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PETROLOGY OF IGNEOUS ROCKS EXPOSED IN KHUNTHA-MINDAW AREA, SALINGYI TOWNSHIP

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Abstract

The Khuntha-Mindaw area is situated in part of the 45-km long Monywa-Salingyi segment of Western Myanmar magmatic arc (WMA). Lithologically, the area comprises diorite, granite, gabbro, and pegmatite of intrusive and basalt, andesite, dacite and rhyolite of extrusive rocks which are formed during Cretaceous. These igneous rocks are overlain by Oligocene to Pliocene clastic sedimentary units with locally Upper Oligocene-Lower Miocene limestone. The mineral composition and textures of diverse rock units are analyzed and interpreted by binocular polarizing microscope and chemical composition by XRF from Department of Chemistry, Monywa University. Mineralogically, the volcanic rocks contain more than 20% phenocrysts of plagioclase feldspar, pyroxene, hornblende, biotite and quartz embedded in microlites to crystallites groundmass. The zoning, cumulophyric and resorbed textures indicate the fractional crystallization and magma mixing igneous activity in long-lived evolving magma. The multiple twinned plagioclase with interstitial quartz and orthoclase in granites suggest the calc-alkaline plutonic rocks. Petrochemically, the plutonic and volcanic rocks in the study area belong to the subalkaline series and falls within the calc-alkaline suite. Moreover, the major chemical compositions of the plutonic rocks fall within I-type and S-type granitoid field. Thus all igneous rocks exposed in the present area may be erupted from subduction related calc-alkaline magmatic volcanic-arc of convergent plate margins.

Keywords: Monywa-Salingyi segment, calc-alkaline, convergent plate margin

Introduction

Myanmar, located in the eastern margin of the India-Asia collision zone (Lee et al., 2016) that is characterized by the exposures of (1) Cretaceous–Paleogene granitoids correlating northward to the Gangdese batholith (Barley and Pickard, 2003; Gardiner et al., 2015; United Nations, 1979; Mitchell et al., 2012), and (2) a series of Miocene–Quaternary volcanoes extending to those in the Andaman–Sunda (Sumatra)–Banda subduction system in southeast Asia (Hutchison, 1989).

The present area is situated within the Central Volcanic Line (Chhibber, 1934) and southern part of the Wuntho-Popa or Western Myanmar magmatic arc (WMA) (Mitchell et al., 2012) (Fig. 1 and 2). The WMA, located in the central part of the Burma terrane, is a N-S trending magmatic belt delineated by the Banmauk-Wuntho Batholith in the north, and the Monywa and Popa Volcanics in the south (Mitchell et al., 2012). In the Salingyi segment of the arc, amphibolites, gabbros, diabases, and pillow basalts (Barber, 1936; United Nations, 1979) are interpreted as part of an ophiolite, overlying mica-schists, gneisses and pegmatites occurring in small inliers beneath conglomerates of similar materials (Mitchell,1993).

The Chindwin Basin including study area lies west of the WMA, and is regarded as the forearc basin of the WMA (Wandrey, 2006 in Wang et al., 2014). The 22° N uplift area separates the Central Basin from the Chindwin Basin that was filled by the upper Cretaceous-Eocene

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shallow marine or deltatic clastic rocks and carbonates, and the unconformably overlying Neogene fluvial sediments (Bender, 1983).

This paper documents petrographical data and geochemical data for igneous rocks in the area, and all results can examine the petrogenesis and tectonic implications to better understand the magmatic evolution of the part of WMA.

Method of Investigation

Detailed field work was carried out in order to perform the geologic mapping at 1: 50,000 scale of UTM map, and geological map of United Nations (1979). The field observations were carried out along car-road, cart-tracts, food-paths, mountain ridges and quarries where good exposures are appeared. 60 samples were collected for petrography and 16 representative samples of different plutonic and volcanic units were selected for geochemical analysis of major elements.

The 60 thin sections are examined by using polarizing microscope for mineral identification according to Kerr (1959), for mineral composition according to William et al., (1982) and for textural analysis according to Winter (2014).

The whole rock geochemical analyses were performed at Defense Service Academy, Pyin Oo Lwin and Department of Chemistry, Monywa University by using XRF (X-ray Fluorescence). From these major oxides, the classification of rocks according to Le Bas et al., (1986) for volcanic rocks and Cox et al., (1979) for plutonic rocks; identification of magma series according to Ivrine and Bragar (1971), Peccerillo and Taylar (1976), Chappel and White (2001), Frost et al. (2001); and then possible tectonic settings are interpreted.

