PETROGENESIS OF IGNEOUS ROCKS EXPOSED AROUND THE ROAD SECTION FROM WASHAUNG TO SADON VILLAGE, WAINGMAW TOWNSHIP, KACHIN STATE

Me Me Aung[1], Htet Htet Wint War[2]

Abstract

The Myitkyina mafic-ultramafic belt, eastern part of Kachin State, is a key to understand tectonic evolution of Tethys Ocean in SE Asia. We took a survey at the Washaung and Sadon villages about 9miles (14km) and 14miles (23km) respectively to east of Myitkyina Township where comprises magmatic rocks of pegmatite/aplite, hornblende granite, granodiorite, diorite, dolerite, peridotite and metamorphic rocks of amphibolite, hornblende-biotite gneiss, biotite gneiss and migmatite. Based on field criteria, petrographic data and previous published literature they jointly suggest that as the boundary between magmatic and metamorphic rocks is intrusive contact. The magmatic rocks have typical SSZ-type (supra-subduction zone) features, suggesting products of partial melting of subduction oceanic plate. The subsequent partial melting of this underplated mafic rock may be caused by heat carried upward by basaltic magma. Fractional crystallization and contamination occurred when it passes through the crust. Some granite and pegmatite were probably formed by partial melting of lower or middle crust. The igneous are estimated to be Mid Jurassic to Cretaceous in age. All facts indicate the igneous rocks from the study area may be formed as continental arc which related to subduction of Neotethys Ocean during the Mesozoic and Early Cenozoic time.

Keywords: Myitkyina, continental arc, mafic-ultramafic rocks

Introduction

In Myanmar, mafic and ultramafic rocks are mainly exposed in two belts: the western belt occurring along the eastern margin of Indo-Burma Range (IBR), and the eastern belt outcropping along the Tagaung-Myitkyina-Mogok. The western belt has been regarded as remnant of the Neotethys Ocean. While the eastern belt is debated on: (a) relict of the Mesotethys Ocean (Liu et al., 2016); (b) the northern extension of the IBR ophiolite (Mitchell et al., 2015); (c) a continental margin arc of the Neotethys ocean (Zhang et al., 2018). Based on the field results and microscopic features, we will describe which model is more appropriate for the study area. The first model is based on Jurassic ages of magmatic rocks along the Myitkyina belt that can compare with ages of the ophiolite from the Mesotethys Ocean in the Tibet region (Liu et al., 2016). The second model is supposed that the Myitkyina belt locates to north of the IBR ophiolite after ca. 300 km restoration of right-lateral strike-slip movement (Mitchell et al., 2015). While the third model is based on rock assemblages in the Myitkyina mafic-ultramafic belt and their SSZ-type geochemical features (Zhang et al., 2018). Each model seems to be supported by their mentioned evidence. However, recent years studies show that remnants along the Neotethys Ocean also contains many Jurassic components, such as the Middle Jurassic chert in ophiolites of the Naga Hills and Yazagyo (Myanmar), which are coeval with the ages of the Myitkyina mafic rocks. Therefore, only the ages of the mafic rocks cannot constrain whether they belong to Mesotethys or Neotethys Ocean. As mentioned in the third model, there are outcrops andesite, hornblende gabbro and diorite along the Myitkyina belt, rock assemblages of continental margin, which would not be component of ophiolite.

[1] Department of Geology, University of Banmaw, Banmaw, Myanmar
[2] Department of Geology, University of Myitkyina, Myitkyina, Myanmar

Above introduction shows that the controversial issue between these models is what kind of rock assemblages along the Myitkyina mafic-ultramafic belt and what kind of relationship between their contact boundaries, and even the magmatic rocks and their host metamorphic rocks. Therefore, this study will be conducted at the northern segment of Eastern Ophiolite belt falls within the Kachin State.

The study area is situated in the eastern part of Kachin State and is located about 5miles (8km) from east of Myitkyina Township. The location of the study area is shown in figure (1) Latitude 25°21' to 25°25' N, Longitude 97°35' to 97°54′ E.

The rock units exposed in the study area are mainly hornblende granite, granodiorite, diorite, dolerite, gabbro and peridotite for igneous, and amphibolite, gneiss and migmatite for metamorphic. We first focus on field relationship of these rocks from the Washaung to Sadon villages and combined with other published lectures to solve above discuss debate. Then we further imply their tectonic affinities and possible regional evolution.

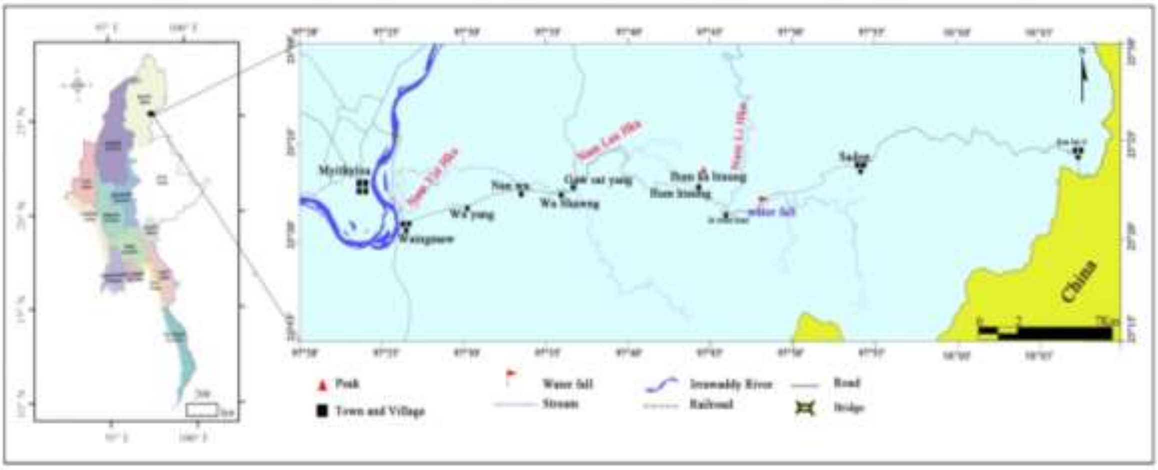


Figure 1. Location map of the study area.

