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MINERALOGICAL AND GEOCHEMICAL CONSTRAINTS ON THE GENESIS OF GRANITE-RELATED W-SN-MO MINERALIZATION IN PADATGYAUNG-MYINMAHTI AREA, EAST OF NAY PYI TAW, CENTRAL MYANMAR*

Aung Zaw Myint[1], YadanarTun[2], Chit Ko Win[2], Maung Maung Oo[2] and Min Myo Ko Ko[2]

Abstract

Padatgyaung-Myinmahti area is located 80km E from Nay Pyi Taw and lies at the eastern margin of the Shan Plateau. W -Sn-Mo mineralization is spatially associated with the biotite granite of Early Eocene age and low-grade metasediments of Carboniferous to Early Permian Mergui Group. The biotite granite is slightly weathered and intensively greisenized in some places. Quartz veins generally trendN-S and NE-SWwith steep dipping (80°-90°). Cassiterite is common in greisenized zone whereas wolframite and molybdenite is prevalent in quartz vein. Greisen is mainly composed of quartz and muscovite with rare fluorite. The quartz veins contain wolframite and molybdenite associated with the minor amount of galena, pyrite, chalcopyrite, sphalerite, arsenopyrite, bismuthinite, cassiterite, scheelite, bornite and covellite. Wolframite composition ranges from hubneritic to ferberitic composition. Geochemical data indicates that the granites are peraluminous and highly fractionated, and characterized by high $SiO_2$and high A/CNK [molecular Al_2O_3/ ($CaO+Na_2O+K_2O$)] values(>1.1). The granite has tectonic affinities with WPG (within-plate granite) or post-orogenic setting. Trace element geochemistry, distinct negative anomalies of primitive-mantle normalized Ba, Sr, Ti, Nb and the positive Pb, Rb, Y anomalies reveal that distinct crustal sources have been involved in the formation of granite and associated W-Sn-Mo mineralization.

Keywords: W-Sn-Mo mineralization, mineralogy, geochemistry, petrogenesis

Introduction

Myanmar is located in the Southeast Asian tin belt and has many tin-tungsten deposits and occurrences (Figure 1). Most of the tin-tungsten occurrences are widely distributed in the Padatgyaung-Myinmahti area, Mawchi area, Dawei area and Myeik area. Padatgyaung-Myinmahti area is

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* Best Paper Award winning Paper in Geology, (2018)

located 72km east from Nay Pyi Taw and forms as a tin-tungsten district comprising several prospects.

Since 1930s, tin-tungsten ore production was initiated in the area of Steel mine (PyiYadanar), Padatgyaung and Peinnedaik. General geology of the area was established by the several workers but detail geological study of granite-related W-Sn-Mo mineralization is poorly understood. Thus, in this research, mineralogical and geochemical studies of granite and associated W-Sn-Mo mineralization is carried out to determine the genesis of granite and associated W-Sn-Mo mineralization.

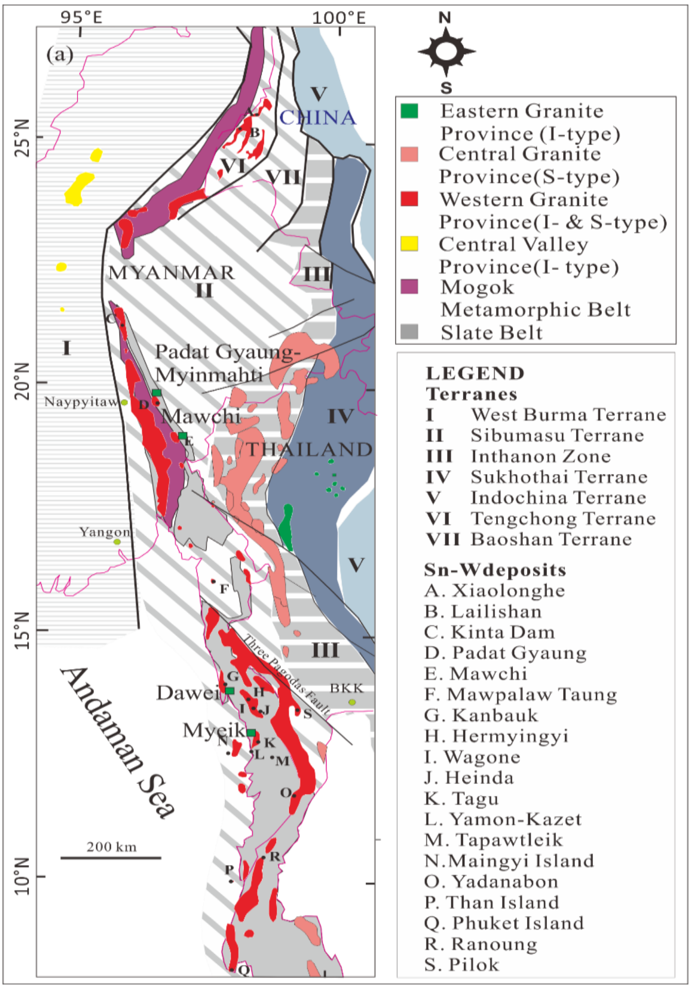

Figure 1: Southeast Asian tin belt showing the occurrences of granite and Sn-W deposits (Aung Zaw Myint et al., 2018 (modified after Cobbing et al., 1992; Mitchell et al., 2007; Sone and Metcalfe, 2008))

Geology of the Padatgyaung-Myinmahti area

Padatgyaung-Myinmahtiarea is composed of the granite and metasedimentary rocks (Figure 2). The metamorphic rocks of the Mogok Metamorphic Belt are exposed in the western part of the area. Banded gneiss and schist are readily observable along the car road to Padatgyaung (Figure 3a). Granite is exposedin the central part of study area, especiallyat the top of and around the Myinmahti Taung (Fig. 3b),formingas north-south elongate pluton. Granite is medium- to coarse-grained, vertically jointed and slightly weathered.The granite is partially greisenized and intruded the Mergui Group (Figure 3c). The greisen is well exposed at Pyiyatanar, Takuntaung and China Cone prospects (Figure 3d).

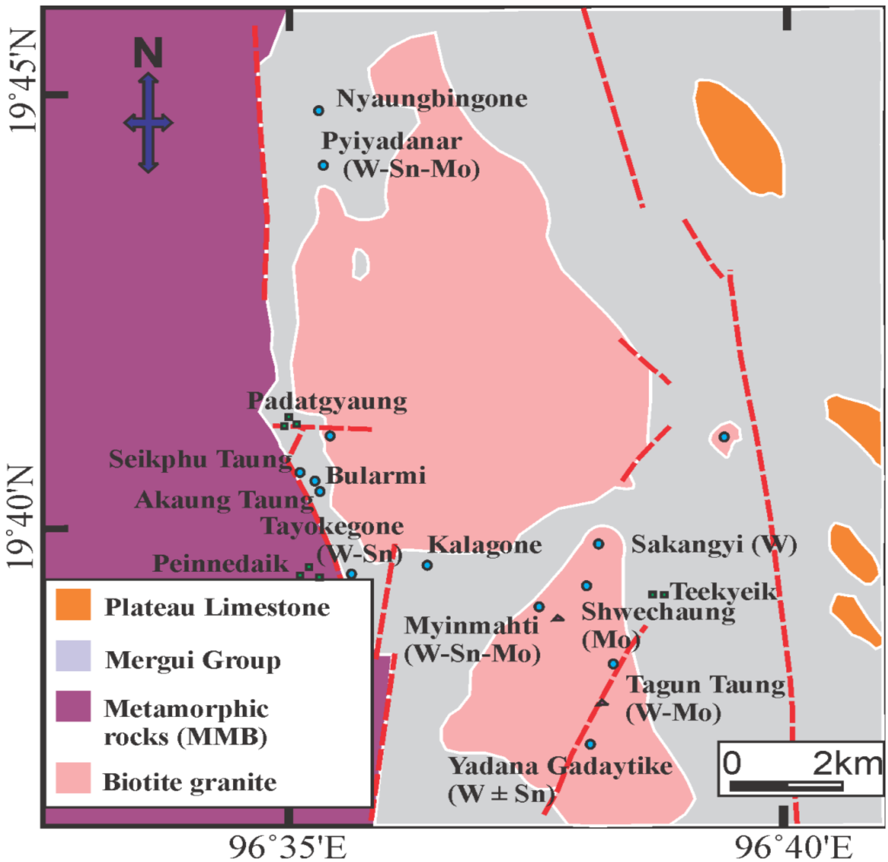

Figure 2: Geological Map of Padatgyaung-Myinmahti area (modified after the sketch map of Bateson et al., 1972)

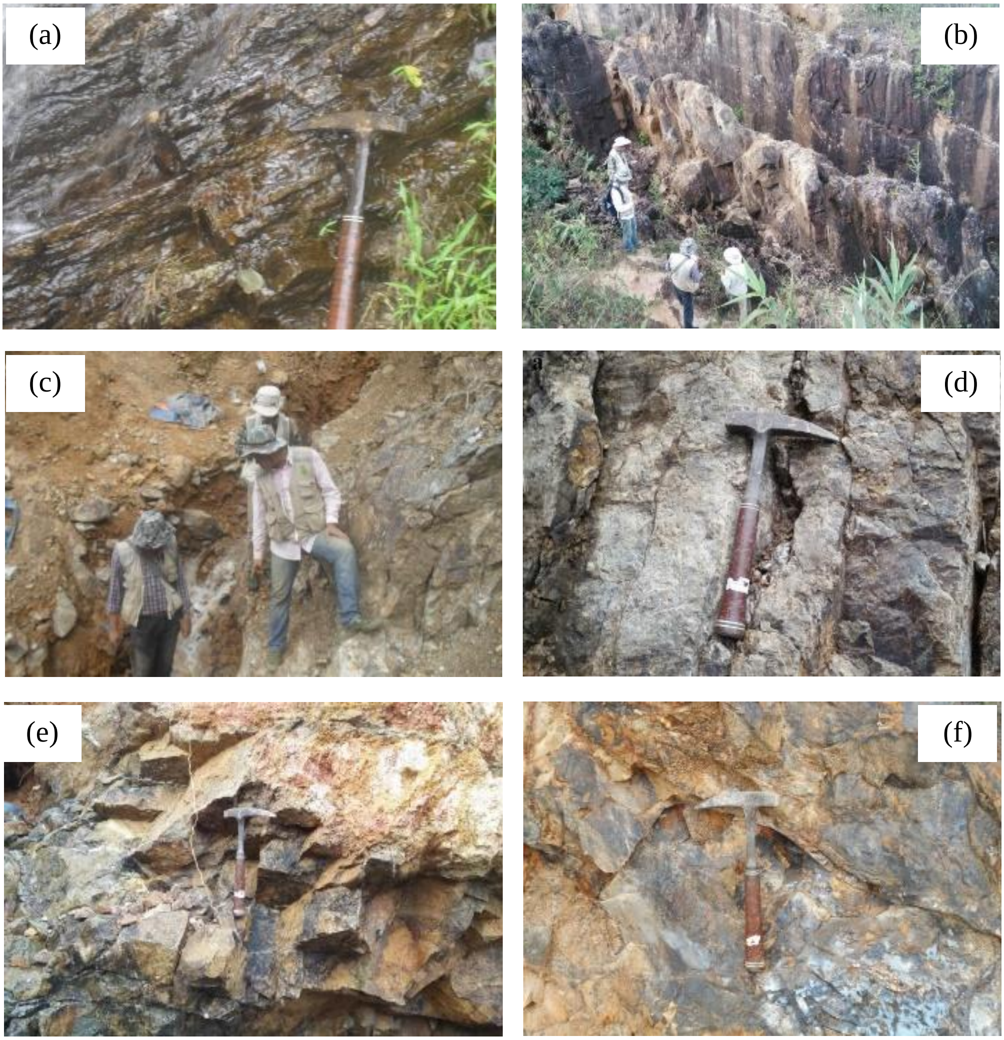

Figure 3: Outcrop nature of rock units exposed in Padatgyaung-Myinmahti area (a) banded gneiss of Mogok Metamorphic Belt (b) weathered granite exposure at the top of Myinmahti hill (c) mudstone intruded by the greisenized granite near Pyiyadanar prospect (d) greisen exposure near Myinmahti (e) well-jointed siltstone unit of Mergui Group (f) metagreywacke unit exposed near Takuntaung Prospect

Metasedimentary and sedimentary rocks distributed in the study areaare sandstone, siltstone, mudstone and metagreywacke. Siltstone with minor thin-bedded sandstone is also found in some localities (Figure 3e). In some localities, the pebbly siltstone has a silicified appearance due to the effect of hydrothermal activity. Metagreywacke is well jointed (Figure 3f) and brecciated. Mudstone is mostly jointed and partly altered. In some places, it contains the quartz pebbles forming as pebbly mudstone.

Granite petrography

Granite is coarse-grained and hypidiomorphic granular texturecomprising quartz, orthoclase, plagioclase, biotite, muscovite and opaque minerals (Figure 4a). Quartz grains are anhedral and formas myrmekite intergrowths with feldspars. Alkali feldspars, orthoclase, microcline and perthite (Figure 4b) occur as subhedral crystals with 0.5 to 2mm size. Plagioclase is generally subhedral to anhedral grains andhas mostly albite composition. Plagioclase is partly altered to sericite and sausurite. Biotiteoccurs as subhedral to anhedral crystals occupying about 10% of the rock. Biotite is partially chloritized (Figure 4c) and exhibits strong pleochroism from yellow to dark brown. Muscoviteoccurs as euhedral to anhedral crystals with size ranging from 0.3mm to 1mm. Iron oxide can be seen as a reddish colored spots.

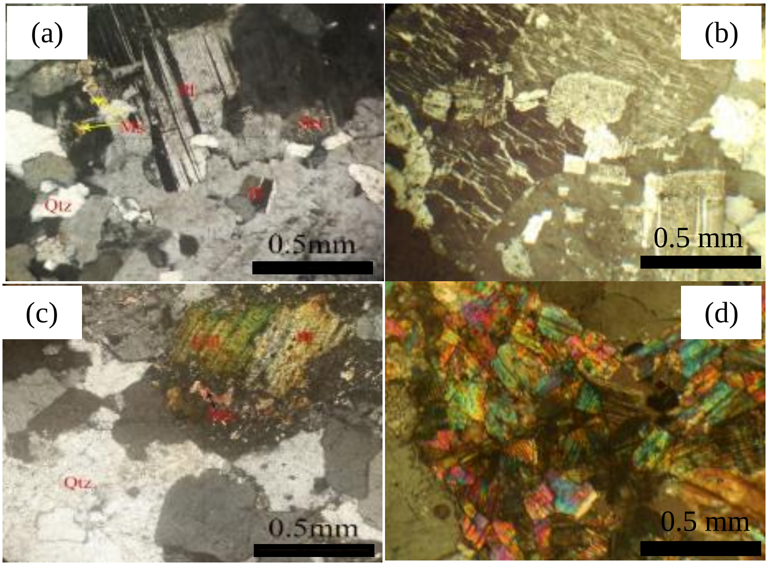

Figure 4: Photomicrographs showing the mineral constituent and textures of granite (a-c) and greisen (d). (a) coarse-grained plagioclase (Pl) with finer grains of quartz (Qtz) and muscovite (Ms), (b)string perthite, (c) partly chloritized (Chl) biotite (Bt) and (d) muscovite aggregate in greisen

Greisenized granite contains chiefly of muscovite, up to 35 percent of the rock, with alkali feldspar and quartz. Greisen is coarse-grainedand mainly composed of muscovite, quartz, (molybdenite) and biotite (Figure 4d). It is greenish grey to dark grey and fragile to compact depending on the portion of mica and quartz. Molybdenite occurs in interstices between muscovite and quartz. Common accessory minerals are cassiterite and fluorite, scheelite and iron oxides are rare accessories. Cassiterite occurs as aggregates of irregular grains and its grain size ranges up to 0.5 cm.

Alteration

The most common alteration associated with W-Sn-Mo mineralization is greisenization. Silicification, sericitization and chloritization are also common. Greisen zone can be served as useful guide for mineral exploration in this area.

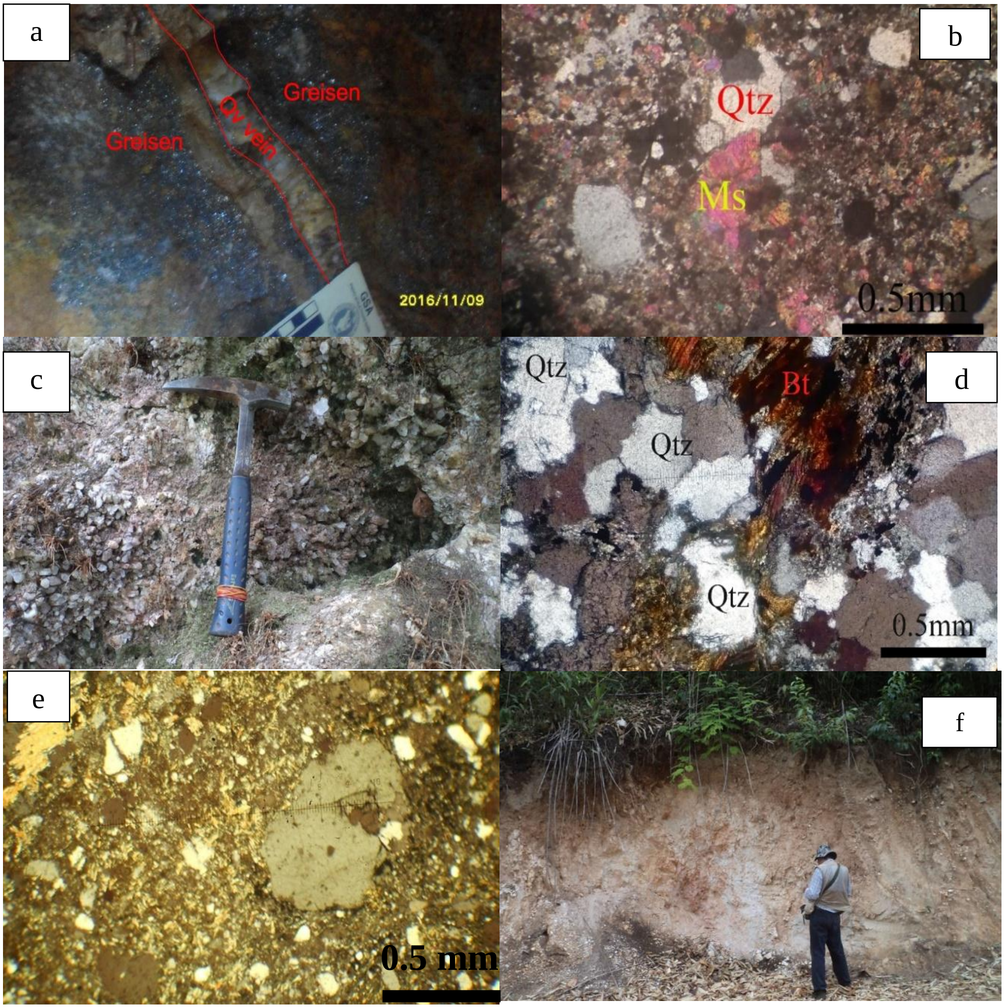

Figure 5: (a) greisenized granite hosting the wolfram bearing quartz vein, (b) greisenization in the siltstone of Mergui Group, (c) silicification occurred in the void of granite, (d) photomicrograph presenting silicification process in granite, (e) sericitization in the metagreywacke and (f) kaolinization on the weathered granite exposed near the top of Myinmahti hill

Greisenization occurs along the margin of mineralized quartz veins, forming as the greisen-bordered quartz veins. Greisen is also found as the form of zonal alteration in the Pyiyadanar, Myinmahti (Figure 5a) and Takuntaung prospects. The greisenization is mainly characterized by quartz and muscovite. In hand specimen,quartz and muscovite are predominant and cassiterite, wolframite and iron oxides are found as common accessory minerals.In Pyiyatanar prospect, greisenization occurs even within the siltstone (Figure 5b). Silicification is the prominent alteration in the mineralized zone. Silicification process can be found at the margin of the granite bodies as vuggy quartz segregation (Figure 5c).Under microscope, the quartz grains are elongate, angular and suture contacts. The small quartz veinlet cut in the granite body (Figure 5d). The quartz grainsoccur as interlocking crystalline mosaic of various shapes. Open spaces such as vesicles, vugs and fractures may also be in filled, often with slightly coarser quartz. Silicification is characterized by the occurrence of vuggy quartz formation.