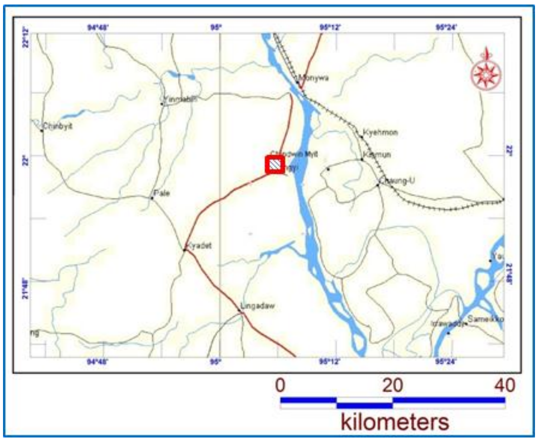

Figure 1 Location map of the study area

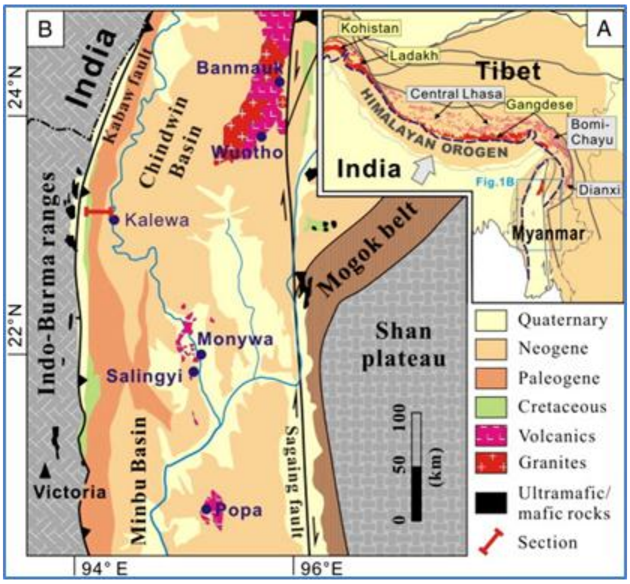

Figure 2 A Simplified tectonic map of the Tibetan plateau and adjacent regions, B: Geological Map of northern Myanmar. Western Myanmar Arc is delineated by the Banmauk - Wuntho - Monywa - Popa magmatic belt (Wang *et al.*., 2014)

Lithologic Units

The Salingyi Uplands consist of a complex of igneous and metamorphic rocks mostly and probably entirely of pre-Tertiary age. Moreover, the Tertiary sediments are also exposed in this area. The geological map of the study area is shown in Fig. (3)

Metamorphic Rock Unit

Hornblende schist

Hornblende schists are well exposed near the Magyikyin of the Kuntha village. The schists are black or dark grey, compact, strongly cleavage and showing compositional banding (Fig. 4). In hand specimens, it consists entirely of hornblende laths or prisms, micas and plagioclase. This hornblende schist is intruded by granite at east of Salingyi (Fig. 5). Thus, the age of this unit may be regarded as pre-Cretaceous.

Igneous Rocks Units

Diorite

Diorite are abundantly exposed in west of Saga village, Shwe-taung-oo taung and Nyaungbinaing monastery. It is medium- to coarse-grained, highly jointed showing dark grey on weathered surface and greyish green on fresh surface (Fig. 6). Diorites are mainly composed of quartz, feldspar and hornblende. In some places, diorite displays faint foliation. The age of diorite at Salingyi has a zircon U-Pb age of 105.3±1.7 Ma (Mitchell, 2012), K/Ar determinations from hornblende ages on diorites of 106±7 Ma (United Nation, 1979).

Granite

Granites are well exposed near at the northern part of the complex, western part of the Kuntha village, southern part of Shwe-own-pin monastery and east of Salingyi. The color of granite is white to grey with the varying proportion of biotite. It is medium- to coarse-grained, pale greenish-grey, highly jointed and fairly exfoliation (Fig. 7). The predominant minerals are quartz, feldspar and biotite with minor hornblende. In some places, hornblende schist and gabbroic dykes are intruded by granite. The age of granite on the basis of a biotite may be 103±1 Ma (United Nation, 1978).

Gabbro

The gabbro bodies form as a small isolated body within the dioritic masses along stream section near the Nyaungbinaing monastery and the quarry at the south of Taung-paw-kyaung monastery. It is a coarse-grained, dark-green on fresh surface and dark-grey on weathered surface (Fig. 8). It is a hard and compact rock, and composed mainly of hornblende, feldspar and pyroxene minerals.

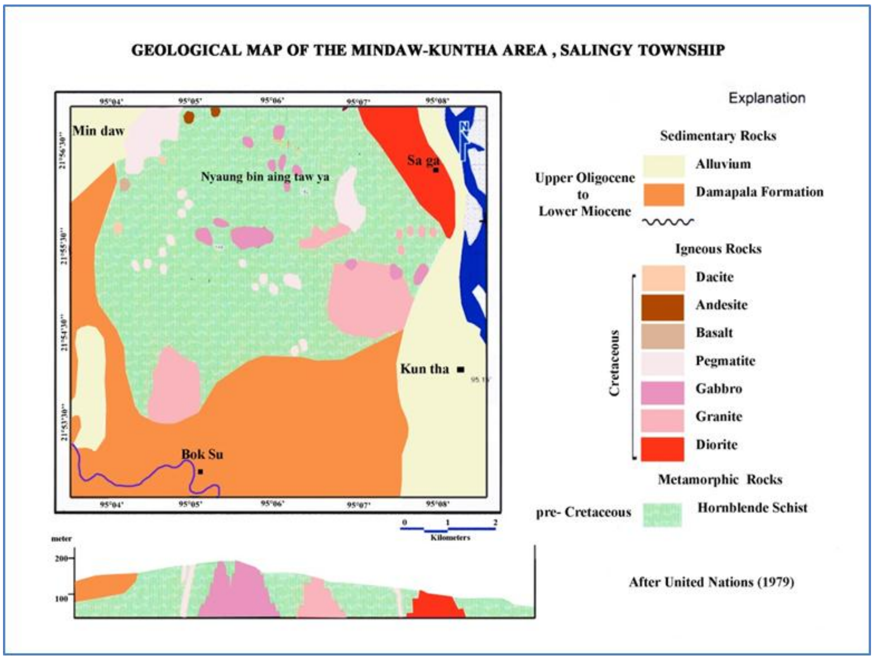

Figure 3 Geological Map of the study area

A K/Ar radiometric age determination on hornblende from a coarse-grained mafic body yielded an age of 91±8 Ma.