Purpose and method of study

The main purposes of this research are (a) to give a map view of distribution and types of the rock units, and (b) to study petrogenesis of igneous rocks.

The locations of the outcrops were recorded by GPS (Global Positioning System) navigator. Structures such as lithologic contacts and structural trends were measured by aiding Brunton transit and checked with the Landsat images. The field data are plotted on Google Earth and UTM map linked with GPS data to illustrate the distribution of rock units. In the laboratory, more than (40) thin sections are observed to understand their constituent minerals and their texture. Major and minor oxides composition of rocks was analyzed by X-ray Fluorescence Method which was made at Mandalay University Research Centre.

Regional Geologic Setting

The Kachin State is one of the best places to search the trace for tectonic evolution of SE Asia. Geologically, it contains six main places from west to east; Jade Mine Uplift (JMU), Nanyaseik diopside-phlogopite-ruby marble, granite (Na), Kumon Range (KR), Katha-Gangaw Range (KGR), Tagaung-Myitkyina Belt (TMB) and Mogok Metamorphic Belt (MMB) (Mitchell et al., 2007). Jade Mines Belt and Tagaung-Myitkyina Belt are parts of the Eastern Ophiolite Belt which was formed during the Middle Jurassic, i.e., ~166–176 Ma (Mitchell, 1993; Mitchell et al., 2007; Yang et al., 2012; Liu et al., 2016). In 2018, Zhang, et al. considered that the Myitkyina-Mogok ultramafic-diorite belt contains peridotite, andesite, hornblende gabbro, diorite, granodiorite and plagiogranite, all with arc geochemical signatures and ages of 177–166 Ma. Barley et al. (2003) mentioned the magmatic age of the protolith of orthogneisses from the Mandalay hill and Kyanikan was Jurassic (170 ± 1Ma) which were recrystallized during an Eocene (~43Ma) high-grade metamorphic event.

The study area, eastern part of the Kachin State, situates the northern continuation of TMB and MMB. In the west, TMB is close to the KGR. On regional scale, there is a large lineament which marked the western boundary of the KGR and is possibly one of the major splays of the Sagaing Fault. The study area extends to Yunnan (China) to the east. The main rock units exposed in the study area are undifferentiated metamorphic rocks, intrusive and extrusive igneous rocks. They are trending nearly N-S with eastern and northeastern dip. Sedimentary rocks comprised with minor amount. Regional geologic setting of Myanmar including the study area is shown in figure (2).