Under microscopic study, segregate and patches of sericite minerals in metagraywacke indicate the sericitization process (Figure 5e). Apart from the hydrothermal alteration, kaolinization occurs as weathering product of granite (Figure 5f).

Mineralization

The W-Sn-Mo mineralization occurs as both primary and secondary deposits. Primary W-Sn-Mo mineralization can be observed in the Pyiyadanar, Tayokegone, Myinmahti, Shwechaung, Tagon Taung, Sakangyi and Yadana Gadaytike prospects whereas Seikphu Taung, Akaung Taung, Bularmi, Kalagone and Nyaungbingone prospects represent both primary and secondary (i.e.eluvial placer) mineralization. The primary mineralization characterized by the quartz veins that are hosted by the NW-SE, NE-SW and N-S trending fractures, and by greisenized zone. W-Sn bearing quartz veins hosted by metasedimentary rocks are common in the Pyiyadanar (Figure 6a) and other prospects that are located in the western part of the W-Sn-Mo region. The quartz veins closely associated with greisen and cut the sedimentary rocks forming as ore zone. Wolframite and pyrite aggregates, particularly in small voids, are common in these quartz veins. These quartz veins has a thickness of 1cm to 7cm.

Figure 6: (a) parallel quartz vein system intruding the metasediments, (b) biotite granite hosting the quartz vein at Myinmahti, (c) gently inclined vein system at Yadangataytike, (d) greisen-bordered quartz vein at Bularmi, (e) dispersed wolframite (Wf) in quartz vein, and (f) disseminated molybdenite grains (Mo) in greisen

The quartz veins in Myinmahti (Figure 6b) and eastern part of the area are hosted by the greisenized granite. Most of the vein system cut the host rock steeply inclined to vertically. Apart from these vein systems, geisenized granite hosts some subhorizontal to gently inclined veins in Yadanargadaytike (Figure 6c). The greisen-bordered quartz veins are weathered, friable and trend N-S direction forming as a parallel vein system.

In some prospects, the quartz veins are characterized by greisenized border on both sides of the vein (Figure 6d).The mineralization is not related to the vein thickness. All ore minerals occur as irregularly or disseminated in the veins.

The W-Sn minerals can be observed as disseminated grains in quartz vein (Figure 6e). The major ore minerals of wolframite, molybdenite and cassiterite are associated with minor amount of pyrite, chalcopyrite, bornite, galena and fluorite. A quartz vein may be entirely barren in some parts and may be rich in ore minerals in other portions of the same vein.

The greisen zone are mainly found in the Pyiyadanar, Myinmahti, Shwechaungand Takuntaung. Greisen is essentially composed of mica and quartz with minor amounts of cassiterite, wolframite, molybdenite and pyrite. The ores, wolframite and cassiterite, are formed mostly as short and prismatic crystals, lining along the wall of the quartz veins and sometimes as erratically distributed massive patches of several centimeters in the quartz veins. Greisenized zone contains chiefly of molybdenite (± cassiterite ± wolframite) with other sulfides such as pyrite (Figure 6f).

Ore mineralogy

The ore minerals are examined by the polarizing microscope with transmitted and reflected light sources prior to construct paragenetic sequence. All of the ore minerals occur as irregularly patches, disseminated grains, small veinlets and pods in the veins. The ore minerals observed by the ore microscope are wolframite, cassiterite, molybdenite, pyrite, arsenopyrite, chalcopyrite, sphalerite, galena, bismuthinite and bornite.

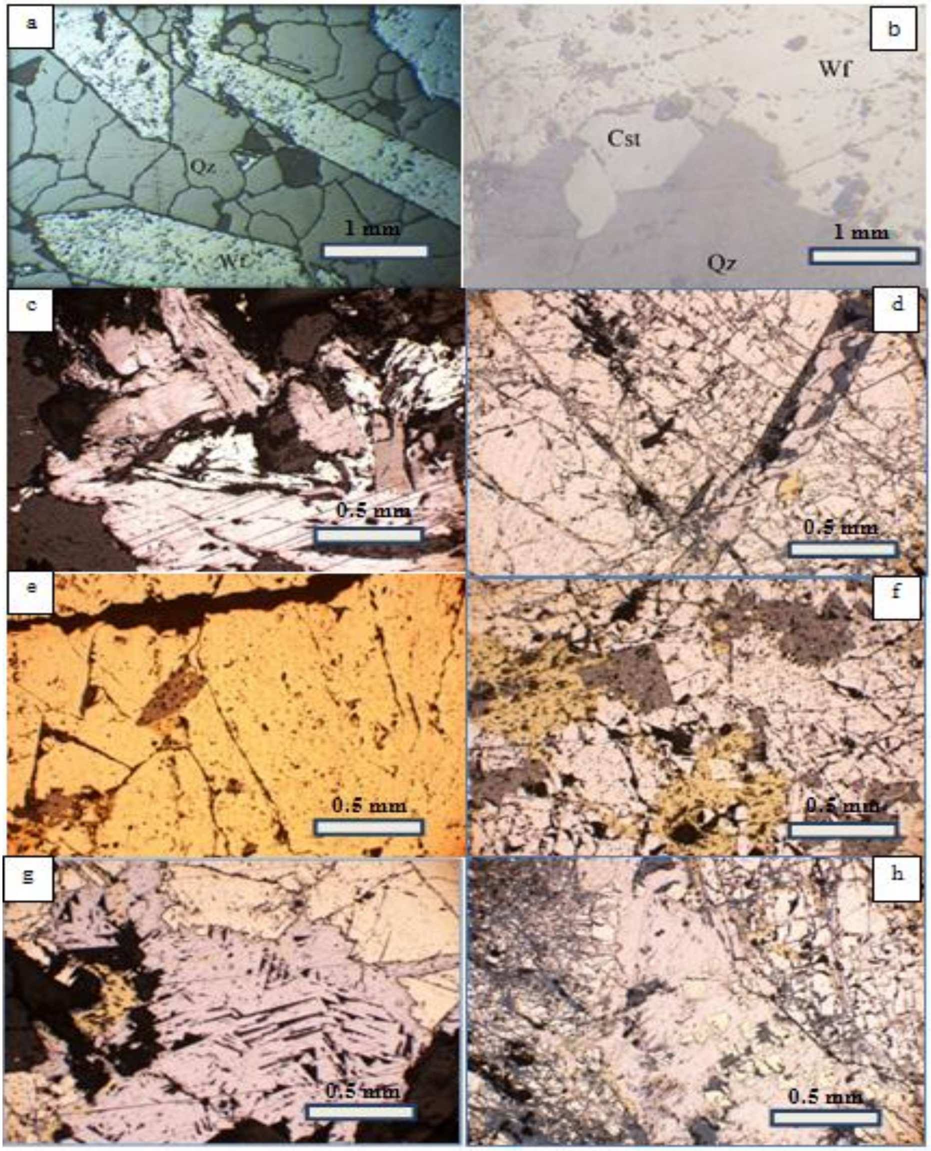

Figure 7: Photomicrographs showing the ore mineral assemblage and their textural relationship: (a) dispersed bladed wolframite crystals in quartz, (b) wolframite and cassiterite in quartz,(c) molybdenite lamellae in quartz (d) fractured arsenopyrite replaced by pyrite and chalcopyrite, (e) voids of pyrite filled with later formed chalcopyrite and sphalerite, (f) chalcopyrite and sphalerite replace pyrite: sphalerite host chalcopyrite blebs (g) triangular-pitted galena replaces early formed pyrite and chalcopyrite, and (h) bismuthinite replaces pyrite cubes and fractured arsenopyrite

Wolframite, the chief ore mineral of the area, occurs as light grey to white, tabular, bladed or prismatic, and lamellar massive (Figure 7a). It is mostly associated with pyrite and molybdenite. Wolframite is usually formed along the walls of greisen-bordered quartz vein. The crystals are more or less perpendicular to the vein walls and projecting into the vein quartz. Individual crystals of wolframite were found up to 0.5 to 1.5 cm long, and sometimes in large masses of crystal aggregate. Wolframite in greisen forms as small crystals and associated with cassiterite.

Cassiterite occurs as common accessory in greisen and its average size is about 1 to 3mm. Cassiterite is associated with wolframite in quartz vein of Myinmahti (Figure 7b). Molybdenite occurs as platy massive aggregate that occurs within or at the margin of quartz veins. It exhibits white to lead grey colour with bluish tint (Figure 7c). Molybdenite is associated with sulfide mineral such as chalcopyrite in quartz vein.

Arsenopyrite is not abundant as pyrite. It is fractured and replaced by the later sulfides such as pyrite and chalcopyrite (Figure 7d). Pyrite is the most common sulfide mineral having yellowish colour, metallic lustre and striated faces on cubes. It is associated with chalcopyrite, galena and sphalerite in quartz veins (Figure 7e) and replaced by these later formed sulfides.

Chalcopyrite has brass yellow and closely associated with sphalerite and pyrite (Figure 7f). It forms later than molybdenite, pyrite and arsenopyrite. It appears somewhat earlier than or synchronously with sphalerite. Sphaleriteis associated with chalcopyrite, pyrite and galena. It is greyish brown to dark grey and has distinct internal reflection. It replaces early formed sulfides such as pyrite and chalcopyrite. Sphalerite encloses chalcopyrite blebs forming as exsolution pattern or chalcopyrite disease texture. Galena is the latest formed mineral in the paragenetic sequence and it is associated with other sulfides such as chalcopyrite and sphalerite (Figure 7g). The bismuthinite, a rare accessory mineral, has whitish colour and replaces early formed sulfides (Figure 7h).

Granite geochemistry

XRF geochemical analysis indicates that the chemical composition of granite samples from the study area contain SiO_2 (74-77%), TiO_2 (0.01-0.3%), Al_2O_3 (10-15%), FeO (0.7-4.2%), MnO (0.16-0.44%), MgO (0.09-0.60%), CaO (0.1-0.53%), Na_2O (0.03-2.19%), K_2O (3.70-6.32%) and P_2O_5 (0.01-0.02%). In fact that SiO_2 content in this rock is extremely high and it can be concluded that it may the mobile nature of SiO_2 and its source is not only from the magma in this case.

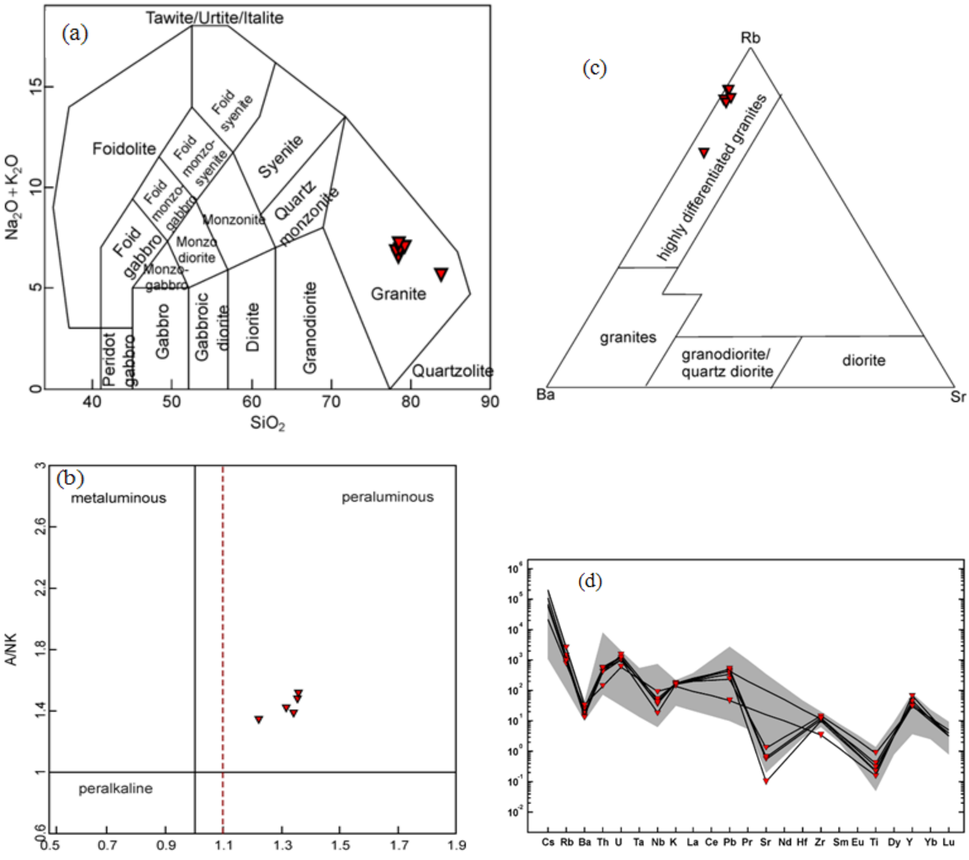

Figure 8: (a) TAS diagram, (b) ASI – A/NK plot showing the peraluminous nature of granites, (c) Rb-Ba-Sr triangular plot presenting highly differentiated (evolved) nature of granites, and (d) spider diagram showing the behavior of trace elements in the granites (red triangle) and greisen (shaded area)

The geochemical data indicates that these granite samples are peraluminous as other tin granites of the Western Province and A/CNK [molecular Al_2O_3/ ($CaO+Na_2O+K_2O$)] ≥ 1.1 (Figure 8b). Besides, some of them have the extremely high A/CNK value (i.e.2.7-5.7) and these values cannot be plotted in the diagram of alumina saturation index (ASI) of Shand (1943).

These samples have LILE (large ion lithophile elements) of Rb (450-1780 ppm), Sr (1-30 ppm) and Ba (89-282 ppm). The ternary diagram Rb-Ba-Sr processes the advantage of being both classificatory and genetic (El Bouseily and El Sokkary, 1975). As a genetic factor, the diagram may indicate whether the granites are magmatic or not. Ba and Sr are sensitive indicators for tracing the differentiation trend of the parent magma. In the differentiation sequence from diorites to normal granites Sr decreases while Ba increases. In such case the ratio of K-feldspar to plagioclase mainly governs the differentiation sequence. Sr decreases readily with differentiation since it replaces Ca in plagioclase and K in K-feldspars while Ba replaces only K in K-feldspars. Rb content remains constant from diorite to granodiorite but it begins to increase in normal granite as a result of increase of the amount of K-feldspars. In the differentiation sequence from normal granites to strongly differentiated granites Ba/Rb ratio becomes rapidly variable while Sr content remains virtually constant. Granite samples from Mawchi fall in the division of strongly differentiated granites and the felsic or leucocratic nature of these samples can prove that fact is reliable (Figure 8c).

The granite samples contain HFSE (high field strength elements) of Y (123-334 ppm), Zr (93-202 ppm), Th (18-58 ppm),U (4-24 ppm) and Nb (10-39 ppm).The U content is similar to the values of 3 to 18 ppm usually present in the other granites of Myanmar (Cobbing *et al*., 1992). The samples have poor Zr concentrations expressing the characteristics of low temperature formation and high level emplacement. Granites and greisens from Padatgyaung-Myinnahti area have 19 ppm – 9% Sn, 15 ppm – 0.5% W and 10 – 186 ppm Mo.

Discussion

Petrogenetic consideration

This felsic and highly fractionated magma may be derived from the parent magma, which may be formed by partial melting of the crust, by assimilation and fractional crystalization (AFC process).The distinct crustal sources may have been involved in the peraluminous granitoid rocks. High peraluminosity of the granites also indicate more pelitic sediments may contribute in the magma. However, extended survey for geological mapping and geochemical analysis (eg. ICP-MS determination) and detailed isotopic study are still needed to determine the petrogenes is of granitic rocks.

Nature of parental magma

Mawchi granite is characterized by MORB-normalized spider diagram applying the data analyzed by the XRF method (Figure 8d) showing enrichment in LILEs such as U, Th and Rb, with distinct negative anomalies for HFSEs such as Ti and Nb. Negative anomalies of Ba and Sr from Rb are remarkable. Most of these features such as pronounced negative Ba, Sr, Nb and Ti anomalies and enriched in Rb, Pb andTh are compatible with those of typical crystal melt. Thus the parental magma may be derived from the crustal source.

Tectonic Setting

When plotted on the trace element discrimination diagrams (Pearce et al., 1984; Batchelor and Bowden, 1985), it is clear that the granites from Padatgyaung-Myinmahti area have tectonic affinities with WPG (within-plate granite) and Post-orogenic settings. Pearce et al. (1984) postulated the discriminative diagrams to integrate granite geochemistry into the plate tectonics framework. Among these diagrams Rb-(Y+Nb) diagram is illustrated indemonstrate the link between source and settings. This diagram is based on against function of Rb, essential large ion lithophile and fluid mobile element, to the Y and Nb, two high field-strength and immobile elements. These two HFSEs behave the opposite ways during the process of melting and crystallization. While Nb is almost always incompatible Y may be compatible (Pearce et al., 1984). The granite samples fall in the field of WPG in the discrimination diagrams of Rb-(Y+Nb) (Figure 10a).

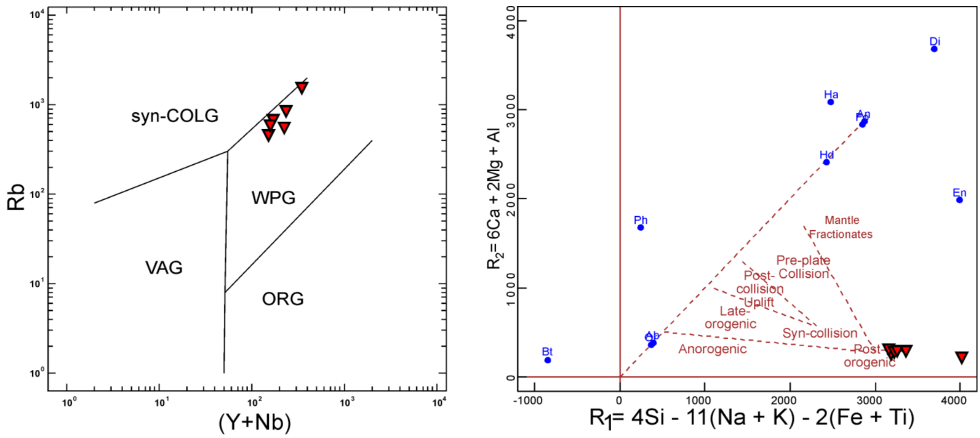

Figure 9: Tectonic affinities of granites from Padatgyaung-Myinmahti area expressed by(a)Rb-(Y+Nb) discrimination diagram (Pearce et al., 1984), and (b)R1-R2 diagram (Batchelor and Bowden, 1985)

Furthermore, the granite samples has tectonic affinities with Post-orogenic granites (Figure 10b) and it can be said that its emplacement is linked with the post-collision movement during the Eocene. The granites exhibit strong depletion of Sr, Ba, Ti and Nb are peraluminous and of S-type. However, more detailed geochemical studies such as ICP-MS analyses and radiogenic isotope (eg. Pb, Nd-Hf, Rb-Sr) are still required to indicate precise tectonic setting and source of granites.

W-Sn-Mo Mineralization

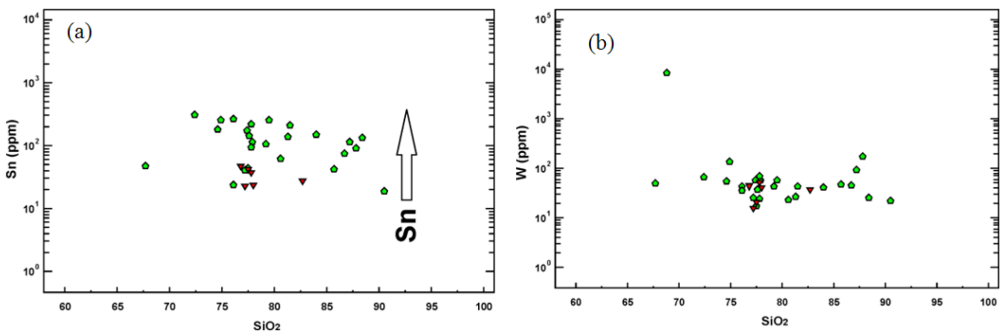

Figure 10: Variation diagram showing the behavior of (a) Sn and (b) W during greisenization process (green pentagon-greisen, red triangle-granite)

The field and lab results reveal that W-Sn-Mo mineralization is genetically related to the granite emplacement. Figure (10) can display obviously the Sn enrichment during greisenization process. However, W abundances in most of greisen samples are not higher distinctly than that in granite samples. It can be concluded that W mineralization is partially related to greisenization but magmatic hydrothermal process is the crucial factor to control the W enrichment in the system.