Basalt

The basalts are locally crop out in the stream section near the Nyaungbinaing Monastery. They are dark green on fresh surface, fine-grained and massive type (Fig. 9). In this rock type, fine-to medium grained diorite or gabbro are locally found. These appear to be irregular bodies, presumably intrusive into the basalt. This basalt may be regarded as pre-Upper Cretaceous in age (United Nations, 1978).

Andesite

The andesites are exposed at the quarry in the southern part of the study area. This rock is dark grey to greenish grey on fresh and reddish brown color on weathered surface. It usually occurs as massive, and bedding like joints often in these bodies (Fig. 10). The andesites have mostly plagioclase, hornblende phenocrysts that vary in size from 0.5mm to 4mm.

Dacite

Dacite outcrop is exposed at quarry near the Taung-paw-kyaung monastery. It shows a dark brown color on the weather surface and whitish pink and whitish blue on the fresh surface (Fig. 11). It is composed essentially of phenocrysts of quartz, feldspar, and biotite embedded in very fine-grained matrix.

Pegmatite

Pegmatite dykes are exposed NE-SW trending at south of the Taung-paw-kyaung monastery and NW-SE trending at Shwe-taung-oo Taung (Fig. 12). These pegmatite dykes are 5 to 10 feet in wide and nearly half-mile long that intrude in the diorite intrusive. The constituent minerals are very coarse-grained mostly quartz and minor feldspar. Mitchell (2012) mentioned in his map as silicic dykes. These pegmatite dykes may be younger than the diorite in age.

Figure 4 Highly weathered, and foliated hornblende schist exposed at east of Salingyi (21°58'02" N, 95°06'35"E)

Figure 5 Dyke like granite intrude in the schist exposed at east of Salingyi (21°58'02"N, 95°06' 35"E)

Figure 6 Greyish green, highly jointed diorite exposed at near Saga village (21°55'55.8"N, 95°07' 11.5"E)

Figure 7 Granite with fairly exfoliation exposed at east of Mindaw village (21°58' 07" N, 95°06' 33"E)

Figure 8 Coarse-grained, dark-green gabbro exposed along the stream section near the Nyaungbinaing monastery (21°56'50.2"N,95°05'36.1"E)

Figure 9 Dark green colored basalt exposed at Taugpawkyaung (21°57'37" N, 95°04' 57"E)

Figure 10 Greyish green, highly jointed, porphyritic andesite exposed at Taungpaw Kyaung (21°57'31.8" N, 95°05'04.5"E)

Figure 11 Dark brown colored on weather surface of dacite (21°55'47" N, 95°04' 18"E)

Figure 12 NW-SE trending Pegmatite dykes that is 5 -10 feet wide and ½ mile long at ½ mile NE of Shwe-taung-oo Taung (21°55'20.4" N, 95°07'0.1"E)

Damapala Formation

This formation was proposed for the rocks of thin- to thick-bedded, pale green to buff colored sandstones with concretion in the lower member and alternation of clay, silt and sandstone layers in Salingyi Township (Min Aung, 1994). Moreover, Damapala Formation is subdivided into two Members, Lower Member and Upper Member.

In the study area, the rocks of Damapala Formation are mainly exposed at the northwestern part. This unit consists of tuffaceous sandstone, limestone, gritty sandstone, medium-grained sandstone, clay and siltstone.

Lower Member

The tuffaceous sandstone are exposed at southwest of Mindaw village. They are whitish, massive, tuffaceous, medium-grained sandstones that are intercalated with buff-colored, medium- to coarse-grained, cross-stratification sandstones (Fig. 13). Moreover, buff-colored, coarse-grained, medium bedded gritty sandstones are found north of the Shwe-taung-oo Taung (Fig. 14).

Figure 13 Buff colored, medium-to coarse-grained sandstone intercalated with the whitish, medium-grained, tuffaceous sandstone (21°55'52.0" N, 95°02'53.0"E)N, 95°07'0.1"E)

Figure 14 Buff colored, coarse-grained, medium bedded gritty sandstone (21°56'57.4" N, 95°03' 58.1"E)

Upper Member

The Upper Member is observed along the Boksu Chaung that is mainly composed of the ripple cross-laminated sandstone-mudstone alternations, thin parallel-bedded sandstones and concretionary thick sandstones, and minor amounts of limestone beds.

In the ripple cross-laminated sandstone-mudstone alternation, the sandstones are greenish grey, medium-grained and thinly laminated interbedded with the mudstone. The ripple marks are current ripple marks that show the way-up indicator of the beds (Fig. 15).

The thin parallel-bedded sandstones are buff-colored, coarse-to fine-grained (Fig. 16). The sandstone beds show graded bedding and the thickness of beds are thinning upward as the grain size decrease. The concretionary thick sandstones are dark grey, coarse-grained, thick bedded sandstone with 10 to 50 cm size concretions (Fig. 17). At 1.5 kilometer south of Mindaw village, fossiliferous limestone are well exposed that strike NNW-SSE direction (Fig. 18). The limestones are light grey, compact and thick bedded that contain abundant gastropod, pelecypod, coral and algae fossils (Fig. 19).

From the assemblage of fossils, the age of Damapala Formation may be regarded as Upper Oligocene to Lower Miocene.