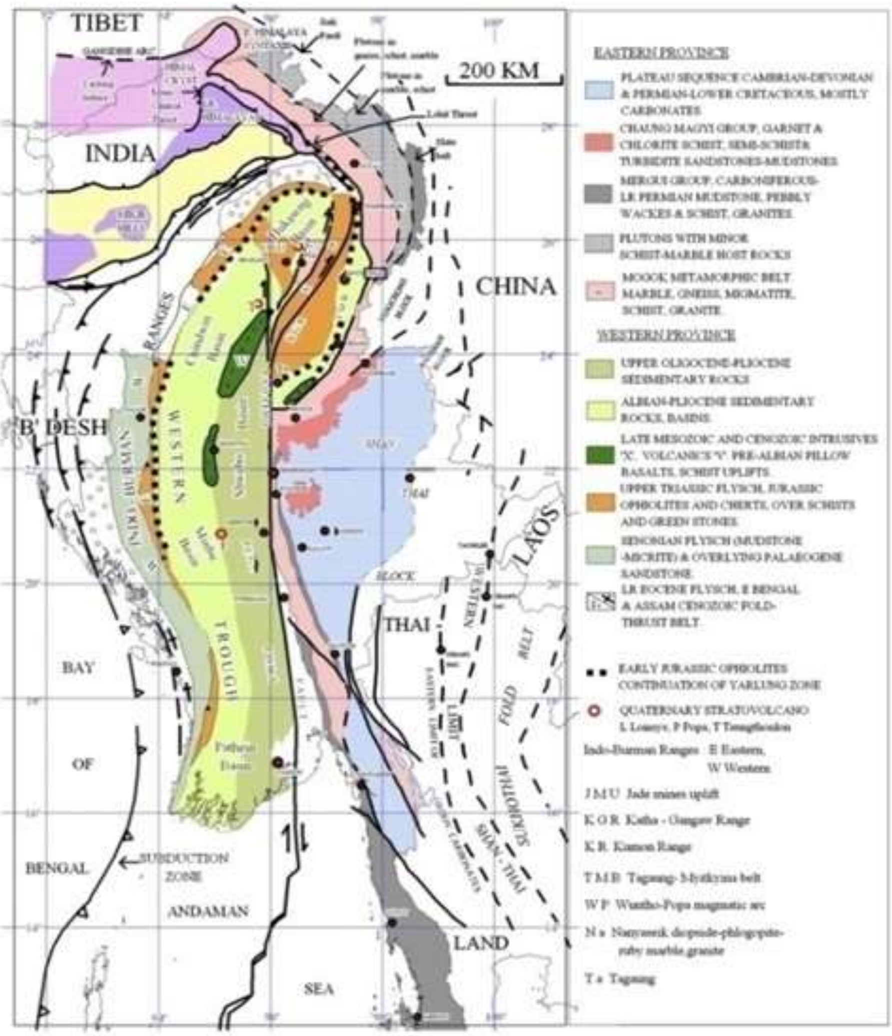


Figure 2. Regional geologic setting of Myanmar including the study area.
(***Source: Mitchell et al., 2007***)

Rock sequence

The rock units comprise within the study area are intrusive and extrusive igneous rocks, along with various metamorphic rocks. Although the rocks exposed are documented as the TMB and MMB, their ages and tectonic affinities are still controversial.

Based on the field data and previous authors' radiometric dating result, the age of metasedimentary rocks of the study area can be correlated to the Lower Paleozoic sedimentary sequence of the western Shan Plateau region and Jurassic for metaigneous. The igneous are estimated to be Mid Jurassic to Cretaceous in age. The rock sequence of the area is shown in table (1).

Table 1. Rock sequence of the study area

	Lithologic Unit	Age
	Sedimentary Units	
	Alluvium	Quaternary
	Siltstone and silty sandstone	Paleocene to Eocene
	∿∿∿∿∿	
	Igneous Units	
	Pegmatite/Aplite	Early Cenozoic
	Hornblende granite	
	Granodiorite	Cretaceous
	Diorite	
	Dolerite	to
	Lherzolite	
	Pyroxenite	Mid. Jurassic
	Metamorphic Units	
Meta igneous	Amphibolite	Jurassic
Meta igneous / Meta sedi - mentary	Hornblende-biotite gneiss	
Meta sedi - mentary	Biotite gneiss	Lower Paleozoic
	Migmatite	

Results on field data

The major rock types range from felsic to ultramafic rocks and metamorphic rocks. The igneous rocks comprise pegmatite/aplite, hornblende granite, granodiorite, diorite, dolerite, gabbro, lherzolite and pyroxenite. Metamorphic rocks contain hornblende-biotite gneiss, amphibolite, biotite gneiss and migmatite. The whole area except the road site is rather difficult to access because of dense forest, highly mountainous nature, and sparse population. Therefore, good exposure can be found along the road section and some stream section. The main ridges in the study area are Bum Taung, Bumkahtaung and Nga layin Taung Figure (3).

Most of the granitoids are intruded into metasedimentary rocks. The contact between diorite and granitoids is sharp, i.e., diorite and granitoids are cropped out separately along the road from Bum Taung to Inwant Kaung villages. Ultramafic and granitoids is faulted contact. Most of the metamorphic rocks, especially amphibolite is found along the La Na Hka Fault (F_3) and Sadon Chaung fault (F_4). The distribution map of rock units for the study area is shown in Figure (4).