Conclusions

W -Sn -Mo mineralization is spatially associated with the biotite granite of Early Eocene age and low-grade metasediments of Carboniferous to Early Permian Mergui Group. Quartz veins generally trend N-S, NW-SE and NE-SW with steep dipping (80° -90°). Cassiterite is common in greisenized zone whereas wolframite and molybdenite is prevalent in quartz vein. Geochemical data indicates that the granites are peraluminous and highly fractionated characterized by high SiO_2 and high A/CNK [molecular Al_2O_3/ ($CaO+Na_2O+K_2O$)] values (>1.1). Sn enrichment is directly related to the greisenization process whereas magma-decent hydrothermal process controls the W abundances. Trace element geochemistry and tectonic affinities (WPG (within-plate granite) and post-orogenic settings) reveal that distinct crustal sources have been involved in the formation of granite.

Acknowledgements

I wish to thank the professors from Economic Geology Lab of Kyushu University for their kind support in XRF facility. Special thanks are due to Myo Kyaw Hlaing and Sai Pyae Sone (Doctoral students, Kyushu University) for their valuable help in XRF analysis.

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MICROFACIESAND DEPOSITIONAL ENVIRONMENT OF THE THITSIPIN LIMESTONE FORMATION EXPOSED IN THE HTI TA HKAW AREA, TAUNGGYI TOWNSHIP, SOUTHERN SHAN STATE

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Abstract

The Thitsipin Limestone Formation extensively covers the entire Shan State. The present investigated Hti Ta Hkaw area, is situated in Taunggyi Township, southern Shan State. The formation is characterized by thin-bedded to massive, bluish grey to dark grey limestone and dolomitic limestone with abundance of shallow marine fauna. The classification of microfacies is based on the presence and proportion of skeletal and nonskeletal components. Based on the detailed petrographic analysis, nine microfacies have been recognized comprising coral boundstone, bioclasticrudstone, algal packstone-grainstone, fusulinidpackstone, peloidalpackstone, intraclasticwackestone-packstone, foraminifer wackestone, lime mudstoneand dolomitic lime mudstone. On the basis of the observed microfacies types, the Thitsipin Limestone Formation would have been deposited in the rimmed platform condition under sub-environments of intertidal, subtidal channel lag, subtidal lagoon, back reef lagoon and open marine environment during the Middle Permian time.

Keywords: Microfacies, Depositional Environment, Thitsipin Limestone Formation, Middle Permian, Rimmed Platform

Introduction

In Myanmar, the Permian-Triassic thick carbonate sequence of the Plateau Limestone Group is widely distributed in entire Shan Plateau. The Middle Permian sequence in southern Shan Plateau was named the Thitsipin Limestone Formation by Garson et al., (1976) for the thick carbonate rocks, including a massive limestone facies, a massive cherty limestone facies and a well-bedded calcarenitefacies, exposed the area around Nayaungga and Ywangan. The stratigraphy of this unit has been studied by Aye Ko Aung and Hlaing Htut Aung (2005) and Aye Ko Aung (2012) in Htam Sang area. It is partly correlated with the dolomitic limestone unit, named by Zaw Win

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(2004), exposed in the area around Lungyaw-Sakangyi area on the western margin of southern Shan Plateau. ThuraOo et al. (2002) carried out the study area on the distribution, lithology and fauna of the Permian units of Myanmar. Although several researchers have conducted sedimentological and paleontological studies of the Thitsipin Limestone Formation in the western part of southern Shan State, it has not been studied well in detail sedimentology of the eastern part of southern Shan State. Thus, we here provide a detailed account of the microfacies and depositional environment of the Thitsipin Limestone Formation exposed the Hti Ta Hkaw area which is situated about 10 km northeast of Taunggyi town (Figure 1).

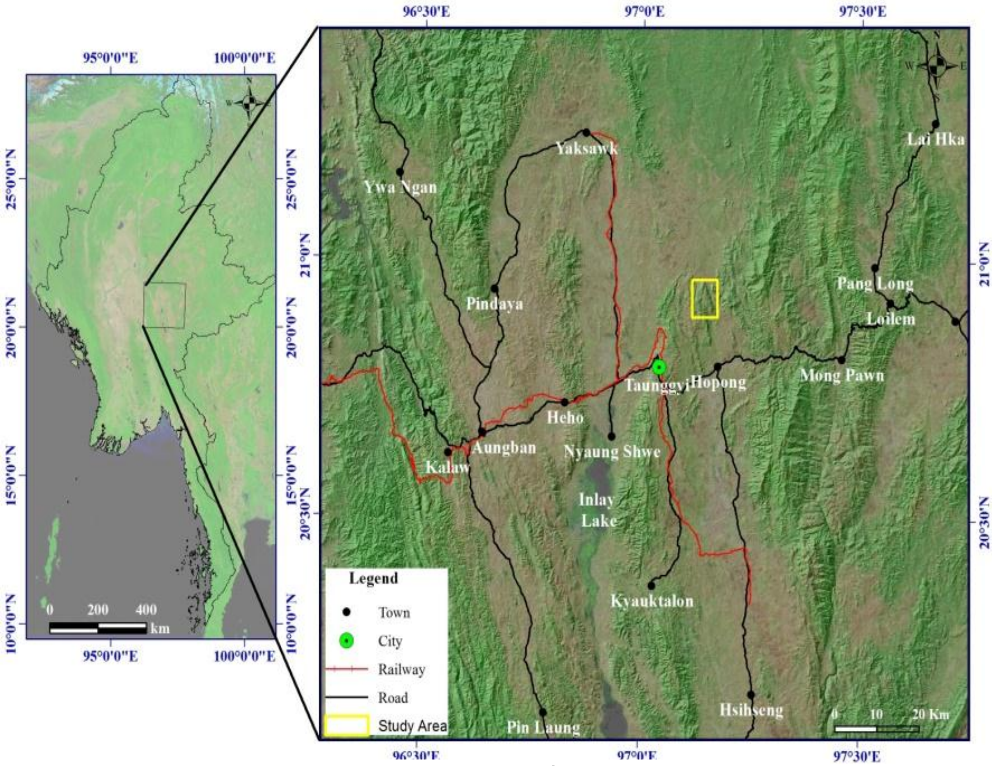

Figure 1: The location map of Hti Ta Hkaw area.

Geological Setting

Tectonically, the study area is situated in the western part of the SibumasuTerrane(Metcalfe, 2009 and 2011). During the Early Permian, the SibumasuTerrane rifted and separated from eastern Gondwana, and drifted northward from southern to northern hemispheres (Metcalfe, 2009). At the beginning of the early Middle Permian, marine sedimentation was initiated as a widespread carbonate platform in the western Shan Plateau region, developing into a warm, open, shallow shelf sea (Zaw Win et al., 2017).

The Middle Permian sequence of Thitsipin Limestone Formation is well exposed in the central part of the study area, and overlies unconformably on the Linwe Formation and passes up conformably to the overlying Nwabangyi Dolomite Formation (Figure 2). It is characterized by fine- to medium-grained, thick-bedded to massive, bluish grey to dark grey limestones; thick-bedded to massive light grey to pale grey micritic limestone and dolomitic limestone. This unit is usually fossiliferous and most of them are well preserved.

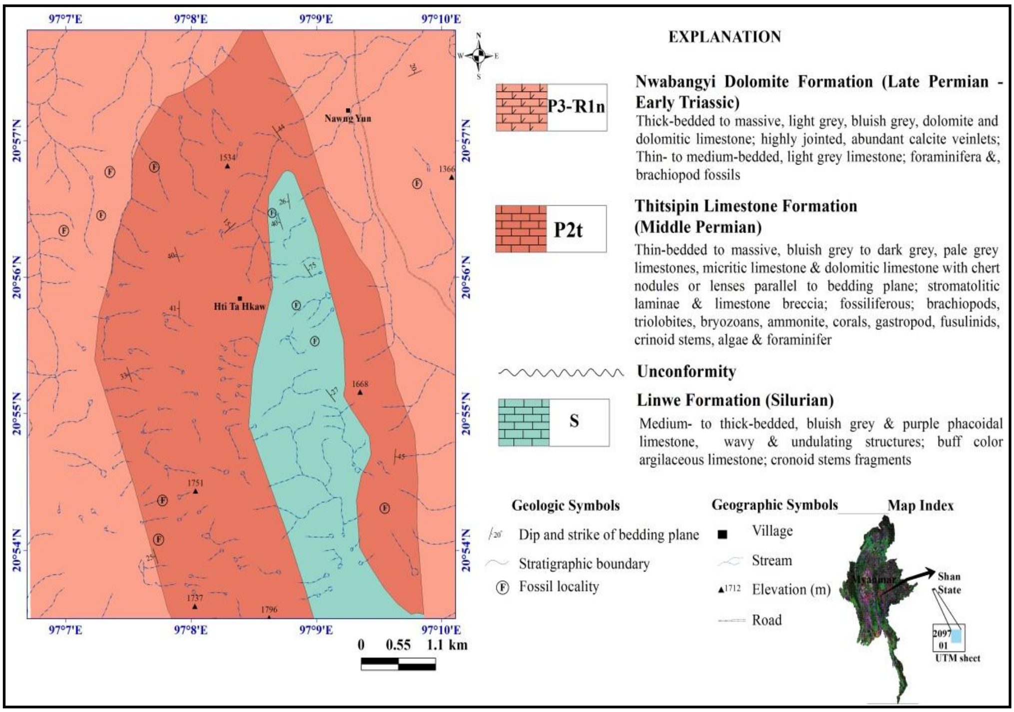

Figure 2: The geological map of Hti Ta Hkaw area.

Materials and Methods

This investigation was done on the basis of the detail stratigraphic section of the Thitsipin Limestone Formation exposed in the Hti Ta Hkaw area. The choice of measured section was based on stratigraphic completeness. A detailed section measurement was undertaken bed by bed using a Jacob staff and tape that was put perpendicular to the bedding planes. A total of three-hundred oriented samples were collected from individual bed in thin- to thick-bedded limestone, whereas the massive limestones were sampled at one meter interval. All collected samples were cut perpendicular to the bedding plane and made into thin-sections for petrographic analysis. The textural classification of the rock unit was followed by Dunham (1962) and Embry and Klovan (1971).

Results

Microfacies Analysis

The classification of microfacies was based on textures, and the presence and proportion of skeletal and nonskeletal grains. The main skeletal components include bryozoans, echinoderms, brachiopods, bivalve, gastropods, foraminifer, corals, algae and trilobite. Peloids are the major nonskeletal grains and intraclasts are rather limited. Based on the detailed petrographic analyses, nine microfacies have been recognized for the Thitsipin Limestone Formation exposed in the study area.

Coral Boundstone (MF1)

The coral boundstone microfacies represent both solitary and colonial rugose corals (Figure 3a). *Syringopora* sp. has also been observed in some horizon. Macrofauna such as brachiopods, bryozoans, gastropod and crinoids stems are associated with those corals. This microfacies may correspond to the SMF 7 of Wilson (1975) and Flugel (2010).

The diverse assemblages of macrofauna indicate open marine, well oxygenated, high energy environment. The rigid frameworks of such colonial rugose corals are very common in reef environment. The presence of nature of growth positioned rugose corals and associated open marine fauna suggests that this microfacies would have been deposited in open marine bioherm environment.

Bioclastic Rudstone (MF2)

The bioclastic rudstone facies is characterized by a diverse fossil assemblage including macrofauna and microfauna. The most distinctive bioclasts are bryozoans and echinoderms (Figure 3b). Gastropod, brachiopod and trilobite are other significant components among the bioclasts. This microfacies may correspond to the SMF 9 of Wilson (1975) and Flugel (2010).

The high diversity of fauna may indicate open marine setting. The predominance of bryozoans suggests intertidal and upper subtidal depositional setting in areas of low sedimentation (Flugel, 2010). This microfacies would have been deposited in open marine environment.

Algal Packstone-Grainstone (MF3)

The algal packstone-grainstone facies indicates the abundance of green algae. The distinctivealgae are dasycladacean, gymnocodium and phylloid algae (Figure 3c). Bryozoan, gastropod, echinoderm, foraminifera and calcisphere are the minor constituents of this facies. This microfacies may correspond to the SMF 18 of Wilson (1975) and Flugel (2010).

The abundances of algae suggest deposition within the photic zone. The presence of gymnocodicean algae may indicate low energy lagoonal environment. The existence of calcispheres suggests that this microfacies was deposited in quiet water condition. Thus the depositional setting of this microfacies may be low energy back reef lagoonal environment.

Fusulinid Packstone (MF4)

The chief character of the fusulinid packstone facies is the abundance of fusulinid that are embedded in micritic matrix (Figure 3d). Other components, such as gastropod and peloids are often present in this facies. Most fusulinids grains were micritized. This microfacies may correspond to the SMF 18 of Wilson (1975) and Flugel (2010).

The larger benthic fusulinids foraminifers are common in shallow marine, high energy environment within the photic zone (Flugel, 2010). The presences of micritized grains suggest marine diagenesis. This microfacies is inferred to represent deposition in open marine environment.

Peloidal Packstone (MF5)

The peloidal packstone facies represents the predominance of peloids and some fecal pellets (Figure 3e). Some bioclasts, including fragments of echinoderms and foraminifer, are associated with those peloids. This microfacies may correspond to the SMF 16 of Wilson (1975) and Flugel (2010).

The fecal pellets were the products of animals' excretions during the deposition of this facies. They are more commonly preserved in subtidal and lower intertidal zones of inner platform setting with low water energy and reduce sedimentation rates (Flugel, 2010). Random size and sorting of peloids within this facies were produced by bio-erosion or micritization of existing bioclasts. This microfacies would have been deposited in subtidallagoonal environment.

Intraclastic Wackestone-Packstone (MF6)

The intraclastic wackestone-packstone facies is characterized by the presence of fine to coarse-grained, poorly sorted angular carbonate clasts (Figure 3f). Microstylolites are also present between some grains. This microfacies may correspond to the SMF 24 of Wilson (1975) and Flugel (2010).

Intraclasts can form in many environments, but most typically are formed in setting with intermittently high energy conditions (Scholle& Ulmer Scholle, 2003). The occurrence of microstylolites can be interpreted that this microfacies was affected by chemical compaction due to deep burial diagenesis. This microfacies would have been deposited in subtidal channel lag environment.

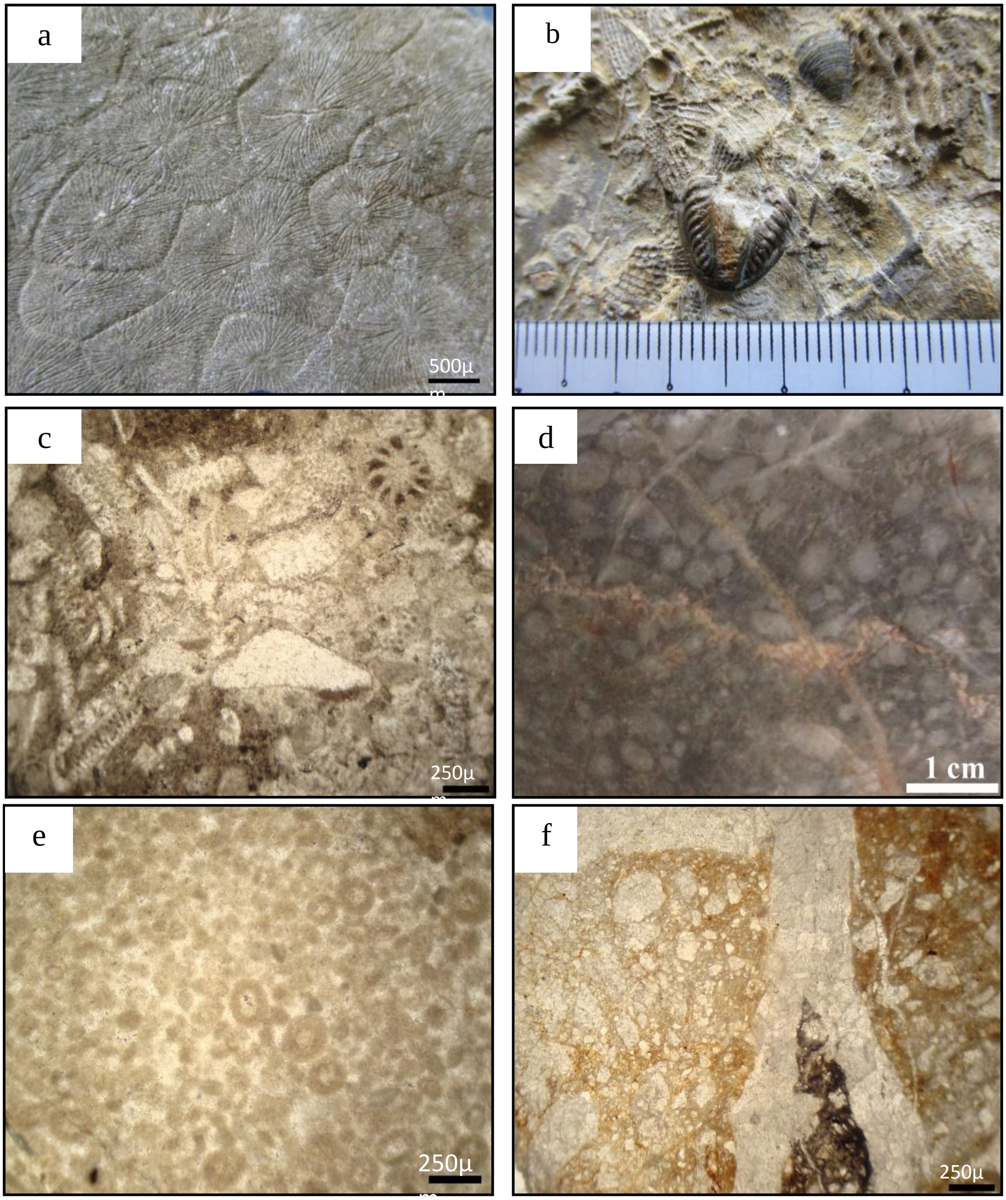

Figure 3: Thin-section photomicrographs showing the microfacies of the Thitsipin Limestone Formation. (a) Coral boundstone; (b) Bioclasticrudstone; (c) Algal packstone-grainstone; (d) Fusulinidpackstone; (e) Peloidalpackstone; (f) Intraclasticwackestone-packstone.

Foraminifera Wackestone (MF7)

The major constituent of the foraminifer wackestone facies is benthic foraminifer (Figure 4a). Ostracods and brachiopods are also associated with those foraminifers. Minor amount of peloids are scattered in the micritic matrix. This microfacies may correspond to the SMF 18 of Wilson (1975) and Flugel (2010).

The presences of benthic foraminifer and other fauna assemblages may indicate well oxygenated shallow water conditions. The minor amount of peloids and wackestone texture suggest in low energy depositional setting. This microfacies would have been deposited in open marine back reef lagoonal environment.

Lime Mudstone (MF8)

The typical characters of the lime mudstone facies are rare biota and predominance of micritic matrix. Only the traces of trilobite, ostracode shells and crinoids have been observed (Figure 4b). Stylolitic seams are frequently occurred. The isolated dolomite rhombs and pyrite are floated in the matrix. This microfacies may correspond to the SMF 23 of Wilson (1975) and Flugel (2010).

The predominance of micrite suggests low energy depositional setting. Most lime mudstone accumulates in a wide range of environments ranging from tidal flat to deep basin condition. The association of lime mud and shallow marine fauna is interpreted to have been formed in lagoonal setting. The presences of dolomite were resulted from dolomitization process that is very common in lagoonal setting. This microfacies would have been deposited in low energy subtidallagoonal environment.

Dolomitic Lime Mudstone (MF9)

The dolomitic lime mudstone facies is characterized by the abundance of replacement dolomite in the micritic matrix (Figure 4c). Generally the crystal sizes are fine- to medium-grained texture. Fauna are very rare in this microfacies. This microfacies may correspond to the SMF 23 of Wilson (1975) and Flugel (2010).

Lime muds are preferentially and many nucleation sites for dolomite replacement that result in a fine-grained texture (Tucker & Wright, 1990). The small crystal sizes are restricted in subtidal to supratidal setting and an early replacement origin (Amthor& Friedman, 1991). Penecontem poraneousdolomitization may take place in intertidal to supratidal setting, giving fine-grained dolomite mosaics (Tucker, 2001). This microfacies was probably deposited in intertidal environment, and dolomitization processes may have been formed by increasing salinity during a relative fall of sea-level.