Figure 15 Ripple cross-laminated sandstone-mudstone alternations exposed along the Boksu Chaung (21°52'41.06" N, 95°04'55.53"E)

Figure 16 Buff-colored, coarse- to fine-grained thin parallel bedded sandstone exposed along the Boksu Chaung (21°52'41.06"N,95°04'55.53"E)

Figure 17 Dark-grey, coarse-grained, thick bedded sandstone with concretions exposed along the Boksu Chaung (21°52'41.06"N, 95°04'55.53" E)

Figure 18 Light grey, hard and thick bedded fossiliferous limestone (21°55' 27.6" N, 95°03'18.4"E)

Figure 19 Pelecypod fossils found on the surface of limestone (21°55'48.0" N, 95° 03'27.7"E)

Petrography

Basalt

The rock is composed of phenocrysts of pyroxene and hornblende and randomly oriented feldspar laths as groundmass (Fig. 20). Moreover, the opaque minerals are disseminated throughout the rocks. Pyroxene phenocrysts are subhedral with a few alterations and hornblende minerals are also present. The groundmass mostly feldspar laths may be more calcic according to the albite twinning.

Andesite

Andesite displays porphyritic texture that is composed essentially of plagioclase feldspar, and hornblende phenocrysts (Fig. 21). Some plagioclase phenocrysts show compositional zoning (Fig. 22) that are formed when a mineral change in composition as it grows during cooling (Gill, 2010). Moreover, this irregular compositional change may indicate magma mixing, unstable crystallization or both (Aslan, 2005).

Dacite

It contains phenocrysts of quartz, plagioclase and biotite embedded in the groundmass of quartz, alkali feldspar, biotite and plagioclase. The groundmass is holocrystalline and felsic minerals.

Quartz occurs as phenocrysts and groundmass and mostly anhedral. Quartz phenocrysts are corroded and embayed (Fig. 23). A drop in pressure or P_{H_2O} is suddenly to 50 MPa, the same melt composition will lie within the alkali feldspar field, making quartz unstable and prone to resorption (Whitney, 1988; Blundy and Cashman, 2001 in Gill, 2010).

Some dacite show spherulitic texture in which needle of quartz and alkali-feldspar grow radially from center (Fig. 24). Spherulites in rhyolitic lavas are spherical to ellipsoidal bodies of radiating, intergrown crystals, typically feldspar and quartz, that form by rapid crystallization of lava in response to significant cooling (Lofgren, 1971a, 1971b; Fenn, 1977; Swanson, 1977 in Befus *et al.*, 2015).

Diorite

The rock is essentially composed of medium- to coarse-grained plagioclase, biotite and hornblende with orthoclase and quartz in subordinate amounts showing hypidiomorphic to allotriomorphic (Fig. 25).

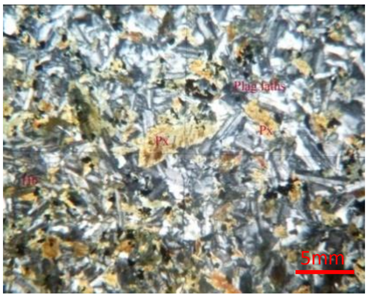

Figure 20 Subhedral phenocryst pyroxene with minor hornblende minerals, plagioclase laths and opaque minerals in basalt (X.N)

Figure 21 Andesite composed of Hornblende and Plagioclase phenocrysts (X.N)

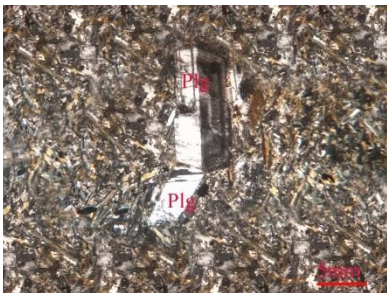

Figure 22 Andesite composed of zoning plagioclase and hornblende phenocrysts embedded in groundmass (X.N)

Figure 23 Dacite composed of orthoclase and embayed quartz phenocrysts embedded in groundmass (X.N)

The feldspars are subhedral plagioclase showing polysynthetic twins that are more common than the orthoclase. Hornblende is the most abundant of ferromagnesian mineral, forming a prismatic or irregular form.

Granite

It is constituted mainly of quartz, alkali feldspar and plagioclase. The accessory minerals are biotite and opaque minerals. Quartz minerals are the subhedral to anhedral forms that fill interstitial spaces between other minerals. Orthoclase minerals are subhedral to anhedral forms that range from 0.8-2 mm in size. The contact between orthoclase and plagioclase is highly irregular and show small myrmekitic textures (Fig. 26). Myrmekites appear to have grown from the plagioclase/K-feldspar boundary into the K-feldspar. As the plagioclase replaces the K-feldspar, SiO_2 released, thereby producing the quartz. Myrmekite commonly forms during cooling of granitic rocks (Winter, 2001; Collins and Collins, 2013).

Biotite minerals are the most ferromagnesian minerals that form in flakes. It is strongly paleochroic variety; vary from brown to deep brown. It shows any degree of alteration to chlorite or ore minerals.

Gabbro

The rocks consist approximately 60 % of plagioclase feldspar and 40 % of pyroxene and small amounts of hornblende (Fig. 27). The pyroxene minerals are coarse-grained and subhedral to euhedral with a few alteration fibrous amphibole. The plagioclase feldspars may be more calcic because they show albite and pericline twinning.