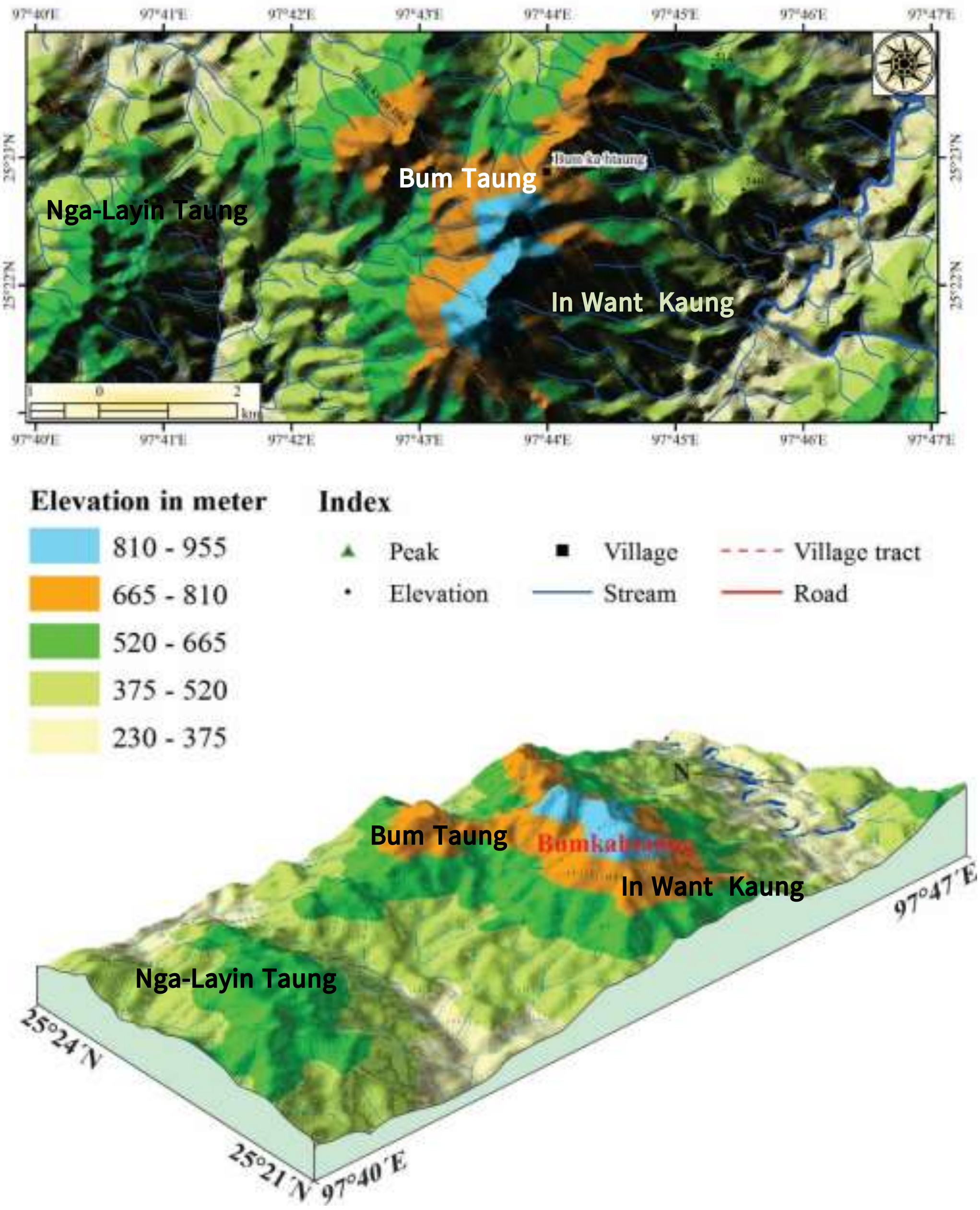


Figure 3. Three-dimensional image of ridges from the study area.

Features of Igneous Rocks

Good exposures of igneous rocks are found along the road site especially at the center and eastern parts of the study area.

Pegmatite occurs as veins and small dykes. Most of the veins are 1 inch to 10 inches in width and the main constituent minerals are quartz and feldspar. These veins are intruded into metamorphic and all igneous units, indicating that these veins are the youngest unit of the study area.

Hornblende granite and granodiorite occupied two third of the whole area. They cropped out at the Wuyan village (N 25º 21' 36.1" and E 97º 47' 50.7"), Bum-Taung (N 25º 22' 54.8" and E 97º 44' 7.7"), In-want-Kaung (N 25º 21' 35.2" and E 97º 45' 27.1") and Sadon waterfall and around Sadon Village. They exhibit batholiths to small semi-circular bodies with exfoliation nature (Fig.5). They have complex texture, i.e., change from granitic to granodioritic composition within a batholith. They have fine to medium-grained, homogeneous texture and display light grey to whitish on fresh surface while dark grey color on weather surface Figure (6). Various sizes of mafic microgranular enclaves are found in some places and their sizes ranges from 2cm to 3ft that are located at the core and margin of pluton and are generally in sharp contact with the surrounding granitoids Figure (7). Hornblende granite composed essentially of quartz, feldspar, hornblende, and biotite. Granodiorite has more mafic minerals and plagioclase feldspar than granite. Xenolith, which are biotite gneiss, are also found in granitoid rocks that indicates granitoids are younger than metamorphic rocks.

Sporadic occurrence of medium to coarse grained texture and greenish grey colour **diorite** is found at N 25º 23' 47.7"; E 97º 37' 14.9", and N 25º 22' 28"; E 97º 44' 10". It is composed essentially of plagioclase and hornblende with biotite. It highly develops joint Figure (8) and extents is about 80 ft in width and 40 ft in thickness. Xenoliths contained in diorite is as same mineral composition as the host diorite, but the texture is different.