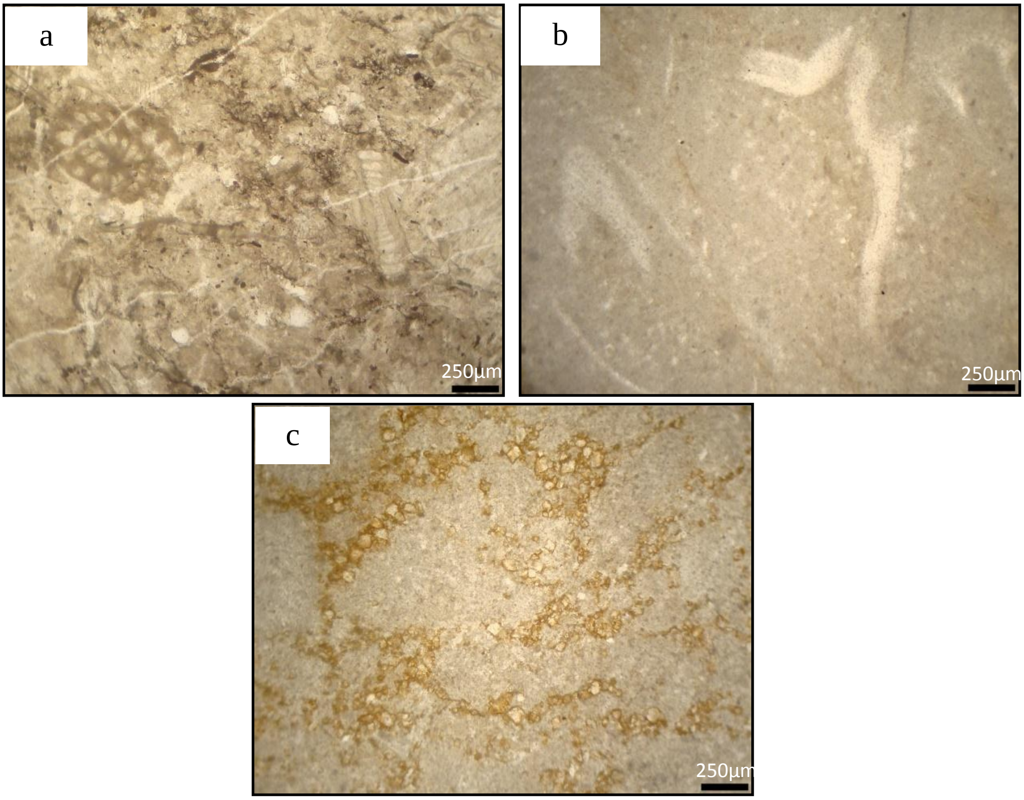

Figure 4: Thin-section photomicrographs showing the microfacies of the Thitsipin Limestone Formation. (a) Foraminifer wackestone; (b) Lime mudstone; (c) Dolomitic Lime mudstone.

Depositional Environments

Based on the analysis of the above microfacies, rimmed shelf carbonate platform model is proposed for the Thitsipin Limestone Formation exposed in the study area (Figure 5). This model occupies platform interior setting and subsequently six sub-environments are defined on the basis of constituent fauna, textures, carbonate grains and hydraulic conditions. They are intertidal, subtidal channel lag, subtidal lagoon, back reef lagoon, open marine and bioherm environments.

The shallowest facies in this model represents intertidal environment that representsthe dolomitic lime mudstone facies. Subtidal channel lag environment includes intraclastic wackestone-packstone facies. Peloidal packstone and lime mudstone facies were deposited in subtidal lagoon environment. Back reef lagoon environment represents algal packstone-grainstone, fusulinid packstone, and foraminifer wackestone facies. Open marine environment includes bioclastic rudstone facies. Coral boundstone facies was deposited in bioherm.

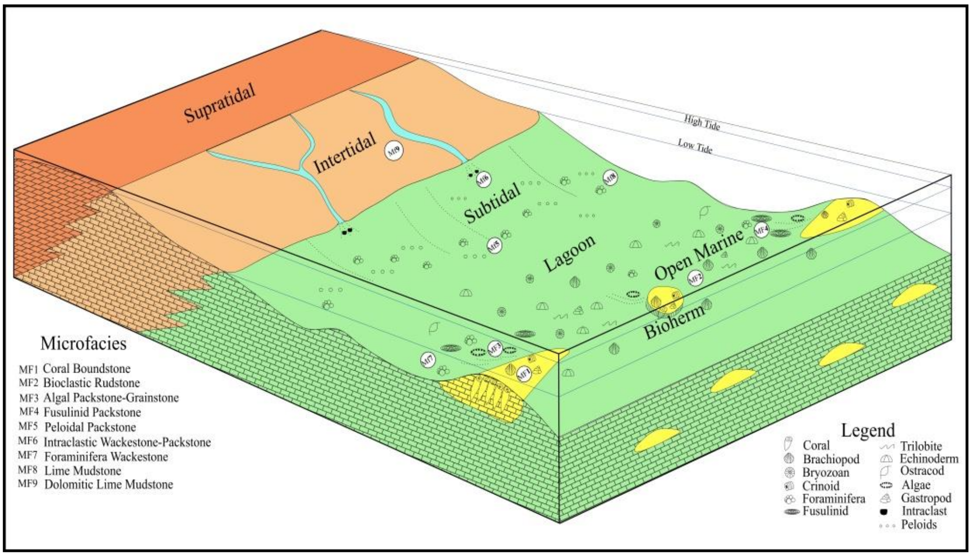

Figure 5: Idealized depositional model for the Thitsipin Limestone Formation

Conclusion

The Middle Permian carbonate sequence of the Thitsipin Limestone Formation exposed in Hti Ta Hkaw area is composed of fine- to medium-grained, thin-bedded to massive, light to dark grey carbonate facies. Based on field and petrographic evidences, the nine microfacies have been observed, and rimmed shelf carbonate platform model is proposed for the Thitsipin Limestone Formation exposed in the study area. The development of these microfacies types and high diversities of shallow marine fauna may indicate that the northward drifting of Sibumasu Terrane was warmer region during the Middle Permian time.

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SILURIAN ROCKS IN THE KYAUKTAP AREA, SHAN STATE (SOUTH): THEIR SEDIMENTATION STYLE AND DEPOSITIONAL PROCESSES

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Abstract

The Silurian rocks in the Kyauktap area comprise seven distinct lithofacies, namely, flat laminated limestone, thin-bedded limestone interbedded with calcareous siltstone, purple phacoidal limestone, whitish grey shale and limestone interbedded unit, medium to thick-bedded limestone interbedded with argillaceous layers, grey phacoidal limestone and Kyauktap graptolite shale. There are nine carbonate microfacies in the Nyaunglwe section, ten microfacies in the Hle Lan section and nine microfacies in the Kyauktap phacoidal section. They are bioclastic rudstone, intraclastic bioclastic packstone, ostracod packstone, ferruginous ostracod packstone, bioclastic wackestone, argillaceous bioclastic wackestone, ferruginous bioclastic wackestone, argillaceous ostracod wackestone, nodular bioclastic wackestone, calcisphere bioclastic wackestone, dolomitized bioclastic wackestone, argillaceous limemudstone, limonitic limemudstone and ferruginous limemudstone. Nyaunglwe section is carbonate dominated unit and Hle Lan section is composed of whitish grey shale and argillaceous limestones in which bioturbated horizons are very common. Kyauktap phacoidal section is entirely grey nodular limestones and it grades into graptolite-bearing grey shales in the southern part of the area. Vertical and lateral variations of the lithofacies and microfacies suggest that the entire Silurian sequence represents a depositional continuum of shallow subtidal, deeper subtidal and slope.

Keywords: Silurian rocks, Kyauktap, Carbonate microfacies

Introduction

The Silurian rock units, comprising both carbonate and siliciclastic rocks, are extensively exposed on the southwestern Shan Plateau, particularly at the Pindaya Range, Bawsaing Range, Taunggyi Range and Loi-lem Range, etc. The present work aims to study sedimentology of the Siurian rocks which are well exposed at the Kyauktap area. The Kyauktap area is demarcated by Lat. 20º 47′ N to 20º 55′ N and Long.96º 45′ E to 96º 48′ E in one-inch

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topographic map no. 93 D/13 in Kalaw township. It is located about 10 miles at the east of Pindaya (Figure 1). It can easily be reached by the car.

Materials and Methods

The petrographic study was based on 130 samples obtained from the three studied sections.

Lithofacies of the Kyauktap Area

There are three measured sections in Kyauktap area from north to south namely Nyaunglwe section, Hle Lan section and Kyauktap phacoidal section in which seven distinct lithofacies can be observed: (1) flat laminated limestone, (2) thin-bedded limestone interbedded with calcareous siltstone, (3) purple phacoidal limestone, (4) whitish shale and limestone interbedded unit, (5) medium to thick-bedded limestone interbedded with argillaceous layers, (6) grey phacoidal limestone and (7) Kyauktap graptolite shales (Figure 2).

Flat laminated limestone

This lithofacies occurs at the Nyaunglwe section, and Hle lan section. The limestone is fine-grained and occurs in thin to massive beds of over ten feet (Figure 2a). Some of them are very hard, resistant and display a step-like appearance. The weathered surfaces are brown or grayish brown and smooth while the fresh surface displays a gray color. A few beds show lamination, and are poorly fossiliferous.

Thin-bedded limestone interbedded with calcareous siltstone

This lithofacies are encountered at the Nyaunglwe section. The limestones appears fine to medium-grained, light to medium gray with thin bedding (Figure 2b). Calcareous siltstone occurs in beds of ½ to 2 inches thick, and thin interbeds are usually consists of limestone. Siltstone beds are hard with blocky fractures, medium gray color where fresh, weathering to light brown color owing to oxidation of pyrite.

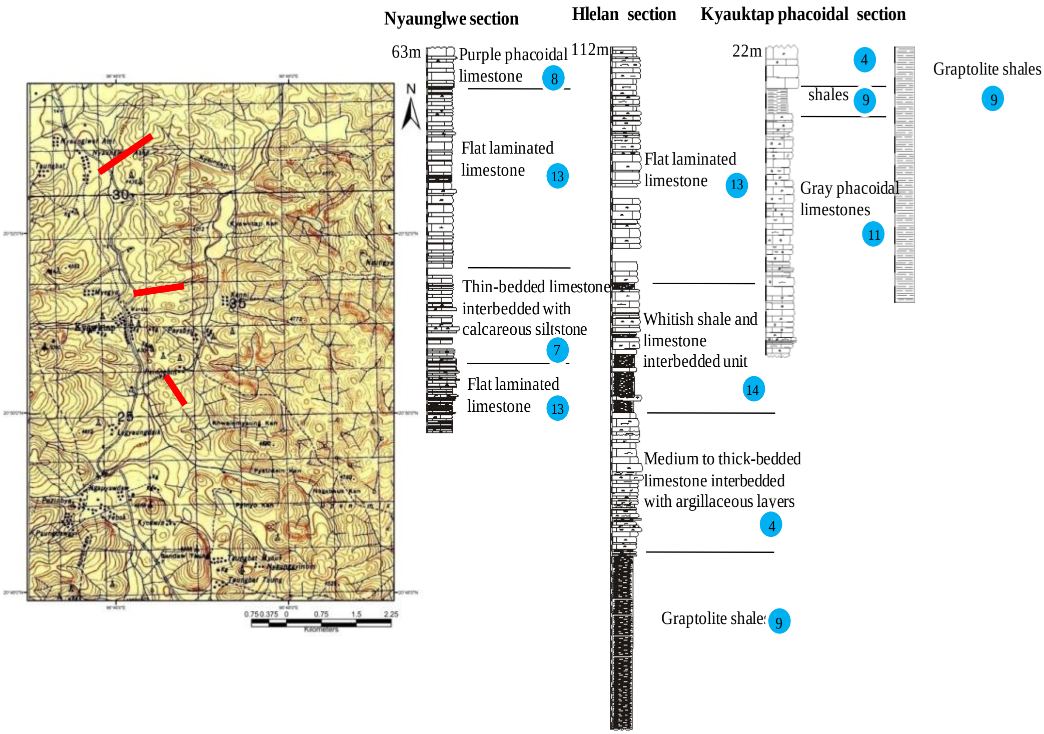


Figure 1: Map showing the locations of sections in the study area

Purple phacoidal limestone

This lithofacies can be observed at the top of the Nyaunglwe section. The limestone is medium grained, indurated, laminated with silt or mud specks showing phacoidal structure, which is aligned to the bedding plane, on the weathered surface (Figure 2c). The fresh surfaces are light to dark reddish brown and reveal a very wide variety of easily identifiable fossils.

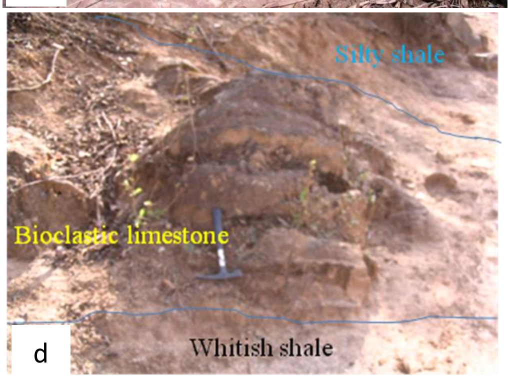


Figure 2: Seven distinct lithofacies of Linwe Formation of the Kyauktap area

(a) Flat laminated limestone

(b) Thin-bedded limestone interbedded with calcareous siltstone

(c) Purple phacoidal limestone

(d) Whitish shale and limestone interbedded

(e) Medium to thick-bedded limestones interbedded with argillaceous layer

(f) Grey phacoidal limestone

(g) Kyauktap graptolite shale

Whitish shale and limestone interbedded units

This lithofacies is encountered at the middle part of Hle Lan section. This medium grained limestone occurs as thin to medium beds which are moderately resistant and fairly fossiliferous (Figure 2d). The shales are up to 4m thick, calcareous, fissile and contain scattered fragments of trilobite.

Medium to thick-bedded limestones interbedded with argillaceous layers

This lithofaies can be observed at the Kyauktap-Hlelan section. This medium-grained limestone occurs as thin to medium beds which are poorly resistant (Figure 2e). The weathered surfaces are light to dark gray or brown. The fresh surfaces are medium gray. The rocks are fairly fossiliferous.

Gray phacoidal limestone

This lithofacies are encountered at the Kyauktap section and is found as medium to massive beds, fairly resistant and very fossiliferous (Figure 2f). The weathered surface is light gray to medium gray and sometimes shows a fretted aspect. The fresh surface is light to dark gray, and displays dark rounded debris in a fine matrix.

Kyauktap graptolite shales

This lithofacies can be observed near Kyauktap Yekan and south of the Kyauktap village. It is more prominent in the southern part of the Kyauktap area. It attains up to 16.5 m thick in this area and extends as lateral facies into nodular limestone facies (Figure 2g). The shale is whitish, bluish gray, buff colored, partially tuffaceous and laminated with subordinate black slates. Many graptolites are present in this shale lithofacies.

Microfacies of the Kyauktap Area

Section measurements are conducted along three different sections in the Kyauktap area namely Nyaunglwe section, Hle Lan section and Kyauktap phacoidal section in which twelve microfacies are encountered (Figure 3).

Bioclastic rudstone

This microfacies is a mud-supported with abundant sand-size scattered organic debris (Figure 3a). The matrix consists of a reddish brown to light gray mosaic of micro-crystalline calcite stained by organic matter and pyrite pigments. The bioclastic material accounts for about 25-30 percent of the slide surface area and some grains show signs of compaction during early diagenesis. Cephalopod shells and trilobites constitute the majority of the larger bioclasts, while smaller particles are made of similar material together with ostracod valves, echnoid and some unidentifiable fragments. Cephalopod shells show some of the oldest preserved primary skeletal aragonite of nearly extinct externally-shelled of cephalopods. Trilobites are a part of a large trilobite fragment showing extinction patterns reflects the orientation of tiny prismatic crystals perpendicular to the carapace wall (Scholle *et al*., 2003).

Interpretation

Cephalopods are a diverse group of highly developed mollusks. Most were nektic creatures with moderate to high mobility; some were benthic, but still mobile, organisms. All modern and ancient forms are interpreted as fully marine. Although cephalopods are found washed into marginal marine settings, they are most common in open shelf and deeper-water deposits (Flugel, 2004). Their remarkable buoyancy controls, propulsion mechanisms, intelligence, and eyesight enabled the cephalopods to be formidable predators throughout their history (Scholle, 2003). In this way cephalopods were washed into open shelf.

Intraclastic bioclastic packestone

This microfacies is a mud-supported intraclastic bioclastic packstone with numerous sand-sized scattered organic fragments in microcrystalline calcite matrix (Figure 3b). Three types of intraclasts are present namely; crinoids, brachiopods and small thin ostracod clast; larger cephalopod with smaller calcified monoaxonic sponge spicules and calcisphers clast and crinoids with thin shell fragment clast. These intraclasts may be reworked because of the appearance of intraclsts outline. Interstitial spaces are filled by fine-grained detrital quartz and locally by void filled crystalline calcite.

Ostracod packstone

This microfacies is a grain-supported fabric with numerous sand-sized thin ostracod valve fitted in the microcrystalline matrix (Figure 3c). Fossil content averages 20 to 50 percent, and consists very largely of ostracods; some specimens consist of almost nothing except ostracods (Folk, 1962). The ostracods usually occur as unbroken and unbraded single valves, but there are some broken but unrounded fragments and some articulated complete shells. Much of the structures of ostracod valve are replaced by chert. Bioclasts are quite susceptible to this type of replacement. The effects of compaction are also noted.

Ferrugenous ostracod packstone

This microfacies is a grain-supported ferruginous ostracod packstone, containing sand-sized twinned ostracod floating in the matrix (Figure 3d). The fauna is very restricted with ostracod valve according for over 60 percent of all particles present. There is a sharp reduction in the frequency of crinoids, brachiopod shells, trilobite fragments and calcispheres. Twinning in ostracod valves usually develops as a result of burial or tectonic stress (Adams & MacKenzie, 1998). Ferrugenous material such as iron oxide, pyrite and limonite alternately are 10-15 percent in the fracture due to effect of compaction.

Bioclastic wackestone

This microfacies is a mud-supported bioclastic wackestone which contains 5-15 percent of sand-sized organic debris floating in a fine-grained matrix (Figure 3e). Angular to subangular fragments of crinoid plates and columnals, brachiopod shells and ostracod valve constitute most of the larger sand-sized particles. The smaller particles are mainly of similar composition, together with calcisphere and bivalve shell fragments. There is a great faunal change within limestone bed horizon with a great decrease in the number of species of brachiopods. Thus, trilobites virtually disappear, appearing again only near the top of limestone bed. Most of the finer fragments of bioclasts set in the red hematitic clay matrix.

Argillaceous ostracod wackestone

This microfacies is a mud-supported argillaceous ostracod wackestone which consists of 10 to 20 percents of ostracod valves and some calcisphere masked in the matrix (Figure 3f). The ostracods usually occur as unbroken and unabraded single valves, but some are broken but unrounded fragments and some articulated complete shells. Ostracod fragments are less conspicuous and are probably obscured by other particles. There is a sharp reduction in the frequency of pelecypod shells, crinoids fragments, brachiopod shells and spines and sponge spicules.

Ferruginous bioclastic wackestone

This microfacies is a mud-supported ferruginous bioclastic wackestone which contains sand-sized organic debris set in a fine-grained matrix (Figure 3g). The bioclastic material accounts for about 10-25 percent of the slide surface area and some grains show traces of abrasion. Crinoids, ostracod valves and brachiopod shells constitute the majority of the larger bioclasts, while smaller particles are made of similar material together with cephalopod fragments and lithic pellets. Some fossils were apparently swiftly deposited with micrite after a strong and sudden current swash, there are many pockets and patches of spar in the 'matrix' adjoin shells.

Dolomitized bioclastic wackestone

This microfacies is a mud-supported dolomitized bioclastic wackestone containing 10-21 percent of sand-sized bioclasts floating in the microcrystalline calcite matrix (Figure 3h). Organic debris are usually scattered in a random fashion throughout the slide surface area. Crinoids arm plates, brachiopod shells and ostracod valves constitute the major bioclasts of this microfacies. The matrix may be crypto- to microcrystalline calcite is now seen as dolomitized micrite. Dolomite seems to have been incapable of attacking fossils, for some very delicate calcitic crinoids and ostracod valve have been unaffected although surrounded on all sides by dolomite which entirely replaces the surrounding micrite. If the surrounding limemud and some bioclast were unstable aragonite, this could be explained, as the calcitic fossils would be more difficult to dolomite (Folk, 1962).