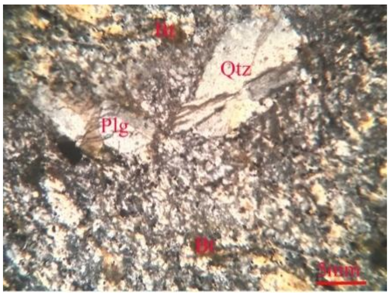

Figure 24 Dacite showing the spherulitic texture that composed of Quartz and Orthoclase spherules (X.N)

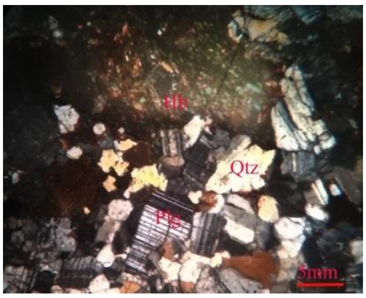

Figure 25 Quartz (Qtz), Plagioclase (Plg), Orthoclase (Ortho), Hornblende (Hb) in diorite showing allotriomorphic-granular texture (X.N)

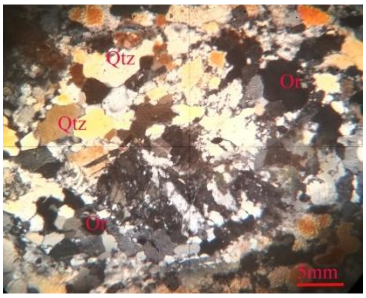

Figure 26 Quartz (Qtz), Orthoclase (Ortho), Biotite (Bt) in granite showing mymerkitic texture (X.N)

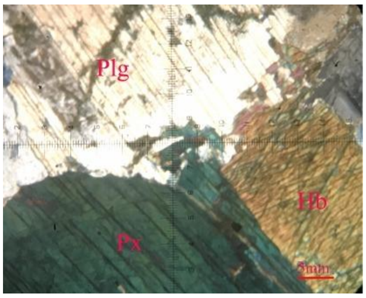

Figure 27 Gabbro composed of Pyroxene, Hornblende and Plagioclase (X.N)

Petrochemistry

Major oxides and minor oxides of igneous rocks in the study area are used to discuss the petrochemical characters. The volcanic rocks are mainly basalt, basaltic andesite, and dacite, and the plutonic rocks mainly consist of the diorite, and granite. The results of the geochemical analysis of whole-rock major oxides data are presented in table (1) and (2).

Petrochemical Character of Volcanic Rocks

According to the chemical classification based on total alkalis and silica content, the volcanic rocks of the study area belongs to the basalt, basaltic andesite, dacite, and rhyolite clan (Fig. 28) (Le Bas *et al.*, 1986). Moreover, these rock samples fall within the subalkaline field.

The subalkaline series of volcanic rocks can be further subdivided into tholeiitic and calc-alkaline type. In the AFM diagram of the (Na_2O+K_2O), FeO and MgO, most of the subalkaline series volcanic rocks falls within the calc-alkaline suite except three sample in thoeliite suite (Fig. 29) (Irvine and Baragar, 1971 in Rollinson, 1993). The calc-alkaline series is essentially restricted to convergent boundaries and is generally the dominant series (Winter, 2014). Moreover, tholeiitic rocks have been found to coexist with calc-alkalic rocks in a single volcanic system in some mature arcs (Tatsumic & Suzuki, 2009).

Shand (1927) grouped igneous rocks based on the total *molar* alkali versus alumina content as either **peralkaline** [Al_2O_3 < (Na_2O + K_2O)], **peraluminous** [Al_2O_3 > (CaO + Na_2O + K_2O)], or **metaluminous** [Al_2O_3 < (CaO + Na_2O + K_2O). All volcanic rocks exposed in the study area falls peraluminous series.

The volcanic samples of calc-alkaline series have a wide range in SiO_2 ranging from 49 wt% to 75 wt% and potassium content is low-K tholeiite, calc-alkaline series (Fig. 30). All three series (low-, medium- and high-K) are well represented in subduction-related magma suites (Winter, 2014). Arc-related volcanic rocks vary widely in their K_2O contents, which often correlate with the stage of arc development and with geographical location relative to the arc axis (Gill, 2010). Moreover, some spatial and temporal patterns in K_2O contents in the distribution of magma series are found in several island arcs (Winter, 2014).

Petrochemical Character of Plutonic Rocks

According to the chemical classification based on total alkalis and silica content, the plutonic rocks of the study area belongs to the gabbroic diorite, diorite and granite clan of subalkaline series (Fig. 31) (Cox *et al.*, 1979). In the AFM diagram of the (Na_2O+K_2O), FeO and

MgO, subalkaline series of all plutonic rocks fall within the calc-alkaline suite (Fig. 32) (Irvine and Baragar, 1971 in Rollinson, 1993). Although the three magma series (tholeiitic, alkaline and calc-alkaline series) are represented at subduction zones, the calc-alkaline series is essentially restricted to convergent boundaries and is generally the dominant series (Winter, 2014).

To classify the I-type and S-type granitoid, when plotted on the ACF (Al_2O_3-Na_2O+K_2O, CaO, and FeO+MgO) diagram on the basis of major oxides, it is found that the studied samples fall in the I-type as well as S-type field (Fig. 33) (Chappell and White, 1992).

Table 1 Major oxides composition (in weight %) of the volcanic rocks in the study area

Sample No	L3	L32	L20	L18	L9	L5	L6
Rock Units	**Basalt**	**Basalt**	**Basalt**	**Basalt**	**Dacite**	**Rhyolite**	**Rhyolite**
SiO_2	50.502	52.01	50.06	49.12	63.861	75.099	71.788
TiO_2	1.365	1.57	1.33	1.11	0.459	0.172	0.303
Al_2O_3	17.653	16.5	17.01	15.67	17.629	13.498	13.586
Fe_2O_3	10.349	9.51	10.4	10.58	5.538	3.003	5.033
MnO	0.202	0.115	0.185	0.171	0.104	0.013	0.034
MgO	8.04	5.23	5.26	6.63	1.466	0.107	0.434
CaO	7.804	9.55	9.81	11.35	5.735	0.85	2.684
Na_2O	2.881	3.65	2.95	2.34	4.091	6.969	5.551
K_2O	0.064	0.53	0.452	0.366	0.417	0.019	0.081
P_2O_5	0.338	0.24	0.375	0.12	0.297	0.017	0.123