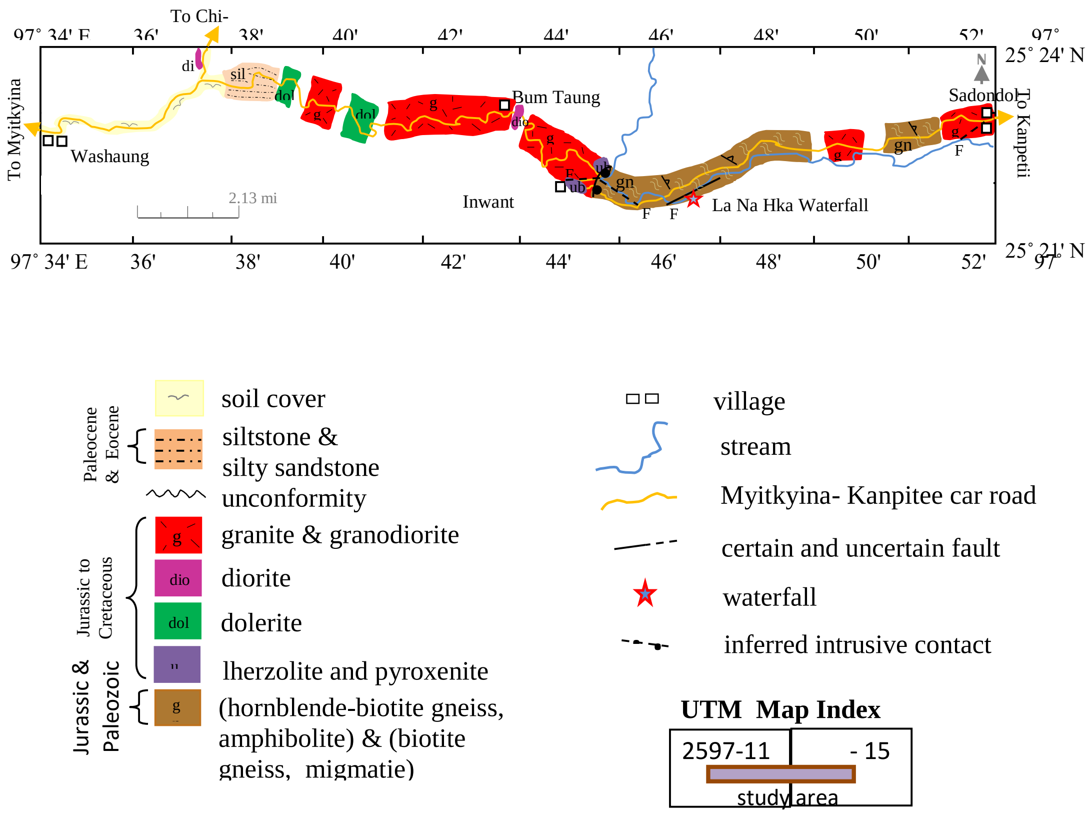


Figure 4. Distribution map for igneous and metamorphic rocks of the study area.

(Modified after Me Me Aung et al., 2019a)

Good exposure of **dolerite dyke** is exposed at N 25° 22' 37.3"; E 97° 40' 59.2", N 25° 23' 30.3"; E 97° 39' 6.4" and N 25° 22' 48.8"; E 97° 41' 34.1". It has very fine to fine-grained, hard, and compact nature and bluish dark to dark grey colour on weathered surface Figure (9). They exhibit massive boulders with highly jointed nature. Some small outcrops are 4.6m (15ft) in width and NW-SE in trend.

Lherzolite and pyroxenite are limitedly cropped out near the Inwang Kaung Bridge especially at N 25° 21' 51.5"; E 97°45' 31.8", N 25° 21' 28.8"; E 97°45' 25" and N25° 21' 51"; E 97°45' 32". They have coarse-grained texture and are composed mainly of olivine and pyroxene. They occur as rather complex nature, i.e., lherzolite to pyroxenite, within a same boulder Figure (10). They possess hard and compact nature and display as sheeted dyke. Most of the weather surface has been at least partly altered to serpentinite, a process in which pyroxene and olivine are converted to green serpentine minerals. These rocks are faulted contact with granitoids.

Figure 5. Exfoliation nature in hornblende granite.

(Loc. N 25° 22' 54.7"; E 97° 52' 54.3")

Figure 6. Dark grey color wea-ther surface in ranodiorite.

(Loc. N 25° 21' 35.2"; E 97° 45' 27.1")

Figure 7. Oval shape with chill margin mafic microgranular enclaves in granite.

(Loc. N 21' 35.8"; E 97° 45' 30.1"')

Figure 8. Highly jointed diorite.

(Loc. N 25° 22' 28";E 97° 44' 10.1")

Figure 9. Hard and compact nature of dolerite.

(Loc. N 25° 21' 28.8"; E 97°45' 25")

Figure 10 Small sheeted outcrop nature of lherzolite and pyroxenite.

(Loc. N 25° 21' 51"; E 97°45' 32")

Features of Metamorphic Rocks

Hornblende-biotite gneiss is exposed at N 25° 21' 19.5"; E 97°47' 9.4" and N 25° 21' 29"; E 97° 46' 44.3". It has foliated medium- to coarse-grained texture and is composed of quartz, feldspar, hornblende, and biotite. It displays hard, compact, and massive to boulder nature Figure (11). Augen texture, size ranges from 0.3 mm to 2 cm in diameter, is well recognized and it suggests metamorphism and shearing. The contact relation between this unit and other metamorphic units is rather complex. **Amphibolite** is especially found along the Sadon Chaung fault (F_4) near the Sadon primary school. It has a highly jointed nature, fine to medium-grained texture and shows dark green to black on fresh surface. Some outcrops show rib-and-furrow nature and karst nature, i.e., pit hole and grooves on weather surface Figure(12). It is chiefly composed of amphibole minerals, plagioclase, quartz, and other accessory minerals.

Biotite gneiss unit is especially cropped out around the Sadon waterfall. It shows a well foliated, medium-grained texture and is composed of quartz, feldspar and biotite. It has medium to thick bedded nature that suggests sedimentary origin Figure (13). **Migmatite** unit is limitedly found at the La Na Hka waterfall at N25° 21' 36.1"; E 97°47' 50.7" and N25° 21' 29"; E 97°46' 44.4". It possesses medium- to coarse-grained texture and composed essentially of quartz, feldspar, hornblende, and biotite. It displays a mixture of well foliated gneiss components and igneous components within a massive. Ptygmatic folds and veins are well recognized on the weather surface. In some places, amphibolite, and biotite rich components (melanosome) intercalated with leucosome Figure (14). Biotite gneiss and migmatite display gradational contact and migmatite occupy lower rock sequence. All of the above facts suggest sedimentary protolith.

Figure 11. Massive Boulder and jointed nature orthogneiss.

(Loc. N 25º 21' 35.2"; E 97º 45' 27.1")

Figure 12. Rib-and-furrow nature on weather surface of amphibolite.

(Loc. N 25º 22' 35"; E 97º 53' 47.1")

Figure 13. Well foliated texture in biotite gneiss. (Loc. N25° 21' 19.5"; E 97°47' 9.4")

Figure 14. Component of melanosome and leucosome in migmatite.