Nodular bioclastic wackestone

This microfacies is a mud-supported nodular bioclastic wackestone with fine-grained matrix (Figure 3i). The bioclastic material accounts for about 15-20 percent of the slide surface area and some grains show signs of abrasion. Ostracods, crinoids and brachiopod shells constitute the majority of the sand-sized bioclasts, while smaller particles are made of similar material together with calcisphere and some unidentifiable fragments. Some shell fragments float in the matrix is also noticed.

Calcisphere bioclastic wackestone

This microfacies is a mud-supported calcisphere bioclastic wackestone in which 10-30 percent of organic material floating in fine-grained matrix. The silt-sized bioclasts are calcisphere, occurring in enormous numbers in some of the limestone beds; there are some concentrations of larger trilobite fragments, and other unidentified fossils. This horizon generally is thin and represents short-lived events relative to the other microfacies of the Linwe Formation.

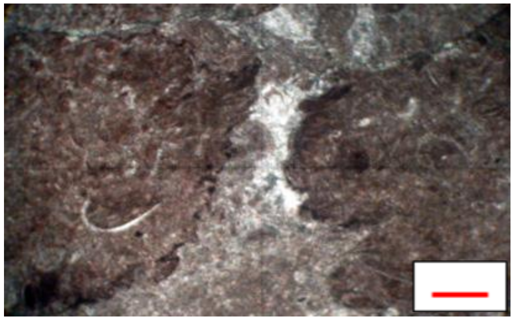
Argillaceous limemudstone

This microfacies is almost pure mud-supported limemudstone with less than 10 percent of organic debris. Organic fragments are limited to central canal of crinoids, small brachiopods shell fragments, and more rarely ostracod valves. The fecal pellets are usually subrounded and small in some slides. The matrix is crypto to microcrystalline, pink to reddish brown calcite, colored by hematite and organic matter. Angular grains of silt-sized quartz are common in this microfacies.

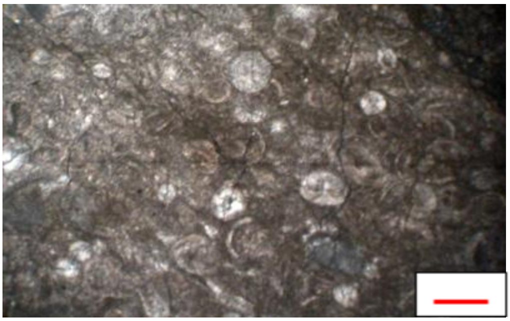
Ferrugenous limemudstone

This microfacies is a mud-supported ferruginous limemudstone with 4-7 percent of the slide surface area and some grains shows sign of abrasion. 10-25 percent of ferruginous material are also noticed in this microfacies. The ferruginous materials are iron-oxide in some slides and limonite or pyrite in other slides. Angular to subangular silt-sized grains of quartz are scattered through the slide surface area. Crinoids and brachiopod shells together with siliceous sponge spicules are major constituent in this microfacies.

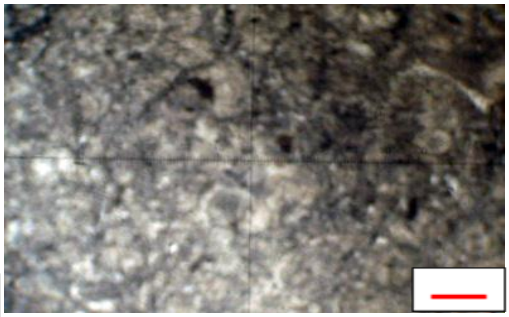
(a) Bioclastic rudstone



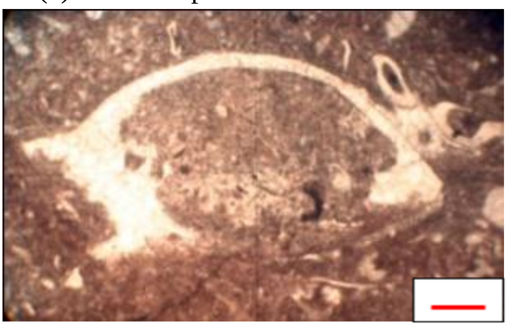
(b) Intraclastic bioclastic packstone



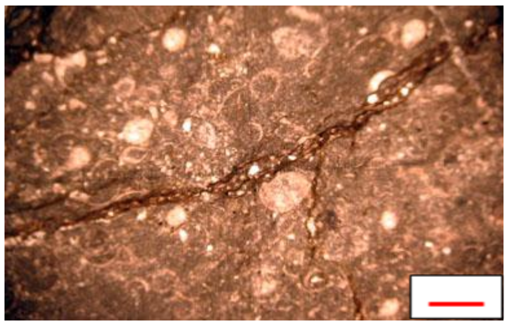
(c) Ostracod packstone



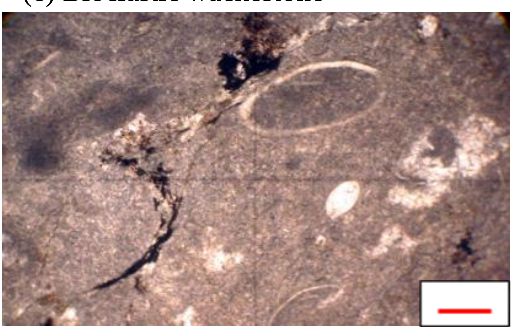
(d) Ferrugenous ostracod packstone



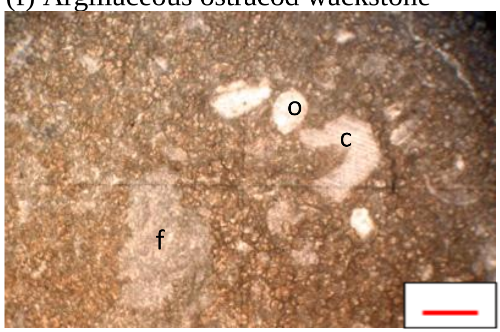
(e) Bioclastic wackestone



(f) Argillaceous ostracod wackstone



(g) Ferrugenous bioclastic wackestone



(h) Dolomitized bioclastic wackestone

Figure 3: (a-h) Microfacies of the Kyauktap area (scale bar = 200 µm)

Results

The limestones from the Kyauktap area comprises Kyauktap graptolite shales, gray phacoidal limestones, some purple phacoidal limestones in Nyaunglwe section, limestones with argillaceous seams and some limestones with pressure solution seams. The regional structural trend of the Kyauktap area is the same as the Linwe-Pegin area, nearly N-S and shale contents are more prominent in the southern part. The bioclastic materials of Kyauktap phacoidal section are more flourished than northern Nyauglwe section. The bioclastic materials are crinoids, trilobites, ostracods, brachiopods, calcisphere, etc. These bioclastic materials are very similar to base section of Wabya Formation. Larger bioclastic fragments can be encountered at some horizon and then smaller fragments of bioclasts are also observed. Gray phacoidal limestones from Kyauktap area are rich in bioclastic materials. Limestones with argillaceous seams are rich in mainly ostracods and some crinoids, and trilobites.

Vertical and lateral facies relationships represent argillaceous and ferruginous materials are alternatives. Among these, Nyaunglwe section which is northern part of study area is more limemud, argillaceous and ferruginous than Hlelan and Kyauktap phacoidal sections. Moreover, ostracoda are more abundant in the northern part. Some horizon is rich in ostracod and others rich in larger bioclastic materials. Three types of iron are present; pyrite, limonite and iron oxides. Typically, subtidal and tidal-flat facies are extensively interbedded through many vertical and lateral transitions. Typical lithofacies are lime mudstone, muddy peloidal packstone and wackestone and bioclastic wackstone (Moore *et al.*, 1983). The Hle Lan section (middle part) in which argillaceous contents are more abundant than ferruginous materials. Moreover, nodular microfacies and bioclastic materials are also more common because of the lower part of this section are interbedded with graptolite shales. The thin bed of calcisphere and larger fragments of trilobite are encountered in one horizon indicates the deposition of sediment under storm condition.

Kyauktap phacoidal section, southern part of study area, is only bioclastic wackestone and limemudstone. Phylloid algae is observed at the lower part of section indicate the deposition in shelf setting. Moreover the reversible nature of calcite and quartz in some horizon seem to indicate sea level fluctuation during deposition. Ferruginous horizon can be observed alternately in the lower part of the section while argillaceous horizon in the upper part. Larger bioclastic materials, brachiopods, crinoids, trilobites and bivalve, are encountered in the lower part of the section that may be the deposition in an open marine during sea-level transgression (Figure 4). The presence of small amounts of replacement dolomite in some limestone horizon indicates that there would have been times of lowered sea level or prolonged droughts the salinity. Intraclasts limestones in the upper part of shale horizon may be deposited in subtidal channals during storms.

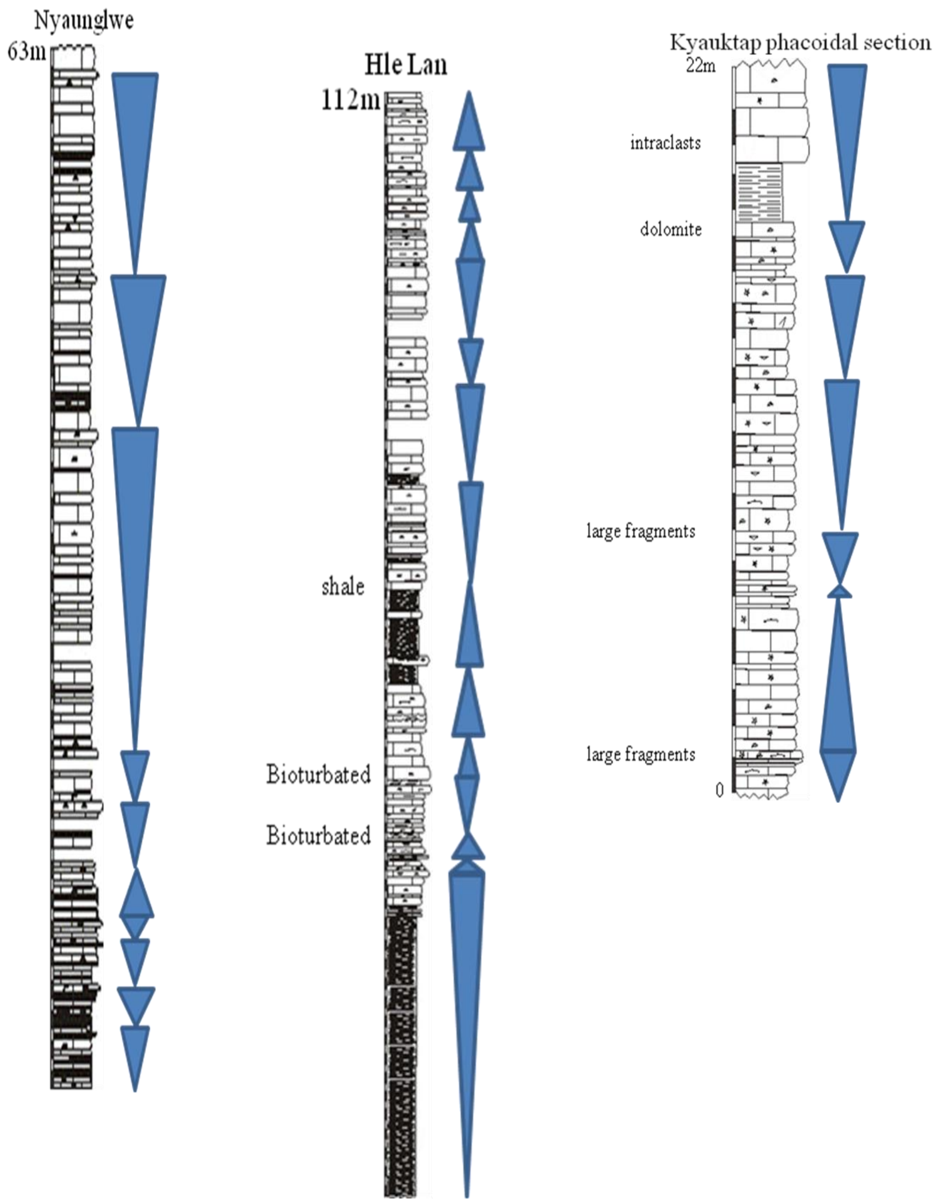


Figure 4: Vertical stacking pattern of deposition in three sections

Discussion

Cephalopods are considered for deposition of these limestones. Most cephalopods were nektic creatures with moderate to high mobility; some were benthic, but still mobile, organisms. All modern and ancient forms are interpreted as fully marine. Although cephalopods are found washed into marginal marine settings, they are most common in open shelf and deeper-water deposits. Purple phacoidal limestones are 2-5m thick sequence that occurred in the upper part of the section and purple colour due to iron-rich in the Naunglwe. Grey phacoidal limestones are normal salinity and 10 to 22 m thick. Thus vertical and lateral variations of the lithofacies and microfacies suggest that the entire Silurian sequence represents a depositional continuum of shallow subtidal, deeper subtidal and slope.

The marine transgression reached its maximum by late Silurian time, and deep water clastic sedimentation became more widespread (Hutchison, 1989). There are two types of transgressions namely slow transgressions and rapid transgressions. The slow transgression associated with internal cycles of carbonate successions which do not interrupt the production of carbonates. The rapid transgressions associated with terminal cycles of carbonate successions which lead to the drowning of carbonate platforms and the change from carbonate to clastic systems. In this way, purple phacoidal limestone is overlained by graptolite shale is the indication of the sediment is overlain by shale and sea-level fluctuations during Silurian time.

Conclusion

The study area is located at the northwestern and southern parts of the Pindaya Range, Shan State (south) in topographic map no. 93C/12 and 93D/9. Five distinct lithofacies and fourteen microfacies in the Linwe-Pegin area and five distinct lithofacies and fourteen microfacies in the Yegyanzin-Wabya area are noticed. The purple phacoidal limestones occur at the base and gray phacoidal to typical nodular limestones occur at the top of the section. Abrupt shift of fossil in some stratigraphic level indicate the environmental control during sedimentation of Silurian sediments. Many of the transgressive surfaces are marked by fossil diversity in measured stratigraphic section.

The crinoidal limestones, phacoidal (nodular) limestones of Linwe Formation and whitish grey shales with many graptolites of Wabya Formation are encountered in Yegyanzin-Wabya area. In addition, the nodular limestones are encountered during Paleozoic (Silurian – Devonian) and Mesozoic (Jurassic – Cretaceous). This is the indication of global sea-level transgression with which nodular forming processes are related. Many of the features related to transgression include the abrupt disappearance of multiple species of graptolites in the shales; cephalopods, trilobites, echinoids, brachiopods, ostracod etc in the limestones; and the abrupt appearance of several new species of these groups.

Acknowledgements

This study was based on my PhD (Thesis). I wish heartedly to thank my supervisor U Myitta, part-time Professor, Department of Geology, University of Yangon, for many of the ideas presented in this work. I am deeply indebted to my co-supervisor Dr. Zaw Win, Prorector, Naypyitaw for giving invaluable suggestions.

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STRATIGRAPHIC PALEONTOLOGY OF THE MIDDLE DEVONIAN UNIT IN HSIPAW AREA, NORTHERN SHAN STATE

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Abstract

The next occurrence of the Middle Devonian Unit which is the equivalent unit of the Pwepon Limestone in Pyinoolwin Township, recognized in the Maymyo Formation, Hsipaw area, northern Shan State. It exposed as an isolated outcrops of only one soil-covered hill which is now seeing as road-cut section near Kontha village. Primary petrographic study indicate that the limestone varies essentially medium- to coarse, locally argillaceous, calcilutite with abundant biogenic debris in the middle part and an intraclastic biogenic calcilutite with fine- to medium-grained in the lower and upper parts. Microstylolites with iron stained argillaceous concentrations and brecciation are developed in places. The fossiliferous unit is laterally passed into dolomite or dolomitic limestone which is regarded as the sandwiched unit of the MaymyoFormation. Initial fossil studies have led to the recognition of rugose, tabulate and brachiopods faunal assemblages. These are solitary rugose corals of *Temnophyllum, Grypophyllum, Macgeea, Cyathophyllum, Acanthophyllum, Dohmophyllum* and abundant colonial rugose corals of *Argutastrea*; tabulate corals of *Alveolites, Coenites, Favosites* and brachiopods of *Spinatrypa*, *Atrypa*, *Desquamatia*, *Strophomena*, *Reticulariopsis*, *Athyris* and *Xystrostrophia*. This coral assemblage is quite similar to Pwepon Limestone but this unit is more argillaceous, fossiliferous, more abundant brachiopods and corals attain larger size. This unit is not previously described in Hsipaw area.

Keywords: Middle Devonian, Hsipaw area, tabulate and rugose corals

Introduction

The study area, located in Hsipaw Township is bounded by north latitude 22°36′48"to 22°42′12" and East Longitude 97°24′to 97°32′20" in UTM map no. 2297 (6 - 10).It is about 5 miles long in the north-south direction and 11.18 miles wide in the east-west direction, approximately covering 55.35 square miles.

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Mandalay–Lashio road runs across the study area from southwest to northeast. It can be accessible by car or train in all seasons. The location map of the study area is shown in Figure (1).

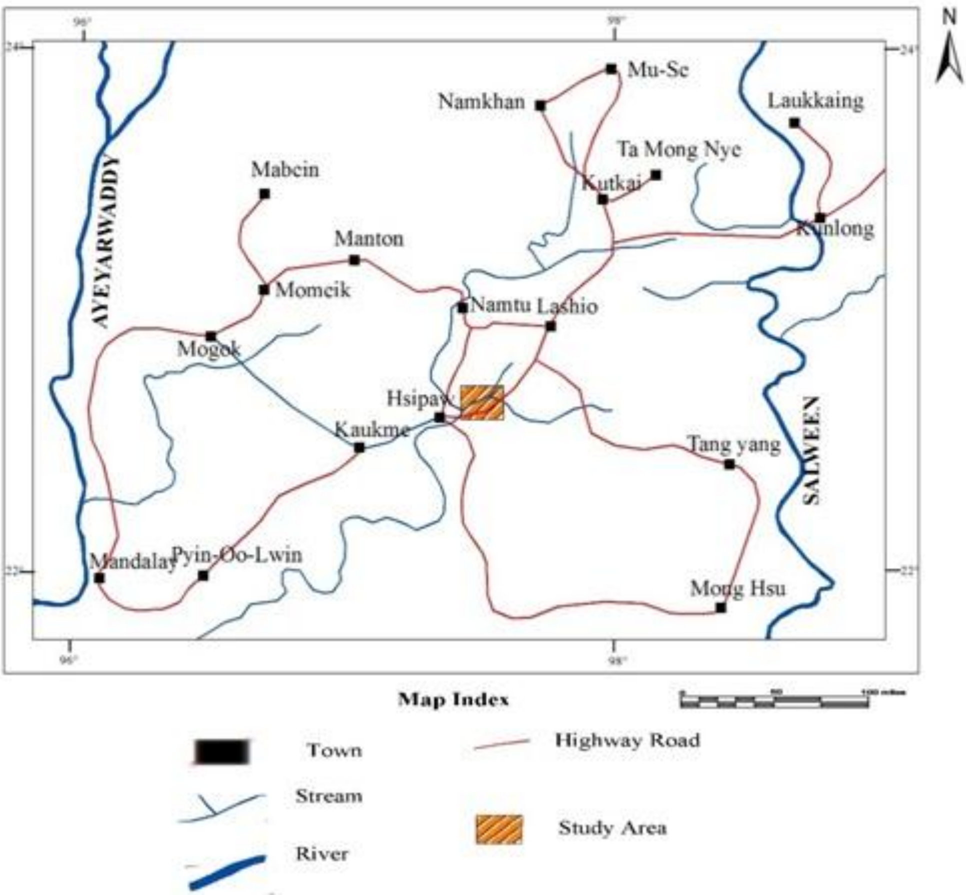

Figure 1: Location map of the study area

Methods of study

Before the field investigations have been carried out, the previous literatures and geological map were studied. The satellite image was used to obtain general nature of geology of the area and the best suitable traverse routes. One inches to 1000 m UTM topographic map is used as a base map. Numerous traverses across the regional structure were measured. The representative samples and diagnostic fossils were systematically collected, properly marked and carefully packed for detailed laboratory investigations.