Table 2 Major oxides composition (in weight %) of the plutonic rocks in the study area

Sample No	L8	L10	L11	L15	L4	L31	L35	L38	L41
Rock Units	**Diorite**	**Diorite**	**Diorite**	**Diorite**	**Granite**	**Granite**	**Granite**	**Granite**	**Granite**
SiO_2	50.502	57.851	53.516	52.404	71.42	74.48	72.44	69.45	70.55
TiO_2	0.692	0.383	0.259	0.452	0.476	0.0703	0.095	0.05	0.08
Al_2O_3	18.948	16.016	26.975	17.884	12.837	14.74	14.51	13.68	14.11
Fe_2O_3	8.731	7.57	2.419	8.371	5.115	1.113	1.36	0.78	1.41
MnO	0.178	0.16	0.046	0.218	0.041	0.018	0.045	0.02	0.033
MgO	5.747	4.973	1.231	5.908	1.389	0.274	0.0369	1.2	0.34
CaO	10.415	9.234	12.538	11.065	4.728	1.41	2.43	2.13	3.65
Na_2O	2.942	2.708	2.251	2.448	3.203	5.26	4.3	3.69	4.01
K_2O	0.166	0.337	0.414	0.469	0.06	2.57	4.43	5.01	4.21
P_2O_5	0.273	0.188	0.132	0.149	0.359	0.191	0.45	0.36	0.41

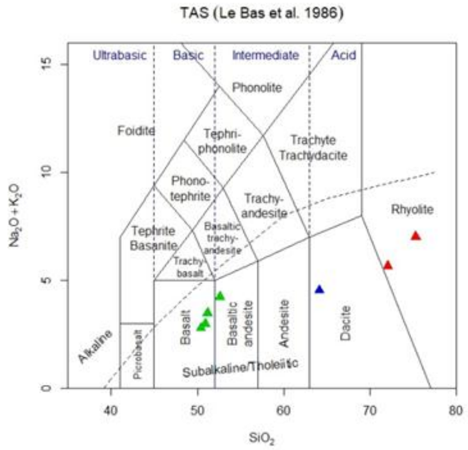

Figure 28 The chemical classification of volcanic rocks based on total alkalis ($Na_2O + K_2O$) and silica (SiO_2) (Le Bas et al., 1986) (GCDkit 5)

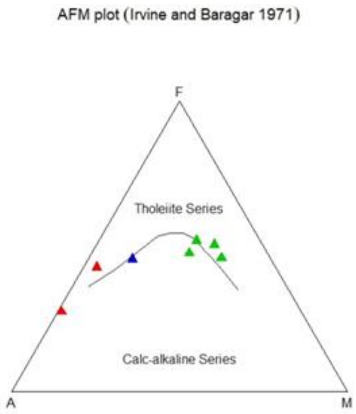

Figure 29 AFM diagram for volcanic rocks of the study area showing the discrimination between tholeiitic and calc-alkaline suite (Ivrine and Bragar, 1971) (GCDkit 5)

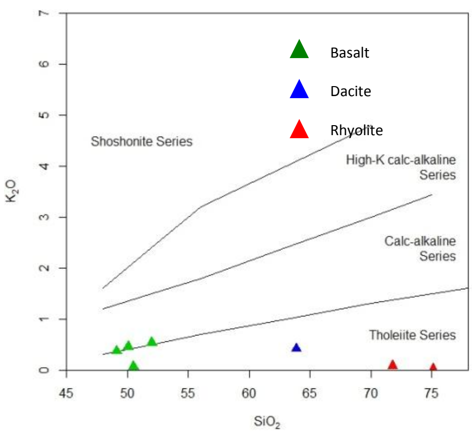

Figure 30 The chemical classification of the volcanic rocks based on K_2O-SiO_2 (Peccerillo and Taylar, 1976) (GCDkit 5)

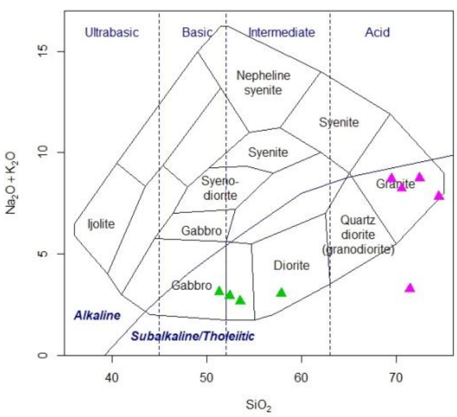

Figure 31 The chemical classification of plutonic rocks based on total alkalis ($Na_2O + K_2O$) and silica (SiO_2) (Cox *et al.*, 1979) (GCDkit 5)

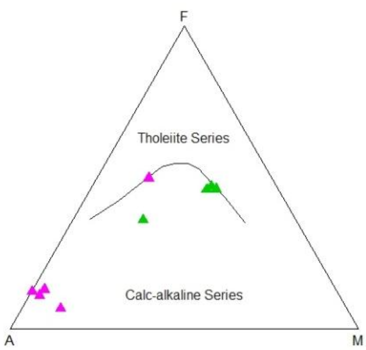

Figure 32: AFM diagram for plutonic rocks of the study area showing the discrimination between tholeiitic and calc-alkaline suite (Ivrine and Bragar, 1971) (GCDkit 5)