(Loc. N 25° 21' 29"; E 97° 47' 44.3")

Petrogenesis of igneous rocks

The petrogenesis of igneous rocks is deciphered based on field data, microscopic features, geochemical results, and previous published literature. The major and trace element oxides are in table (2).

Field Criteria

1. Along the Myitkyina-Kanpitee road section, from Washaung to Sadon village, hornblende granite and granodiorite comprise **40 to 60 %**, diorite **1 to 5%**, dolerite **5 to 15%** and lherzolite and pyroxenite **1 to 5%** Figure (4). Metaigneous rocks especially amphibolite is occupied **1 to 5%** of the overall abundance. Rhyolite, dacite and gabbro are cropped out at the northeastern part of the area. The composition ranges from **basalt to rhyolite** in volcanic is corresponding by the **peridotite-gabbro-diorite-granodiorite-granite** plutonic sequence. These rock assemblages suggest continental arc, which would not be component of ophiolite. Therefore, the igneous rocks from the study area may be formed by plumbing system feeding the continental arc volcanic.

2. Mafic microgranular enclaves are found in hornblende granite, granodiorite, and diorite. They indicate the introduction of mafic magma into the magma chamber and its subsequent cooling following incomplete mixing.
3. Some enclave displays chill margin which suggests large temperature difference from the host granite. Some shows zone nature that indicates the trace of difference composition and difference cooling rate of enclaves. All these facts suggest that these granitoids rocks and enclaves are a product of partial melting and fractional crystallization of basic magma, and enclaves are trapped blobs of basic initial magma.
4. Mostly discordant and some concordant structural relations to the country rocks.
5. Temperature of country rock, metamorphic rocks, from the study area may be greater than 450˚C, i.e., the country rock belongs to amphibolite facies.

Microscopic Features

1. Under the microscope, hornblende is common mafic minerals in granite, granodiorite, and diorite. Pyroxene and olivine constitute pyroxenite and peridotite. (Figures. 15,16,17,18,19)
2. Dolerite exhibits ophitic texture that indicates the minerals crystallized out of the magma to in a certain order: first plagioclase, then pyroxene. (Figure. 20)
3. Cross-hatched twins are frequent in alkali feldspar. Zoning and twinning are common in plagioclase. (Figures. 21, 22)

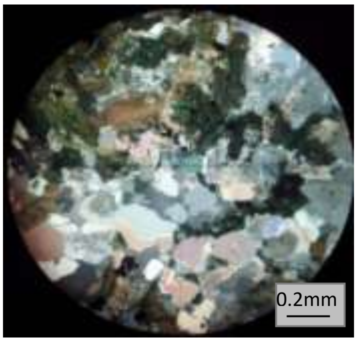


Figure 15. Orthoclase, quartz and hornblende in horn-blende granite. (X.N)

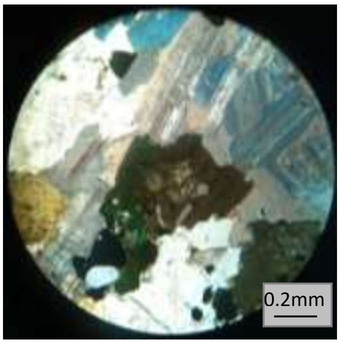


Figure 16. Polysynthetic twin-ing in oligoclase of the granodiorite. (XN)

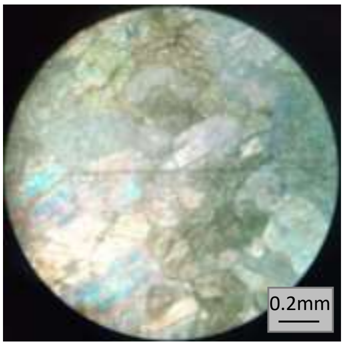


Figure 17. Hornblende in diorite. (X.N)

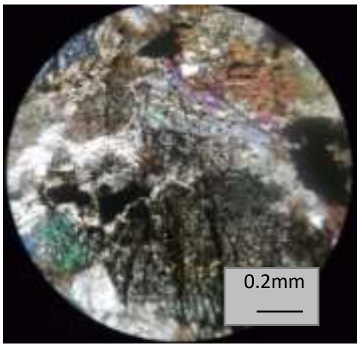


Figure 18. Orthopyroxene and clinopyroxene minerals in pyroxrnite. (X.N)

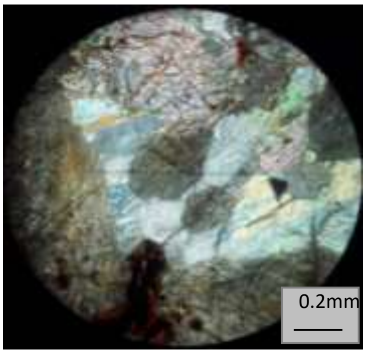


Figure 19. Olivine (Olv), diopside (Di) and enstatite (En) minerals in lherzolite. (X.N)

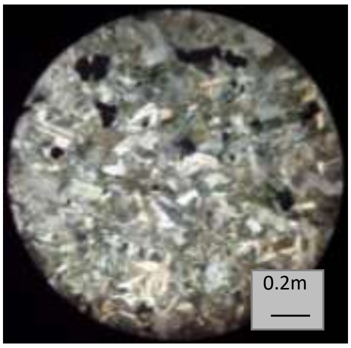


Figure 20. Ophitic texture in dolerite. (X.N)

According to the previous published literature and petrographic criteria, the granitic rocks from the study area are dominated by I-type granites rather than S-type granites. The estimated depth of emplacement may be epizone to mesozone. In addition, mafic enclaves in granites suggest the process of partial melting and fractional crystallization of basaltic magma.