Representative rock and fossil samples were cut into thin section and these were studied under a polarizing microscopic identification of micro and mega fossils and detailed study to determine the type and age of the rock units. After that, fossils are classified and identified for systematic description.

Previous Works

The numerous works have been done on the geology, stratigraphy and paleontology of nothern Shan State. It is noteworthy that the following critical valuable tasks were carried out in the study area and its environs. La Touche (1913), Pascoe (1959), Brunnshweiler (1970) and Amos (1975) made a regional geology and the Post Silurian geology of Myanmar of the northern Shan State. Local studies are carried out by Khin San (2010) had done the work on the Hsipaw-Bawgyo Area, Northern Shan State for her PhD dissertation and Cho Cho Lwin (2002) & Zin Mg Mg Thein (2002) studied the geology and stratigraphy of the Hsipaw – Bawgyo Area for their M.Sc dissertation.

Result and Discussion

The study area is mainly covered by carbonate and clastic sedimentary rocks of Late Paleozoic to Mesozoic age. There are five lithostratigraphic units of Formation rank;

5. Hsipaw Red Bed (Late Jurassic)
4. Tati Limestone (Middle Jurassic)
3. Nwabangyi Dolomite Formation (Late Permian- Middle Triassic)
2. Plateau Limestone (Early - Middle Permian)
1. Maymyo Formation (Middle Devonian)

Geological map of the study area is shown in Figure (2)**.** The sandwiched unit of the Pwepon Limestone of the Maymyo Formation is described in detailed because this study is mainly emphasized on the fossiliferous Middle Devonian unit.

Stratigraphy of the Middle Devonian Unit

In the study area, Maymyo Formation is the oldest unit of Middle Devonian age.This Formation is well exposed in northeast of San Lau (Apyin), east and southeast of San Lau (Atwin) village, miles post of 164/3 beside the Mandalay-Lashio car road, east of Sang hang village and west of NawngHken village.

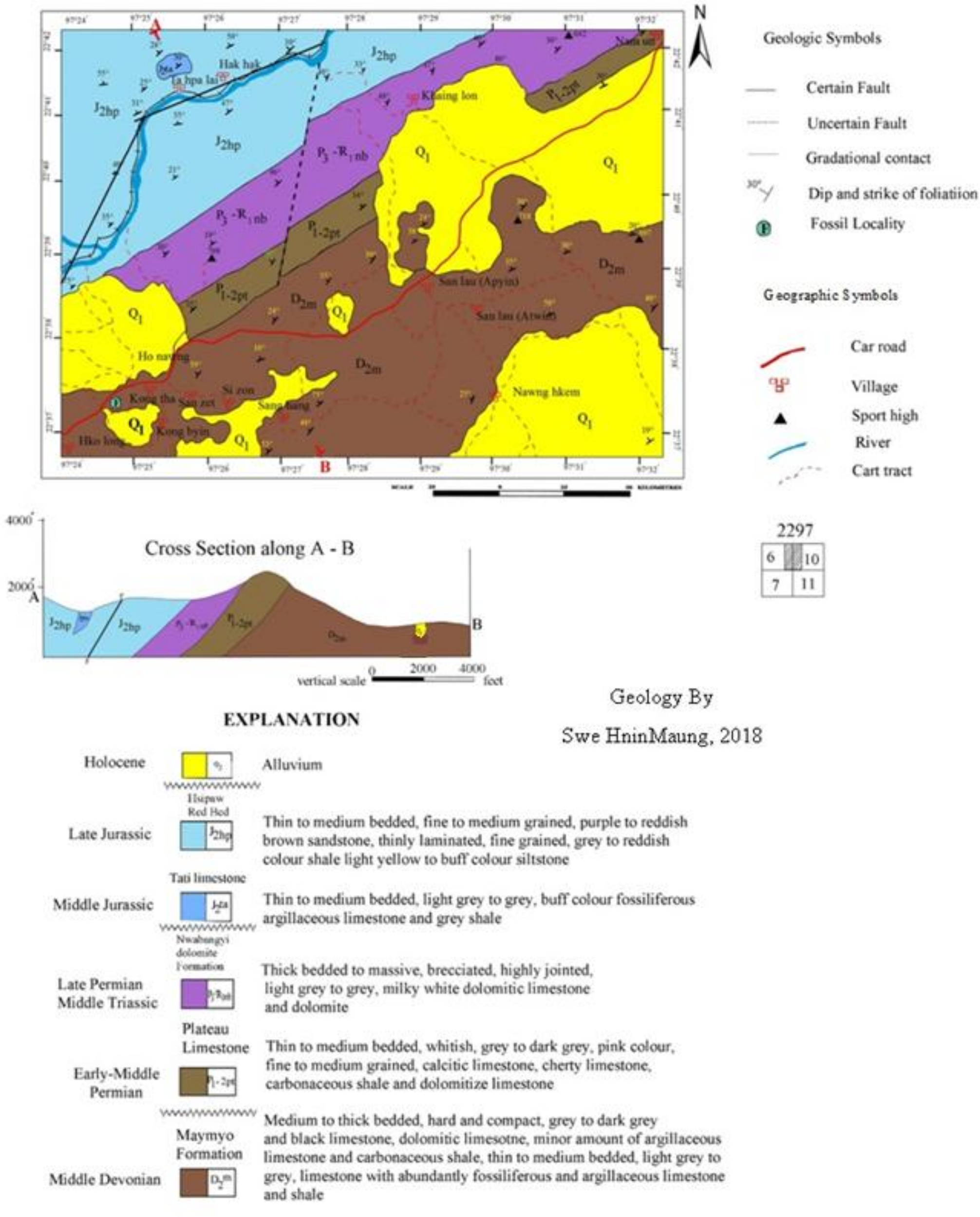

Figure 2: Geological map of the study area

This unit is mainly composed of dolomite, dolomitic limestone and minor amount of argillaceous limestone and carbonaceous shale (Figures.3-8). Thin to medium-bedded, light-grey to grey, limestone and argillaceous limestone with abundantly fossiliferous (rugose and tabulate corals and brachiopods) interbedded with buff-coloured shale and thin-bedded, black limestone unit are sandwiched between the limestone and dolomitic limestone. This sandwiched nature is clearly seen near Aungtheikhtee pagoda, west of Kontha village. This fossiliferous unit is considered as the equivalent unit of the Pwepon Limestone. The contact with the underlying unit cannot be seen because this unit is the oldest unit of the study area. The nature of boundary with the overlying Plateau Limestone is unconformable contact in the study area.

Maymyo Formation is rare in fossils because this Formation is subjected by highly brecciation and intensely dolomitization. But in the study area, gastropods, crinoid stems and corals can be observed in the Pwepon Limestone of the Maymyo Formation. On the basis of stratigraphic position, the lithologic character and the sandwiched unit of fossiliferous Pwepon Limestone is indicating Middle Devonian (Eifelian to Givetian) age.

Figure 3: Medium to thick bedded, light grey to grey, highly brecciated and well jointed dolomite and dolomitic limestone of the lower part of Maymyo Formation (N 22° 39' 24'' and E 97° 28' 56'')

Figure 4: Thick to massive grey to dark gery, highly brecciated and highly jointed dolomite and dolomitic limestone of the lower part of Maymyo Formation.(N 22° 38' 56'' and E 97° 29' 20'')

Figure 5: Iron strained in the bedding plain and joint plainof the dolomitic limestone in lower part of the Maymyo Formation(N 22° 38' 46" and E 97° 26' 25")

Figure 6: Medium to thick bedded, grey to light grey,calcitic limestone intercalated with siltstoneof the upper part of the Maymyo Formation.(N 22° 39' 10" and E 97° 32' 05")

Figure 7: Hard and compact limestone with calcite veins in the Maymyo Formation.(N 22° 38' 16" and E 97° 28' 47")

Figure 8: Calcitic limestone with solution pits on the weathered surface of the Maymyo Formation(N 22° 39' 46" and E 97° 31' 50")

Pwepon Limestone

In the study area, Pwepon Limestone is mainly exposed in the south western part. The best exposures of Pwepon Limestones occur the road cut section at the mile post (156/5) of the Mandalay-Lashio car – road (N22º53'36" and E96º40'50").

The Pwepon Limestone is the sandwiched unit of the Maymyo Formation which laterally passed into dolomite or dolomitic limestone. It is the escaped unit of the dolomitization. It consists of thin- to medium-bedded, buff colour, grey to black, fine- to medium-grained, soft and indurated, limestone, calcareous limestone, argillaceous limestone, carbonaceous shale and grey shale (Figures. 9-18). Where shale or argillaceous materialsis dominated, fossils fragments (Corals and Brachiopods) aremost abundantly occurred and easily extracted from this unit.Detailed description for measured section of the Pwepon Limestone is shown in Table (1). This unit is continuously exposed along Mandalay–Lashiocar road mile post (156/3) and (62) meter in thickness. The biostratigraphic columnar section of the Pwepon Limestone is shown in (Figure 19).

This Limestone is the fossiliferous unit containing a number of rugose and tabulate corals, brachiopods and crinoids. The following fauna are collected from the Pwepon Limestone of the study area; (plates 1-2).

Coelenterata:

Rugosa: *Temnophyllumpyinoolwinensis*.,*Temnophyllumcreber, Temnophyllumminimum,Macgeeabirmanicum, Macgeeabathycalyx, Macgeeaeifeliana, Stringophyllum*sp., *Gurichiphyllum*sp., *Grypophyllum*sp.*, Argutastrea* sp.

Tabulata: *Favositegoldfusi, Alveolitessuborbicularis, Alveolites*aff.*expatiate, Alveolitesillusa Coeniteseschamoides,Alocystisconigera*

Brachiopoda: *Spinatrypa*sp.,*Uncinulus*sp., *Desquamatia*sp. *Reticulariopsiseifiensis, Athyris* sp., *Xystrostrophia*sp, *Strophomena* sp., *Atrypa* sp., *Markitoechia*sp

Table 1: Detailed description for measured section of the Pwepon Limestone (arranged in stratigraphic order)

Unit No.	Lithology (Brief Description)	Thickness (meters)	
		Unit thickness	Total From base
12	Medium- to thick- bedded, light grey to dark grey, calcitic limestoneinterbedded with light grey to grey argillaceous limestone	7	62.2
11	Medium- to thick- bedded, black limestone with calciteveins	4	55.2
10	Medium- to thick- bedded, light grey to dark grey, calcitic limestone interbedded with thin- to medium-bedded, light grey to grey argillaceous limestone	11	51.2
9	Thin- to medium- bedded, milky white, grey to light grey, highly jointed calcitic limestone	5.3	40.2
8	Thin- to medium- bedded, grey to light grey, argillaceous limestone	1.1	34.9
7	Thin- to medium- bedded, light grey to black limestone interbedded with grey to dark grey shale containing corals(*Argutastrea* sp., *Gurichiphyllum* sp., *Alveolites*sp., *Coenites* sp.) and brachiopods (*Markitoechia* ? sp., *Xystrophia sp*.)	9.5	33.8
6	Thin-bedded, blacklimestone interbedded with buff colored shale with corals *(Cyathophyllum*sp., *Temnophyllum*sp, *Macgeea*sp., *Alveolites*sp., and *Coenites* sp.) and brachiopods (S*pinatrypa* sp., *Atrypa*sp., *Reticulariopsiseifiensis*,	5.2	24.3
5	Thin-bedded, grey limestone interbedded with grey shale containing abundant brachiopods (*Strophomena* sp., S*pinatrypa* sp., *Atrypa*sp., *Athyris* sp., *Uncinulus* sp.) and corals (*Macgeea* sp., *Temnophyllum* sp., *Favosites* sp., *Alveolites*sp., and *Coenites* sp.	2	19.1
4	Grey shale containing small brachiopods	1.2	17.1
3	Medium-bedded, light grey to black, hard and compact limestone containing corals with *Stringophyllum* sp., *Grypophyllum* sp.*,* *Alveolites* sp. and *Coenites* sp.	2.3	15.9
2	Thin- to medium bedded, grey to black, argillaceous limestone intercalated with shale containing corals	7.6	13.6
1	Thin- to medium -bedded ,light to dark grey, argillaceous limestone	6	

The occurrence of above faunal assemblage indicates that the age of the Pwepon Limestone in this area can properly be designated as the Middle Devonian (Eifelian to Givetian).

This Limestone can be correlated with the Padaukpin coral reef of La Touche (1913), Padaukpin Biostrome of Anderson (1969), Padaukpin Limestone Member of Aye Ko Aung (1995), Padaukpin Limestone of Khaing Khaing San (2005), Pwepon Limestone of Khaing Khaing San (2005) and Aye Ko Aung (2012).

Figure 9: Medium-bedded, light grey to buff colored shale and argillaceous limestone containing abundanttabulate and rugose corals in the lower part of the Pwepon Limestone (N 22° 37' 45" and E 97° 25' 20")

Figure 10: Well-bedded, argillaceous limestone interbedded with light grey to grey shale containing abundant tabulate and rugose corals in the lower part of the Pwepon Limestone (N 22° 37' 46" and E 97° 25' 22")

Figure 11: Thin to medium bedded, grey to buff colored argillaceous limestone intercalated with shale containing abundant corals and few brachiopods of the lower part of Pwepon Limestone (N 22° 37' 50" and E 97° 25' 24")

Figure 12: Medium to thick bedded, light grey to grey, buff colour highly jointed calcitic limestone of the Pwepon Limestone (N 22° 37' 30" and E 97° 25' 05")

Figure 13: Thin to medium bedded, light grey to buff colour, argillaceous limestone in the middle part of the Pwepon Limestone (N 22° 37' 32" and E 97° 25' 10")

Figure 14: Thin- to medium-bedded, yellowish to buff colour argillaceous limestone intercalated with carbonaceous shale in the middle part of the Pwepon Limestone (N 22° 37' 36" and E 97° 25' 51")

Figure 15: Medium-bedded, dark grey to black carbonaceous limestone intercalated with grey shale in the middle part of the Pwepon Limestone (N 22° 37' 38" and E 97° 25' 19")

Figure 16: Medium- to thick-bedded, grey to buff colored argillaceous limestone and calcitic limestone intercalated with the thinly bedded carbonaceous shale of the upper part of Pwepon Limestone (N 22° 37' 48" and E 97° 25' 29")

Figure 17: Medium- to thick-bedded, grey to dark grey calcareous limestone with abundant calcite veins in the upper part of the Pwepon Limestone (N 22° 37' 41" and E 97° 25' 16")

Figure 18: Medium-bedded, dark grey limestonewith iron stained mud cracks on the bedding plane of the upper most part of the Pwepon Limestone (N 22° 37' 50" and E 97° 25' 41")

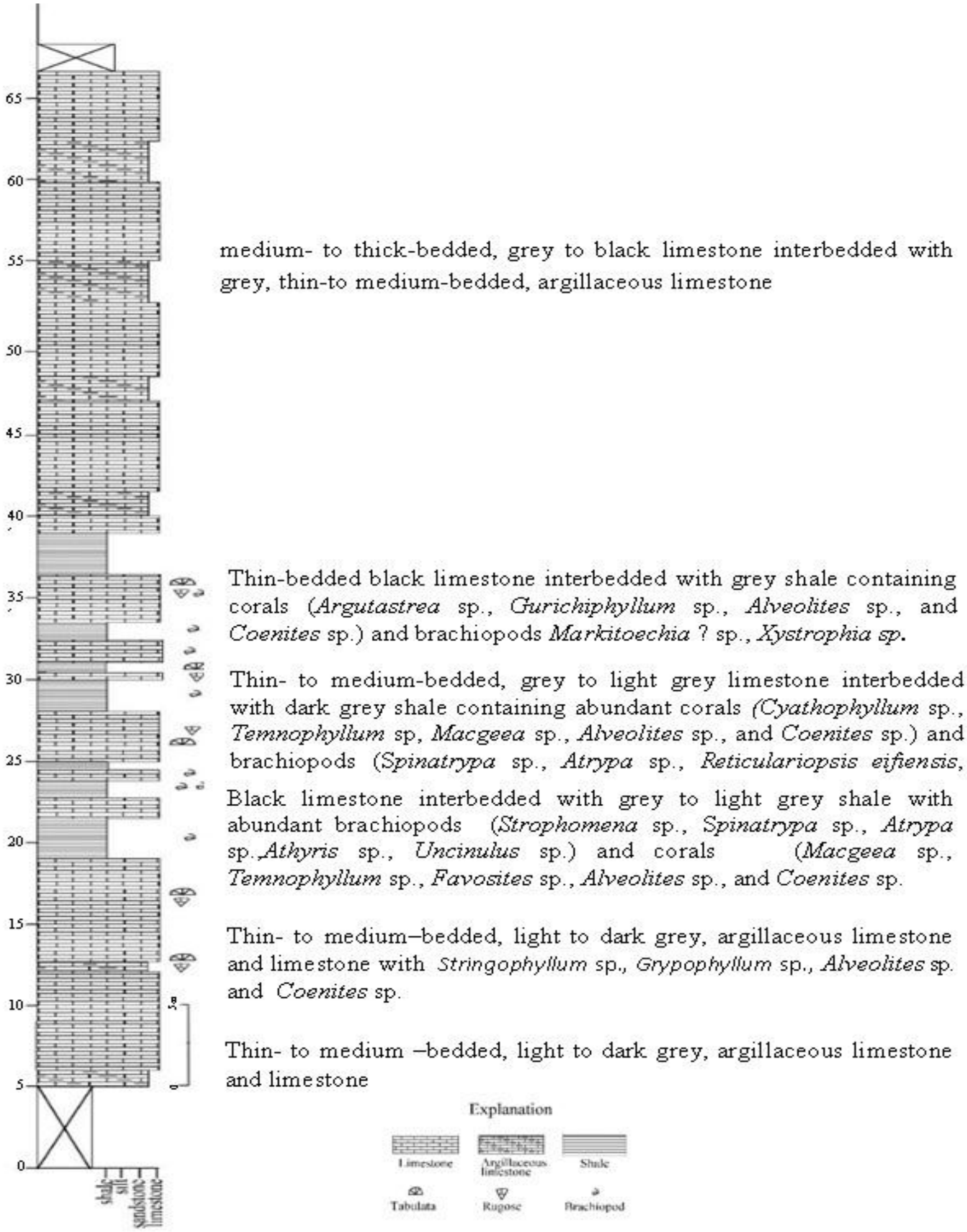

Figure 19: Stratigraphic measured section of the Pwepon Limestone with the occurrence of fossils (mile-post 156/3 furlong) along Mandalay - Lashio Car-road; base at N 22° 37' 28" and E 97° 25' 18"and top at N 22° 37' 48" and E 97° 25' 29".

Plate 1

All corals from Middle Devonian, Pwepon Limestone, Hsipaw, northern Shan State

Figures: a-b.*Macgeea*,s. c-d. *Temnophyllum* sp., e. *Grypophyllum* sp., f. *Cyathophyllum* sp., g. *Stringohyllum*sp., h.*Gurichiphyllum* sp., i. *Argutastrea* sp., j. *Alveolites* sp., k. *Favosites* sp., l. *Coenites* sp., m. *Aulocystic* sp.

Plate 2

All figures from the Middle Devonian, Pwepon Limestone, Hsipaw, northern Shan State

Figure: a. *Strophomena* sp.; b.*Spinatrypa* sp., c.*Atrypa*sp.,d. *Athyris* sp., e. *Markitoechia* ? sp., f. *Xystrophia* sp., g.*Uncinulus* sp., h. *Reticulariopsiseifiensis*, i. *Desquamatia*sp.,j. *Spinatrypa* sp., k. *Desquamatia*sp

Paleontology of the Pwepon Limestone

The Pwepon Limestone is the sandwiched unit of the Maymyo Formation. It is laterally passed into dolomite or dolomitic limestone. The lower most part of the Pwepon Limestone is thin-bedded, light grey argillaceous limestone and thin- to medium-bedded, grey to dark grey limestone with abundant calcite vein. The first occurrences of corals (*Stringophyllum* sp., *Grypophyllum* sp., *Alveolites* sp. and *Coenites* sp.) occurin thin-bedded, light grey to grey argillaceous limestone and limestone. The fossils are abundantly occur in medium-bedded, light grey to black, hard and compact limestone interbedded with grey shale containing abundant brachiopods (*Strophomena* sp., S*pinatrypa* sp., *Atrypa*sp.,*Athyris* sp., *Uncinulus* sp.) and corals (*Macgeea* sp., *Temnophyllum* sp., *Favosites* sp., *Alveolites*sp., and *Coenites* sp.).