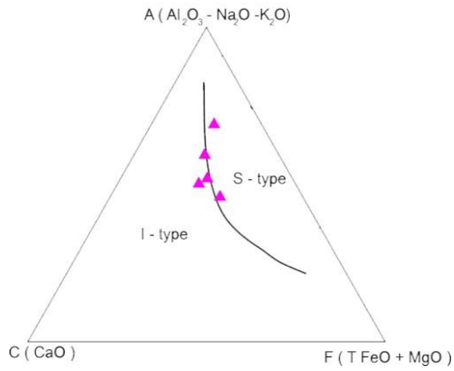

Figure 33 ACF diagram for the granite rock of the study area compared with the typical I- type and S-type (Chappel and White, 1992)

Tectonic Discrimination of Igneous Rocks

Basalt

According to eight major element discrimination diagram, the three samples of basalt falls calc-alkali basalt and island arc tholeiite field whereas only one sample falls within the MORB (Fig. 34). Moreover, the three samples fall within volcanic-arc and active continental margin (orogenic) field but one sample falls within the MORB based on MgO-FeO^T-Al_2O_3 (Fig. 35). Most of these basalts are island-arc tholeiite whereas one is the ocean-island tholeiite based on MnO-TiO_2-P_2O_5 (Fig. 36).

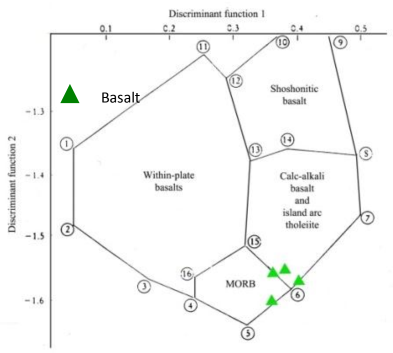

Figure 34 Major element discrimination diagrams for basalts (after Pearce, 1976 in Rollinson, 1993), showing the fields of within-plate basalts, MORB, calc-alkali basalts, island-arc tholeiites and shoshonitic basalts.

$F1 = + 0.0088SiO_2 - 0.0774TiO_2 + 0.0102Al_2O_3 + 0.0066FeO - 0.0017MgO - 0.0143CaO - 0.0155Na_2O - 0.0007K_2O$

$F2 = - 0.0130SiO_2 - 0.0185TiO_2 - 0.0129Al_2O_3 - 0.0134FeO - 0.0300MgO - 0.0204CaO - 0.0481Na_2O - 0.0715K_2O$

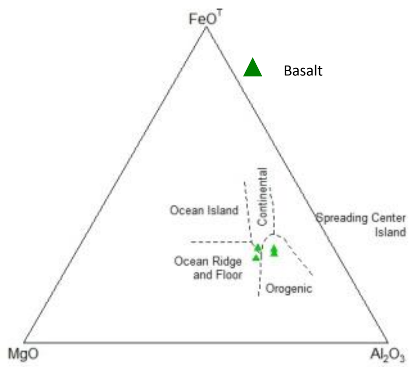

Figure 35 MgO-FeO^T-Al_2O_3 diagram for basalt (after Pearce, 1976 in Rollinson, 1993), showing MORB, ocean-island basalt, continental basalt, volcanic-arc and active continental margin (orogenic), and spreading center island basalts. (GCDkit 5)

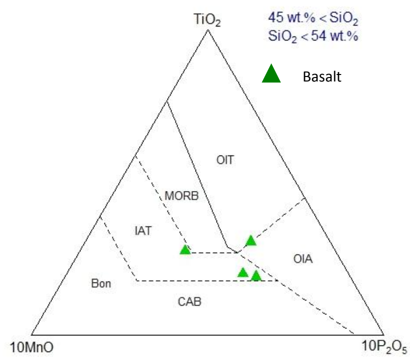

Figure 36 MnO-TiO_2-P_2O_5 discrimination diagram for basalt and basaltic andesite (45-54 wt% SiO_2) (Mullen, 1983 in Rollinson, 1993), showing MORB, OIT- ocean-island tholeiite, OIA-ocean-island alkali basalt, CAB- calc-alkaline basalt, IAT- island-arc tholeiite, Bon-boninite (GCDkit 5)

Granite

According to Frost *et al.* (2001), the geochemical classification for granitoids was determined based on Fe-number [FeO/(FeO + MgO)] ratio of the rock to classify the 'ferroan' (Tholeiitic) and 'magnesian' (Calc-alkaline); based on modified alkali-lime index (MALI) (SiO_2 vs Na_2O + K_2O – CaO); and is based on aluminum saturation index (ASI). The samples fall within the magnesian field except one sample; within calcic to alkali-calcic field; and within metaluminous field except one sample (Fig. 37).

The granites of the study area fall within the syn-collision field based on the R_1-R_2 binary multicationic parameter (Batchelor and Bowden, 1985) (Fig. 38).

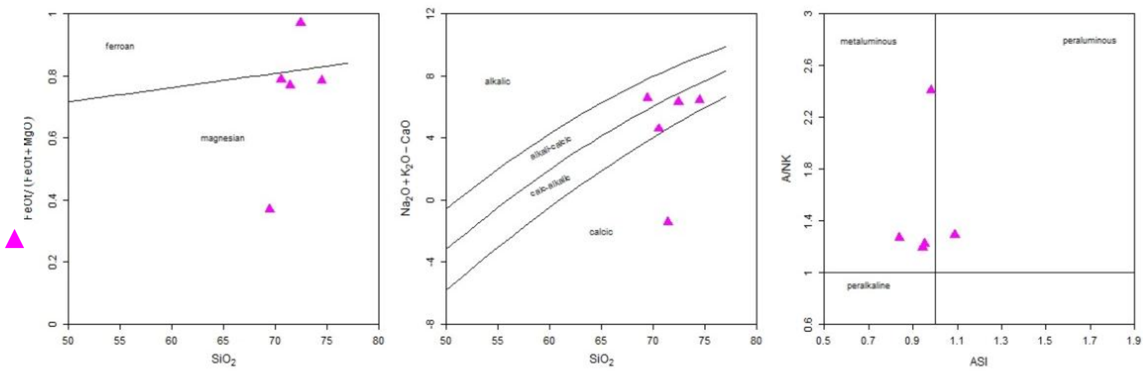

Figure 37 Granite tectonic discrimination (Frost *et al.*, 2001) (GCDkit 5)