Geochemical Results

From the petrochemical interpretation, the chemical description in most common use is based on silica percentage. For the study area SiO_2 content ranges from 65.7 to 67.3 % in granite, 67.3 % in diorite and 47.2% in dolerite. Based on the above criterion, the magma responsible for the igneous rocks of the study area possess acidic to basic in composition.

Concerning the mineral chemistry, the igneous rocks of the study area have the mole percent alumina is greater than the sum of lime, soda, and potash ($Al_2O3 > CaO+Na_2O+K_2O$). According to the Shand'classification (1949), these rocks belong to peraluminous suite.

In AFM diagram Figure (23), all the igneous rocks fall in the calc-alkaline field. In addition, the later stage of magmatic evolution trend showing an increase in K_2O and Na_2O with depletion of MgO.

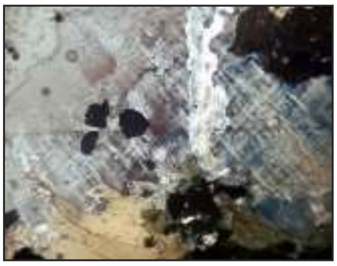


Figure 21. Cross-hatched twin in microcline of hornblende granite. (X.N)

Figure 22. Zoning in albite of hornblende granite. (X.N)

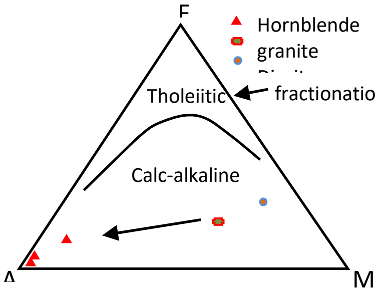
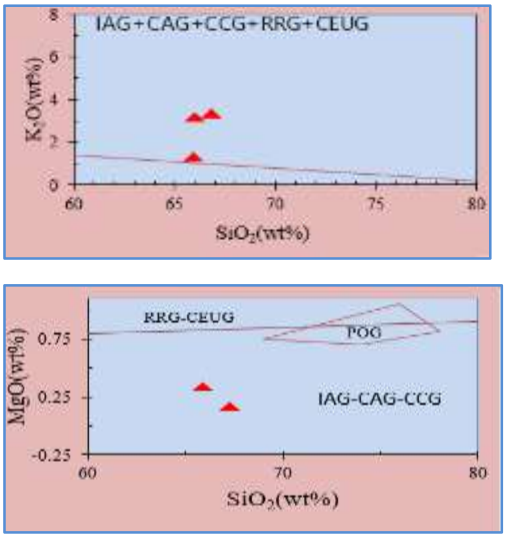


Figure 23. $FeO_{(t)}$ (Na_2O+K_2O) –MgO, AFM diagram.

Discrimination of the tectonic environment for the granites of the study area has been based on the work of Maniar and Piccoli (1989). K_2O versus SiO_2 diagram discriminates the IAG+CAG+CCG+ RRG+ CEUG and OP fields. All the granitic rocks from the study area fall within the IAG+CAG+CCG+ RRG+ CEUG field (Fig.24a). In the MgO versus SiO_2 variation diagram Figure (24b), all granitic rocks fall in the IAG+CAG+CCG field too. According to the above criterion, it can be resolved that the granitic rocks from the study area fall in the IAG+CAG+CCG field which indicates the orogenic granitoids. Hence it seems reasonable that the granite was formed in the continent in relation to the subduction of an oceanic plate beneath the continent.



Orogenic Granitoid
- POG - Post Orogenic Granitoid
- IAG - Island Arc Ganitoid
- CAG - Continental Arc Granitoid
- CCG - Continental Collision Granitoid

Anorogenic Granitoid
- OP - Oceanic Plagiogranite
- CEUG - Continental Epiorogenic Uplift Granitoid
- RRG - Rift-Related Granitoid

Figure 24. (a) K_2O versus SiO_2 diagram for granitic rocks of the study area.

(b) K_2O versus SiO_2 diagram for granitic rocks of the study area.

(based on Maniar and Piccoli, 1989)

Zhang, J.E. et al., 2018 explained the Myitkyina-Mogok ultramafic-diorite belt, located along the eastern margin of the Myanmar Central Basin that was associated with the continental sliver, contains peridotite, andesite, hornblende gabbro, diorite, granodiorite and plagiogranite, all with arc geochemical signatures and ages of 177–166 Ma. Moreover, he mentioned their outcrops andesite, hornblende gabbro and diorite along the Myitkyina belt, rock assemblages of continental margin, which would not be component of ophiolite. According to the field relationships and microscopic features, his model is more appropriate for the study area.

According to the above criteria, the igneous rocks from the study area may be formed as continental arc which related to subduction of Neotethys Ocean during the Mesozoic and Early Cenozoic time. The magma source may relate to the partial melting of subduction oceanic slab generates primary magma and then at the base of the crust where assimilation and the solidification of a gabboric crustal underplate process may take place. Subsequent partial melting of this mafic underplate may result from heat carried upward by subsequent basaltic magma. Fractional crystallization and contamination of continental crust materials occurred when it passed through the crust. Some granite and pegmatite were probably formed by partial melting of lower or middle crust.