The middle part of the Pwepon Limestone is also fossiliferous with corals *(Cyathophyllum*sp., *Temnophyllum*sp, *Macgeea*sp., *Alveolites*sp., and *Coenites* sp.) and brachiopods (S*pinatrypa* sp., *Atrypa*sp., *Reticulariopsiseifiensis*, *Desquamatia*sp.) which occur in thin- to medium-bedded, light grey to grey limestone interbedded with dark grey shale. The abundant colonial rugosecorals of *Argutastrea* sp. andsolitary*Gurichiphyllum* sp., tabulate corals of *Alveolites*sp., and *Coenites* sp.; and brachiopods of *Markitoechia* ? sp., *Xystrophia*sp. occur inthin-bedded, black limestone interbedded with grey shale. The upper most part of the Pwepon Limestone is interbedded unit of limestone and argillaceous limestone containing a few fossil fragments of tabulate corals and small brachiopods.

Age of the Fauna

The Padaukpin fauna designated as Eifelian age by Reed (1908). Anderson *et al*. (1969) described systematically the Padaukpin brachiopod fauna referring to conodont and foraminifera. The Padaukpin fauna has marked affinity with the Eifelian brachiopod fauna of the Western Europe and was regarded to be of Eifelian age. Aye Ko Aung (1995) described some new rugose coral fauna from Padaukpin and Pwepon area which closely resemble with the Eifelian rugose corals of North Queensland and Southern China. Khaing Khaing San (2005) described and illustrated the rugose corals from

Padaukpin and Pwepon Limestones and pointed out that they have close affinities with contemporaneous fauna in Europe, South China and Australia and designated the age of the Padaukpin Limestone as Eifelian. Khin Nyein Chan Thar (2017) also studied the rugose corals from Padaukpin Limestone, Lashioarea and assigned the Middle Devonian. Comparison of the rugose coral fauna occurrence of Padaukpin, Pwepon, Lashio and Hsipaw areas is shown in Table (2).

Table 2: Correlation of the present described genus of Hsipaw area with the previously described Middle Devonian genus of Myanmar.

No.	described rogose corals from Myanmar	Padaukpin area (Khaing Khaing San, 2005)	Pwepon area (Khaing Khaing San, 2005)	Lashio area (Khaing Khaing San *et al*, 2017)	Hsipaw area (Present study)
1	*Calceola*	√		√	
2	*Cystiphylloides*	√			
3	*Puanophyllum*	√	√		
4	*Metrionaxon*		√		
5	*Catactotoechus*	√	√		
6	*Acanthophyllum*		√	√	
7	*Dohmophyllum*		√		
8	*Grypophyllum*		√	√	√
9	*Strigophyllum*	√		√	√
10	*Disphyllum*	√	√		
11	*Argutastrea*		√		√
12	*Spinophyllum*	√			
13	*Temnophyllum*	√	√	√	√
14	*Hexagonaria*		√		
15	*Phillipsastrea*	√	√		
16	*Macgeea*	√	√	√	√
17	*Thamnophyllum*	√			
18	*Heliophyllum*	√			
19	*Cyathophyllum*	√	√	√	√

No.	**described rogose corals from Myanmar**	**Padaukpin area (Khaing Khaing San, 2005)**	**Pwepon area (Khaing Khaing San, 2005)**	**Lashio area (Khaing Khaing San *et al*, 2017)**	**Hsipaw area (Present study)**
20	*Peripaedium*	√	√	√	
21	*Enallophrentis*			√	
22	*Gurichiphyllum*			√	

In this study, brachiopod fauna (*Strophomena* sp., S*pinatrypa*sp., *Atrypa*sp., *Athyris* sp., *Markitoechia* ? sp., *Xystrophia* sp., *Uncinulus* sp., *Reticulariopsiseifiensis*,, *Spinatrypa* sp. and *Desquamatia*sp.) are the same with brachiopods from Padaukpin area described by Anderson *et al*. (1969).

Most of the genus of tabulate corals in this area are long-range. *Favosites* first appear in Upper Ordovician but it ranges to Middle Devonian in Cosmopolitan and Devonian from Myanmar. *Alveolites* and *Coenites* are the occurrence of Silurian to Devonian in Cosmopolitan and Middle Devonian (Eifelian) from Myanmar. *Aulocystis* is the Devonian of N. America, Europe, Asia, Australia and Middle Devonian (Eifelian) from Myanmar.

The rugose corals of *Gurichiphyllum* occur in Middle Devonian-Upper Devonian of Europe and West Australia. The type species of *Gurichiphyllum* is Middle Devonian from Poland, Skaly. *Grypophyllum* is the occurrence of Midddle Devonian from Europe, Asia and Australia and N. America. *Stringophyllum* first appeared in Early Devonian, Europe and also Middle Devonnian in Europe, North Africa and Australia. *Temnophyllum* is the Givetian genus of Europe, but it also observed in Middle Devonian (Eifelian) of Padaukpin Limestone, Myanmar. *Macgeea* is the occurrence of Middle to Late Devonian from Europe, Asia, North America and North Africa. *Macgeeabirmanica* is the Eifelian fauna of the Padaukpin Limestone in Myanmar. *Argutastrea* occurred in Latest Eifelian to Early Givetian in Australia; Eifelian to Givetian in Germany, Myanmar, China; Givetian in France; Givetian to Frasnian in Belgium and Eifelian to Frasnian in USSR (Hill, 1981). Based on the above fauna evidences strongly indicate that the age of the corals from the study area is Middle Devonian (Eifelian to Givetian) and close resemble with South China and Europe.

Conclusion

This study is the new occurrence of the Middle Devonian fossiliferous unit in Hsipaw area, northern Shan State. This unit is previously described as the Nwabangyi Dolomite Formation (Late Permian to Middle Tirassic) and present study is the first to inform the occurrence of Middle Devonian unit in Hsipaw area. The fauna occurrence (corals and brachiopods) of Middle Devonian unit in this area is closely similar with Padaukpin Limestone in Padaukpin area, Pyinoolwin Township except the occurrence of *Grypophyllum, Gurichiphyllum* and colonial rugose coral of *Argustastrea*sp. which are the occurrence of Pwepon Limestone in Kyadwinye area. The fauna of the study area is also similar with Lashio area by the same occurrence of *Grypophyllum*, *Strigophyllum*, *Temnophyllum*, *Macgeea*, C*yathophyllum* and*Gurichiphyllum.* The present study of the stratigraphy and fauna occurrence of rugose corals, tabulate coralsand brachiopods from this Limestone suggest Middle Devonian (Eifelianto Givetian) age and probably to designate the Pwepon Limestone but this unit is more argillaceous, fossiliferous, more abundant brachiopods and corals attain larger size.

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We are greatly indebted to Acting Rector, Dr. Kyaw Tun, Pro-Rectors of Dr. Yaw Han Tun and Dr. HlaHla Tin, Lashio University for their permission to carry out this research work. We greatly appreciate the help of Professor Dr. Marie Coen-Aubert, Belgium for her supporting the literaturesof the corals.

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PERMIAN UNIT EXPOSED IN THE HOPANG AREA, WA SELF-ADMINISTERED DIVISION, NORTHERN SHAN STATE, MYANMAR

Zar Ni Swe[1], Ali Akbar Khan[2], Myo Min[2], Kyi Pyar Aung[3]

Abstract

The investigated area is situated in Hopang Township, Wa Self-Administered Division, northern Shan State, Myanmar. The Plateau Limestone of the study area mainly consisted of medium-to thick-bedded, light grey to grey limestone. Most fossils found are fragmentary; complete fossils are rare or absent. The lithology is not much changed except fossils become more complete than the lower. They contain crinoid stems and unidentifiable shells of gastropod, fragments of bryozoan, *Syringopora,* and solitary corals. It is followed by medium-bedded limestone with more fossil fragments appear in the fusuline horizon composed of gastropods, crinoid stems, corals and a small number of chert nodules. The abundant *Cancellina* species were found in the Hopang limestone. The associating genera include *Pseudofusulina, Parafusulina, Nankinella and Toriyamaia*. The dominance of *Cancellina* and absence of both *Misellina* and *Neoschwagerina* indicate a Kubergandian (Late Kungurian) age.

Keywords: Permian, Plateau Limestone, Fusuline, Hopang

Introduction

Location of the study area

The investigated area is situated in the Hopang Township, 'Wa' Self-Administered Division, northern Shan State. It is located about 156 km NE of Lashio City. Lashio-Chinshwehaw Highway passes through the northern part of the Hopang Area. The Permian unit of the research area is exposed at (23º 24' 03.9''N, 98º 45' 30.7''E) near Hopang City, the eastern part of Thanlwin River or along the road between Hopang to Hpa-lin Mine. The location map of the research area is shown in (Fig.1).

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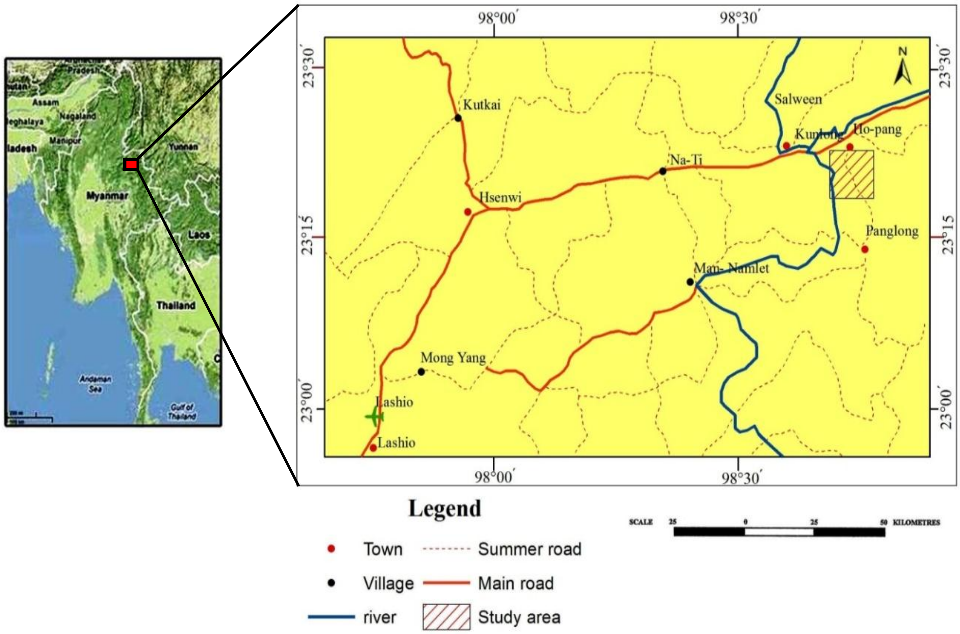

Figure1: Location map of the research area.

Method of Study

A detailed geological field investigation of lithologic contacts, structural trends and fossils locality of the research area was carried out by using a Brunton compass, GPS and data were plotted on the UTM topographic map sheets No.2398 (11,15). Representative samples were cut into thin section and these were studied under a microscope and identification of micro fossils.

Previous Works

The stratigraphic succession of northern Shan State had been investigated and described by Datta (1900), Reed (1906), La Touche (1913), Chhibber (1934), Pascoe (1959), Brunnschweiler (1970), Amos (1975), Garson (1976), Mitchell et al. (1977), IGCP (1980), Bender (1983), Wolfart et al. (1984), Thura Oo et al. (2002) and Aye Ko Aung (2012).

La Touche (1913) carried out the geology of the northern Shan State. Brunnschweiler (1970) described the contributions to the post-Silurian geology of Burma (northern Shan State and Karen State). Amos (1975) mentioned the stratigraphy of some of the upper Paleozoic and Mesozoic carbonate rocks of the Eastern highlands, Burma. Mitchel et al. (1977) also carried out Geology and exploration geochemistry of the Yadanatheingi and Kyaukme-Longtawkno areas, northern Shan State, Burma. IGCP (1980) studied the stratigraphic Committee field excursion in the Maymyo-Yadanatheingi-Hsipaw and Bawdwin areas. Wolfart et al. (1984) documented the stratigraphy of the western Shan Massif, Burma. But the geological investigation of the Hopang area had not been yet detailed.

Regional Geology of the study area

The study area lies in the Shan-Taninthayi Block (Mg Thein, 2014). It is situated in the Shan Plateau which generally trending NNW-SSE direction. This area lies in the northeastern part of the Lashio Basin. Major lineament identified from satellite image of the area is Momeik Fault, trends approximately ENE-WSW in direction. Moreover, the area lies between the Momeik Fault (Nanting) in the north and Lashio Fault in the south. The Hopang area is mainly composed of various lithologic units ranging in age of the pre-Paleozoic to Mesozoic sediments are shown in (Fig.2). Good exposures can be observed along the road cutting side.

They are Precambrian Chaungmagyi Group (near Nan-pi and Pan-kauk Villages), Ordovician Sitha Formation (near Har-phyat Village), Silurian Nyaungbaw Formation (Narzayet-Pangmong car-road), Permo-Triassic Plateau Limestone (Hen-na Village and car-road between Hopang and Hpa-lin mine) and Nwabangyi Dolomite Formation (car road between Hopang to Chushwe, near Naung-san and Hpa-kyut Villages), and Cretaceous Hsipaw Red Bed (Naung-hate and Na-za-yet villages). The porphyritic granite boulders are well exposed along the stream of the eastern part of Thanlwin River (along the Hpa-lin and Chu-shwe). Some metamorphosed limestones are well observed in Hpa-lin mine and Pan-kauk Village.

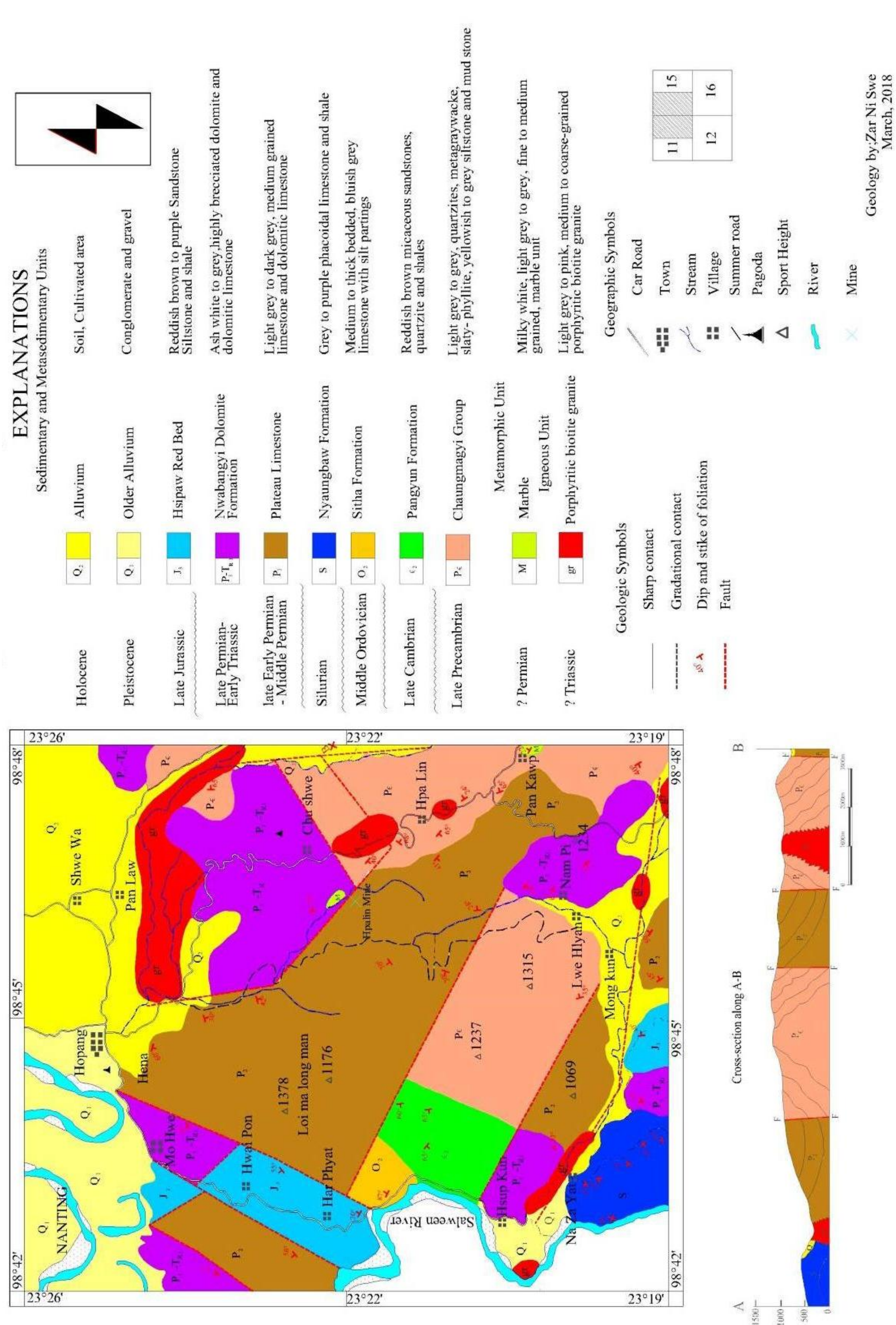

Figure 2:Geological map of the study area, Hopang Township, northern Shan State.

General Geology of the study area

The Permian carbonate sequence of the Eastern Myanmar is part of a widespread stratigraphic unit, which extends through western Thailand into northwestern Malaysia, and through western Yunnan into central Tibet (Thura Oo et al., 2002). From the Myanmar-China frontier area in the northern Shan State, the limestones extend southwards and westwards, through Thipaw (Hsipaw) and Pyin Oo Lwin (Maymyo) Townships into Pindaya Township in the southern Shan State (Thura Oo et al., 2002). Rocks of unbounded Permian age in Myanmar form part of a Late Paleozoic carbonate sequence which has been described as the 'Plateau Limestone' covering the greater part of eastern Myanmar.

Aye Ko Aung (2012) described the Paleozoic stratigraphy of Shan Plateau, Myanmar. He designated the Permian unit of western part of northern Shan State as the 'Tonbo Limestone' and the eastern part of the northern Shan State as 'Plateau Limestone'.

However, the name 'Plateau Limestone' is now preferred to use because of its realistic and more complete description in the study area. The highest peak of Loi ma long man Taung (1378 m) is located in the western part of the study area (Fig.3). Morphology view of the study area is shown in (Fig. 4) and (Fig.5).

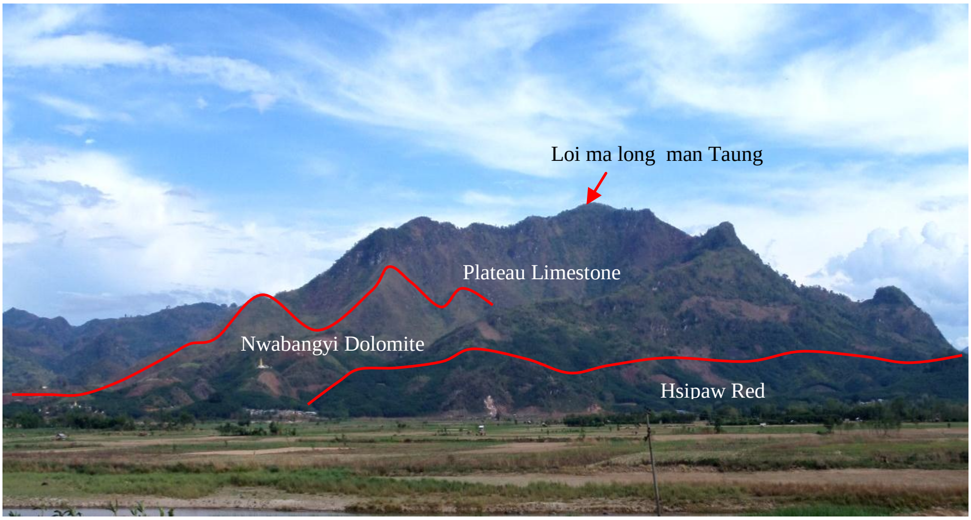

Figure 3: Panoramic view of the study area (looking South-East).