(a) Fe-number [FeO/(FeO + MgO)]

(b) modified alkali-lime index (MALI) (SiO_2 vs Na_2O + K_2O – CaO)

(c) aluminum saturation index (ASI)

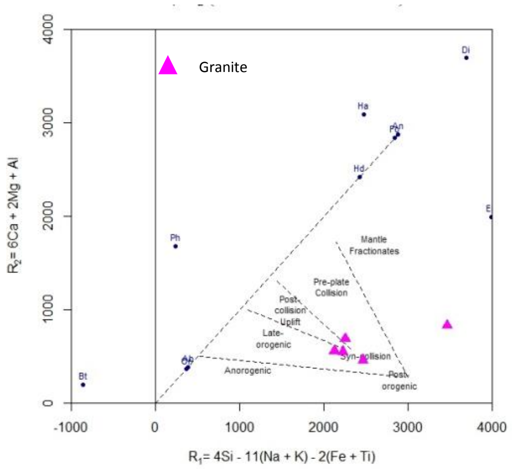

Figure 38 Multicationic discrimination diagram of granites (Batchelor and Bowden, 1985) (GCDkit 5)R_1 = 4Si – 11(Na+K) – 2(Fe+Ti) R_2 = 6Ca + 2Mg + Al

Discussion

The present area, part of Salingyi Upland of the Western Myanmar Magmatic arc, consists of diverse igneous rocks from felsic to mafic in composition during pre-Tertiary age.

Most of the volcanic rocks in the area display porphyritic texture that exceeds more than 20% of the total volume of rocks. The phenocrysts are mostly pyroxene in basalts, plagioclase in andesites, and quartz and biotite in dacite. The phenocrysts are used to determine rock origins and transformations, as when and whether crystals form depends on pressure and on temperature. Island arc volcanic rocks are generally phyric (>20%), although tholeiitic rocks may be less so (Winter, 2001).

These phenocrysts show some characteristics of magmatic processes during cooling. The compositional zonings in andesites and dacites point out magma mixing, unstable crystallization. When phenocrysts exhibit zoning, it is a sign that the plutonic stage of crystallization has been sufficiently prolonged for significant evolution in melt composition to take place (Gill, 2010). The embayed quartz phenocrysts in dacite indicate the drop of pressure in the same melt composition. In plutonic rocks, some plagioclase show zoned textures in diorite whereas myrmekitic textures in granites. In addition to that the multiple twinned plagioclase with interstitial quartz and orthoclase is the characteristic feature of calc-alkaline granodioritic plutonic rock (Wilson, 2007).

The orderly sequence in which phenocrysts appear and change their relative proportions in a series of intermediate to acid lavas or phyroclastics is treatment to advancing fractional crystallization (Gill, 2010). Moreover, the various disequilibrium features in igneous rocks suggest that magma mixing is common (Eichlberger, 1978) but may also reflect complex convection effects (plus recharge) in shallow magma chambers (Singer, 1995 in Winter, 2001). Thus the igneous processes acting on the rocks exposed in the area may be the combination of fractional crystallization and magma mixing.

The chemical composition of the volcanic and plutonic rocks falls within the subalkaline based on total alkalis (Na_2O + K_2O) and silica (SiO_2). These subalkaline igneous rocks are further classified as calc-alkaline and tholeiite based on (Na_2O+K_2O), FeO and MgO in which most rocks fall within the calc-alkaline except two basalts and one rhyolite in tholeiite. The volcanic rocks contribute the tholeiite and calc-alkaline series according to SiO_2-K_2O content. The granites in the study area belong to I-type and S-type granitoid according to A (Al_2O_3-Na_2O-K_2O), C (CaO), F (FeO+MgO) data. Considering the I-type granitoid, White and Chappell (1983 in Chappell and White, 2001) concluded that S-type granites probably were formed near continental margin environment from anatexis of sediments at the base of a thickened crust during continental collision, whereas the I-type granites probably assumed as products of Cordilleran subduction post orogenic uplift regimes (Pitcher, 1983 in Ibrahim *et al.*, 2000).

The major and minor chemical composition of basalts and granites are further discriminated to infer possible tectonic environment. The basalts belongs to the calc-alkali basalt and island arc tholeiite field based on the eight major elements discrimination, volcanic-arc and active continental margin (orogenic) field based on MgO-FeO^T-Al_2O_3, island-arc tholeiite based on MnO-TiO_2-P_2O_5. Moreover, most of the granites fall within the magnesian (calc-alkaline) field based on Fe-number [FeO/(FeO + MgO)] ratio; within calc-alkalic field based on modified alkali-lime index (MALI); and within metaluminous field based on aluminum saturation index

(ASI). In addition to that the granites belong to the syn-collision field based on the R_1-R_2 binary multicationic parameter.

In conclusion from the above facts, all igneous rocks exposed in the present area may be erupted from subduction related calc-alkaline magmatic volcanic-arc of convergent plate margins.

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