Table 2. Chemical composition of igneous rocks from the study area. (in wt %)

Rock Types	**Hornblende Granite**			**Diorite**	**Dolerite**
Sample. ID	**H-8**	**T-11**	**S-4**	**W-10**	**T-29**
SiO_2	65.70	67.3	66.00	54.80	47.20
Al_2O_3	19.70	21.1	21.6	19.00	22.60
Na_2O	9.75	6.90	7.20	2.40	7.51
K_2O	0.55	3.31	3.10	0.06	0.09

Rock Types	**Hornblende Granite**			**Diorite**	**Dolerite**
Sample. ID	**H-8**	**T-11**	**S-4**	**W-10**	**T-29**
CaO	1.79	0.72	0.94	8.97	5.81
MgO	0.93	0.21	0.34	9.79	11.7
Fe_2O_3	1.38	0.24	0.55	3.75	4.23
MnO	0.04	0.01	0.02	0.05	0.08
P_2O_5	0.07	0.02	0.04	0.65	0.06
Cr_2O_3	0.00	0.00	0.00	0.00	0.05
SrO	0.004	0.02	0.02	0.01	0.004
TiO_2	0.13	0.04	0.07	0.46	0.24
Total	**100.04**	**99.87**	**99.88**	**99.94**	**99.57**

Summary and conclusion

The study area mainly comprises intrusive and extrusive igneous and metamorphic rocks created at differing geological episodes. The igneous rocks include pegmatite/aplite, hornblende granite, granodiorite, diorite, dolerite, lherzolite and pyroxenite. Metamorphic rocks are metaigneous rocks (amphibolite and hornblende-biotite gneiss) and metasedimentary rocks (biotite gneiss and migmatite). The Kachin State is one important segment to trace tectonic evolution of Tethys Ocean in SE Asia. Field data, microscopic features and previous published literature indicate that the igneous rock assemblages point out continental arc, which would not be component of ophiolite. The igneous rocks of the study area may be formed by the partial melting of subduction oceanic plate which generates primary magma first. And then, it would be contaminated by the continental crust materials when it travels through the crust. Some granite and pegmatite probably formed by partial melting of lower or middle crust. Therefore, they may be formed as continental arc which related to subduction of Neotethys Ocean during the Mesozoic and Early Cenozoic time. The full age range of the rocks is unknown, but intrusive activity probably extended from the Jurassic into the early Cenozoic.

In the present study, we described petrogenesis of rocks based on field relationship combined with microscopic features, but many data need to support to solve the tectonic evolution of Tethys Ocean in SE Asia. Therefore, many researchers should make researches respect to geochemistry and petrology to get the reliable tectonic history.

Acknowledgement

We would like to extend our thanks to Rector Dr Nay Thawel Kyi for granting us permission to submit this paper. We are especially grateful to Dr. Ji'en Zhang from State Key Laboratory of Lithospheric Evolution, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing for his energetic discussions and valuable suggestions for the present work.

References

Barley, M.E., Doyle, M.G., Khin Zaw, and Pickard, A.L., Rak, P., 2003. Jurassic to Miocene magmatism and metamorphism in the Mogok metamorphic belt and the India-Eurasia collision in Myanmar. *Tectonics* 22, 1-11.

Liu, C.Z., Zhang, C., Xu, Y.,Wang, J.G., Chen, Y., Guo, S., Wu, F.Y., Sein, K., 2016b. Petrology and geochemistry of mantle peridotites from the Kalaymyo and Myitkyina ophiolites (Myanmar): implications for tectonic settings. Lithos 264, 495–508.

Me Me Aung, Hnin Min Soe, Aung Naing Thu (2019a). Outcrop nature and types of Igneous and Metamorphic Rocks exposed around the road section from Maingna to Sadon Waterfall, Waingmaw Township, Kachin State. Departmental Research (Myitkyina University)

Mitchell, A.H.G., 1993. Cretaceous-Cenozoic tectonic events in the western Myanmar (Burma)-Assam region. J. Geol. Soc. Lond. 150, 1089–1102.

Mitchell, A.H.G., Myint Thein Htay, Kyaw Min Htun, Myint Naing Win, Thura Oo, Tin Hlaing, 2007. Rock relationships in the Mogok Metamorphic Belts, Tatkon to Mandalay, central Myanmar. *Jour. of Asian Earth Sciences*, 29(2007), 891-910.

Mitchell, A.H.G., Htay, M.T., Htun, K.M., 2015. The medial Myanmar suture zone and the western Myanmar Mogok foreland. Journal of the Myanmar Geosciences Society 6(1), 73–88.

Yang, J.S., Xu, Z.Q., Duan, X.D., Li, J., Xiong, F.H., Liu, Z., Cai, Z.H., Li, H.Q., 2012. Discovery of a Jurassic SSZ ophiolite in the Myitkyina region of Myanmar. Acta Petrol. Sin. 28,1710–1730 (in Chinese with English abstract).

Zhang, J.E., Xiao, W. J., Windley, B. F., Wakabayashie, J., Cai F. L., Seing, K., Wua, H., Soe Naing, S., 2018. Multiple alternating forearc- and backarc-ward migration of magmatism in the Indo-Myanmar Orogenic Belt since the Jurassic: Documentation of the orogenic architecture of eastern Neotethys in SE Asia. Earth-Science Reviews 185 (2018) 704–731.