either alteration or addition through subducting slab derived hydrous component to the melt source region, *i.e.* a depleted mantle wedge. However, the positive anomaly of Ba and negative anomaly of Nb relative to other incompatible elements in the NMORB normalized plots support the latter possibility (Wood, 1980; Hofmann, 1997, in Kakar *et. al.*, 2015) (see Fig. 8 A).

Tectonic Setting

In order to understand the tectonic setting for the emplacement of different magma types of the Kyaukphyu-Webaung ophiolite suites, different tectonic discrimination diagram were used. Tectonic settings of the basaltic rocks of the present study area were determined using discrimination diagram based on the HFs elements. Zr/Y vs. Zr diagram of Pearce and Norry (1979) divides between NMORB, VAB and WPB. The samples of the basaltic rocks fall in the overlapping field of NMORB and VAB (Fig. 9 A) except sample no.7 which straddles WPB and MORB.

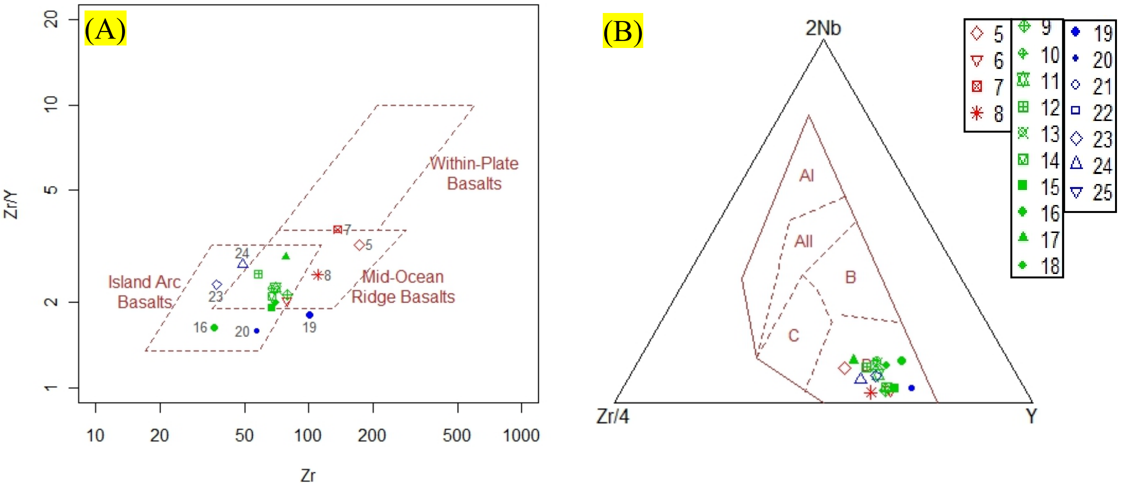

Figure (8). (A) Zr-Zr/Y binary diagram showing tectonic setting of basaltic rocks (Pearce and Norry, 1979), and (B) The ternary plot of Zr/4-2Nb-Y of Meschede (1986)

The ternary plot of Zr/4-2Nb-Y of Meschede (1986), differentiated between A I (within-plate alkali basalts), A II (within-plate alkali basalts and within plate tholeiites), B (E-type MORB), C (within-plate tholeiites and volcanic arc basalts) and D (N-type MORB and volcanic arc basalts field). All basaltic rock samples plotted in the D (Fig. 8 B).

According to 10MnO-TiO_2-10P_2O_5 discrimination diagram of Mullen (1983), the basaltic rocks plot in the field of island arc tholeiitic (IAT) and calc-alkaline basalt(CAB)

(Fig. 9 A). TiO_2 and P_2O_5 contents remain stable over sea floor alteration and regional metamorphism, whereas MnO is relatively more mobile (Saha, *et. al.,* 2012).

The transitional characteristics between NMORB and IAT of the samples from the basaltic rock units were further confirmed when plotted on Cr vs. Y diagram of Pearce (1982) (Fig. 9 B). It plotted the samples of the basaltic rock units in the overlapping field of NMORB and IAT fields. The combined MORB and IAT like signature in the present study basaltic rocks suggest supra-subduction environment.

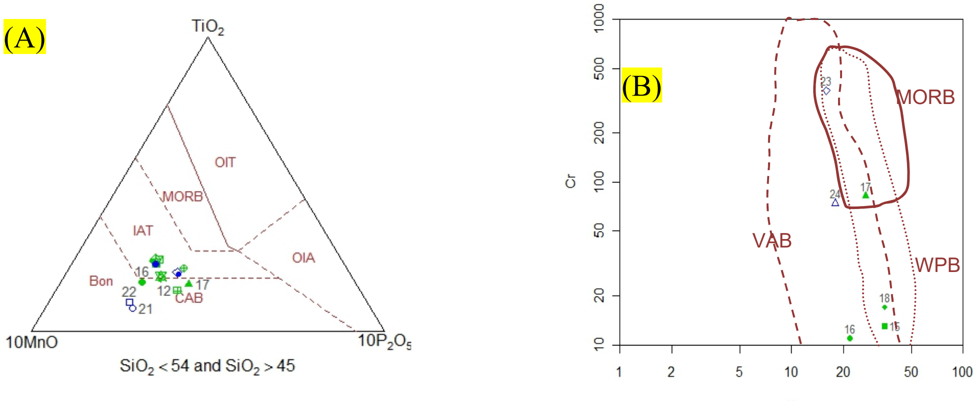

Figure (9). (A) $10MnO-TiO_2-10P_2O_5$ discrimination diagram showing the tectonic setting of basaltic rocks (Mullen,1983); (B) Tectonic discrimination Cr vs. Y diagram of the basaltic rocks (Pearce, 1982)

Discussion

It is inferred that tholeiitic rocks have been interpreted as NMORB according to previous workers (Siddiqui *et. al.*, 1996; Sawada *et. al.*, 1992 and Khan *et. al.,* 2007). But result from this study suggests that these are having characteristics transitional between NMORB and IAT. The geochemical characteristics of the basaltic rocks in the present study area have a signature of either IAT or are transitional between MORB and IAT. Generally, oceanic rocks exhibiting such characteristics are thought to have formed in a supra-subdiction zone tectonic setting (Pearce and Norry, 1979; Shervais, 1982; Pearce, 2003; Shervais *et. al.*, 2004; Robinson *et. al.*, 2008, in Kakar *et. al.,* 2015).

Acknowledgements

We are greatly indebted to Rector Dr. Maung Maung Naing, Pro-rectors Dr. Si Si Khin and Dr. Tin Moe Thuzar, Yadanabon University, for their permission to carry out this research and for paying attention to this works. We wish to express my sincere gratitude to Dr. Htay Win, Professor and Head, Dr. Khaine Khaine San, Professor and Dr. Min Nyo Oo, Associate Professor of Geology Department in Yadanabon University for allowing to do this research.

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