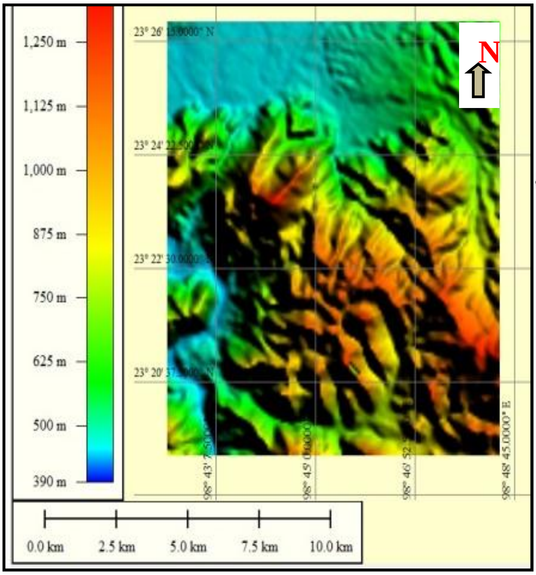

Figure 4: Two dimensional view of the study area. (SRTM image with atlas shader)

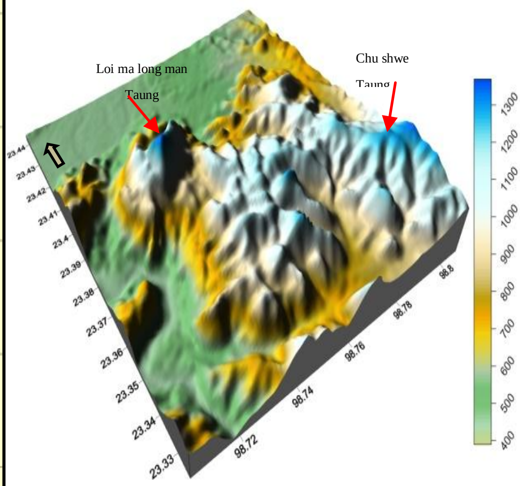

Figure 5: Three dimensional view of the topography of the study area. (SRTM image with atlas shader)

Lithology

The logged section of Plateau Limestone comprises 65 m of exposed strata. Below this, a stratigraphically the lower part of the Plateau Limestone was destroyed during quarry for road construction before it could be investigated. Therefore the lower part of this unit is not exposed in the area. The unit is dominated by light grey to grey, thick-bedded to massive hard and compact limestone. In this part, most fossils found are fragmentary; complete fossils are rare or absent in (MH-1) outcrop.

In the upper part, the lithology is not much changed except fossils become more complete than the lower, containing crinoid stems and unidentifiable shells of gastropod, fragments of bryozoan, syringopora, solitary corals are scattered on the bedding surface of (MH-2) section (Fig.6A). It is followed by medium-to thick-bedded limestone with more prominent fossil band (Fig.7). This limestone with more fossil fragments appears in the fusulinid horizon and consists of gastropods, crinoid stems and corals in (MH-3) section (Fig.6B) and (Fig.8). The small amount of chert nodules occur along the road side between Hopang to Hpa-lin Mine in (MH-4) outcrop (Fig.6C,D).

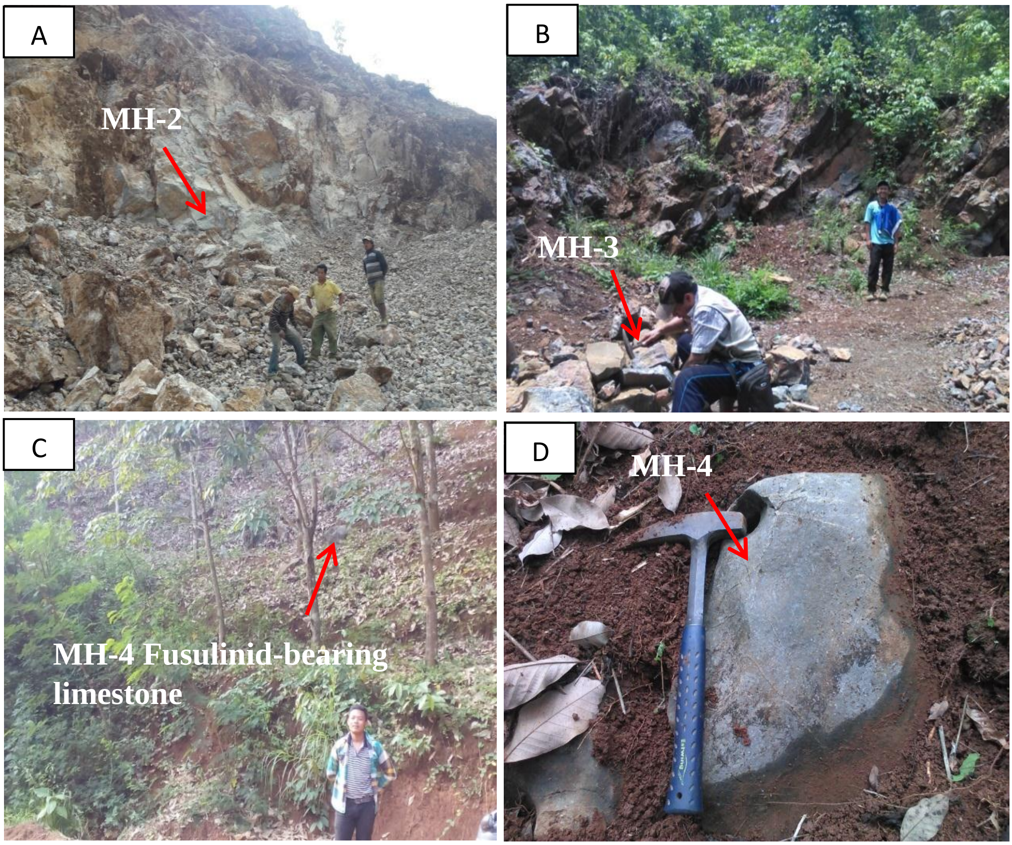

Figure 6: (A) Outcrop nature of the Fossils-bearing Sample MH-2; (B) Outcrop nature of the of Fusulinid-bearing Sample MH-3 (Exsitu sample); (C) Fusulinid-bearing outcrop in the Rubber plantation along the road side between Hopang to Hpa-lin Mine; (D) Close up view of Fusulinid-bearing outcrop. (N 23º 24' 03.9" & E 98º 45' 30.7")

Figure 7: Light grey to dark grey, medium-to thick- bedded fossiliferous limestone showing well bedded nature; view to NE.

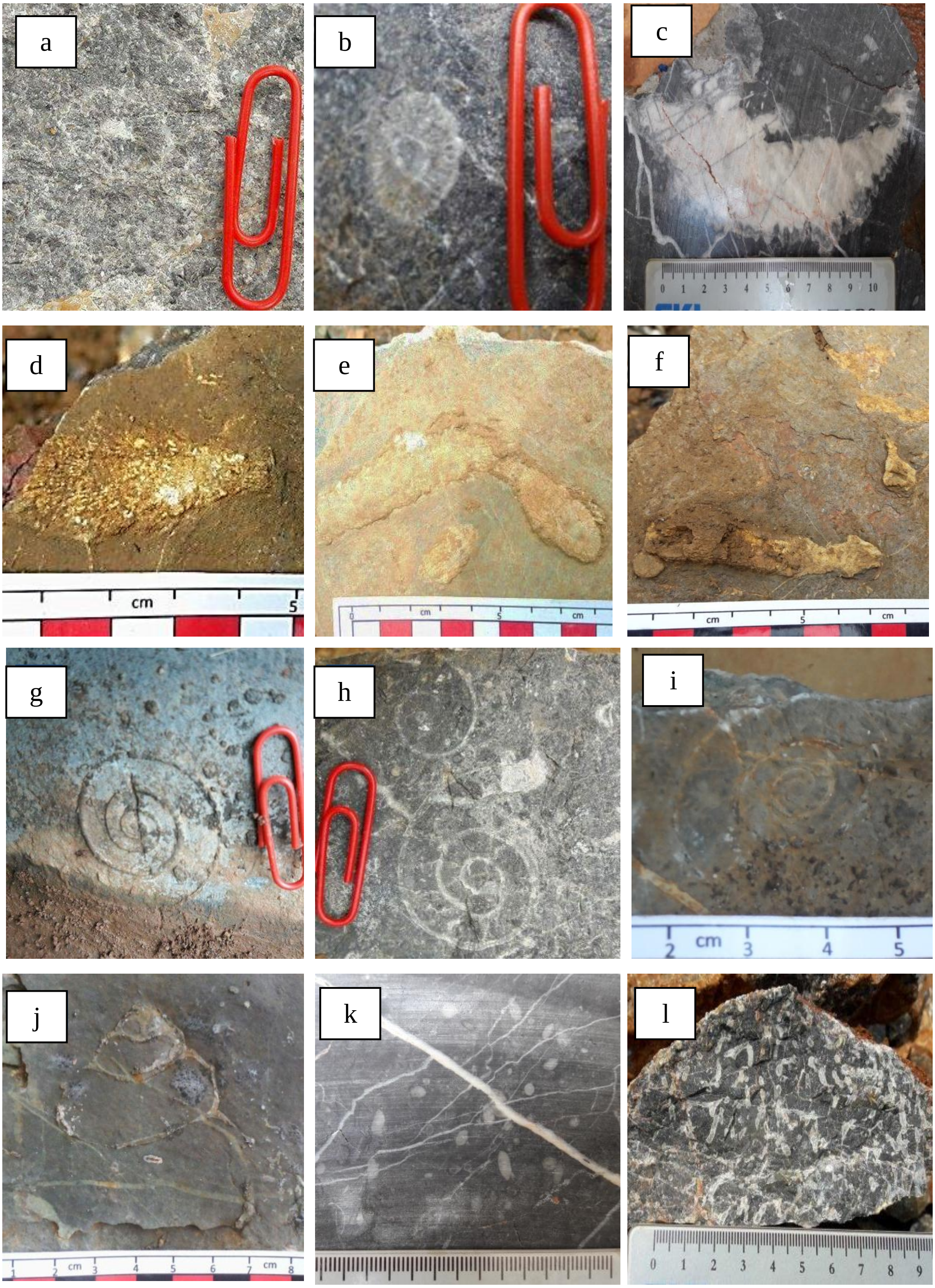

Figure 8: Macrofauna from Plateau Limestone of study area. Figures1-6 Corals. Figures 7-10 Gastrpods. Figure 11 Fusulinids. Figure 12 Syringopora.

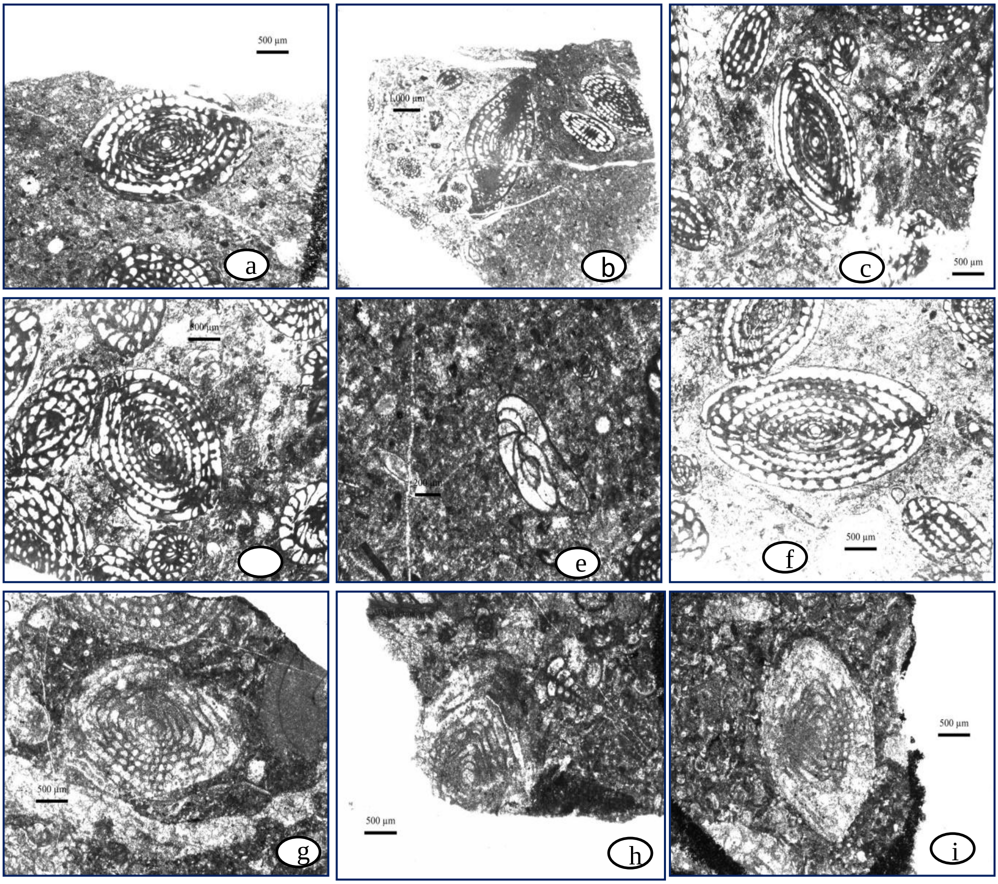

Figure 9: Fossils collected from Plateau Limestone of study area. (N 23° 24′ 03.9″, 98° 45′ 30.7″) Fig.(a) *Cancellina primigena* sp., MH-3. Fig.(b) *Chusenella ellipsoidalis* sp., MH-3. Fig.(c) *Cancellina tobensis* sp., MH-3. Fig.(d) *Cancellina primigena* sp., MH-3. Fig.(e) *Toriyamaia* sp., MH-3. Fig.(f) *Cancellina tobensis* sp., MH-3. . Fig.(g) *Nankinella regularis* sp., MH-4. Fig.(h) *Nankinella regularis* sp., MH-4. Fig.(i) *Nankinella hunanensis* sp., MH-4. Scale bar represents 500μm.

The numerous Permian fauna including *Cancellina primigena* sp., *Chusenella ellipsoidalis* sp., *Cancellina tobensis* sp., *Cancellina primigena* sp., *Toriyamaia* sp., *Nankinella regularis* sp., *Nankinella hunanensis* sp., were found in the Plateau Limestone of Hopang area. The associating genera and dominance of *Cancellina* species indicate Kubergandian (Late Kungurian) age, tethyan type fusulines (Personal communication with Prof. Z.Yichun, 2017) preserved in research area.

According to the stratigraphic position, lithology and faunal assemblages, the Plateau Limestone of study area can be correlated with the Upper Plateau Limestone of (La Touche, 1913), the Tonbo Limestone of the northern Shan State (Brunnschweiler, 1970), Thitsipin Limestone Formation occupies in southern Shan State (Garson et.al., 1976) and Plateau Limestone of Aye Ko Aung (2012).

Conclusion

The Plateau limestone was discovered during conducting a traverse along the road side between Hopang to Hpalin mine site. This limestone section is about 65 m thick consisting of hard and compact, medium to thick-bedded, light grey limestone. In the study area, abundant *Cancellina* species were found in the Permian Plateau limestone. The associating genera include *Pseudofusulina*, *Parafusulina*, *Nankinella* and *Toriyamaia*. The dominance of *Cancellina* and absence of both *Misellina* and *Neoschwagerina* indicate a Kubergandian (Late Kungurian) or (late Early Permian) age. But, this assemblage was not reported from the Shan State of Myanmar, which is a main part of the Sibumasu Block.

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CHARACTERISTICS OF GOLD DEPOSITS FROM MOGOK BELT: CASE STUDIES ON ZAYETKWIN-KWINTHONSE AND PHAYAUNG TAUNG AREAS, MANDALAY REGION, MYANMAR

Aung Tay Zar[1], Win Phyo[2]

Abstract

Mogok Belt is the one of metallogenic province in Myanmar. This belt has two sub-belts such as Mogok Metamorphic Belt and Slate Belt. Along these two sub-belts, gold deposits are difference characteristics and features. Zayetkwin-Kwinthonse gold deposit from Mogok Metamorphic Belt is mainly hosted in marble unit as fracture-filling vein with silicification, sericitization and propylitization alteration. Gold occurs in quartz vein as disseminated specks in pyrite, sphalerite and galena. The diagnostic quartz vein textures, coexistence of vapor-rich and liquid-rich fluid inclusions and the presence of adularia and calcite in the vein mineralogy are distinct characteristics features. In place, fluid inclusion homogenization temperature '*Th*' and salinity from Zayetkwin-Kwinthonse deposit are 159-315°C and 0.88-12.51 wt%NaCl equivalent respectively. Alternatively, Phayaung Taung gold deposit from Slate Belt is hosted in phyllite, schist and quartzite. The mineralization is associated with stockwork quartz vein system. Wall-rocks silicic alteration by cryptocrystalline quartz or amorphous silica is dominant; phyllic alteration is expressed by sericite, quartz, chlorite and pyrite with disseminated hematite. Gold occurs as small spots in tourmaline-quartz vein and sulfide bearing quartz vein. It is associated with pyrite and chalcopyrite as well as Au-Ag-Bi-Te ore assemblages. Fluid inclusion homogenization '*Th*' in quartz fall within the range of 234-426°C and salinities ranging from 0.35-8.41 wt%NaCl equivalent. In fact, Zayetkwin-Kwinthonse gold deposit represents the epithermal expression whereas Phayaung Taung gold deposit shows typical mesothermal characters.

***Keywords*:** Mogok Belt, Mogok Metamorphic Belt, Slate Belt

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Introduction

Myanmar is rich in natural resources and largest country in mainland of Southeast Asia. Mineralization in Myanmar is basically related with tectonic events of subduction, collision and other related processes such as faulting and accretion. Recently, primary gold deposits are extracted from porphyry, epithermal, mesothermal (orogenic) and local skarn types. Mogok Belt (Searle and Haq, 1964) is one of prominent metallogenic and geological province in Myanmar, along this belt variety of mineral deposits are observed including gold-silver, tin-tungsten and precious stones of ruby and sapphire. Basically, primary gold deposits along Mogok Belt are inferred as orogenic gold (Mitchell et al., 2004) but it would belong epithermal and locally skarn gold deposits. Mogok Belt is divided into two sub-units; Mogok Metamorphic Belts and Slate Belt. Gold mineralization from both of sub-units are possessed different characteristics features. In this paper, authors describe the regional tectonic setting, deposit geology and characteristics of gold deposits from these sub-units of Mogok Belt where we selected one deposit from each sub-units: 'Zayetkwin-Kwinthonse gold deposit' from Mogok Metamorphic Belt and 'Phayaung Taung gold deposit' from Slate Belt.

Research Methods

This research paper writing has been done through various steps such as studying literatures, field works and laboratory analyses. Actually, there is very few previous research and publication related to gold mineralization of Mogok Belt. Moreover, no one is focused the comparison and studying difference characteristics of gold mineralization from sub-units of Mogok Belt. Some of publications related with gold mineralization from Mogok Belt such as Mitchell et al., (1999 & 2004) and Cho Cho Aye and Ye Myint Swe (2014) were reviewed at the beginning of this research. Subsequently, altered rock samples and mineralization ore samples were collected and conducted for petrology study by microscopy and X-ray diffraction (XRD). In place, the kind of ore minerals and their chemical composition were measured by scanning electron microscope with energy dispersive X-ray (SEM-EDX). Furthermore, quartz veins samples from different generation were prepared for fluid inclusion study and conducted by LinkanSG600 combined heating and freezing stage. All of these laboratory analyses were performed at Department of Earth Resource Engineering, Mineral Resource lab and Center for Advanced Instrumental Analysis, Kyushu University, Japan.

Regional Tectonic Setting

Myanmar region is composed with micro plates such as (1) the India plate to the west, (2) Burma microplate (West Burma) in central part and (3) Shan-Thai block (Sibumasu) east of the Sagaing Fault (Figure 1). These plates are created to Myanmar landform by Mesozoic-Cenozoic subduction and collision of a series of plates during the closing of Tethys Ocean. The collision of Sibumasu terrane with Indochina at late Triassic describes the closure of Paleo-Tethys (Wakita and Metcalfe, 2008; Sone and Metcalfe, 2008; Metcalfe, 2002. The collision suture observed along through western Thailand and central Malaysia (Sone and Metcalfe, 2008; Hutchison, 1973). Sibumasu terrane can be split into two distinct geological provinces in Myanmar such as Shan Plateau in east and Mogok Belt to the west (Gardiner, 2015). Mogok Belt is one of the distinct geological suture zone and metallogenic province in Myanmar which located between Central low-land (West Burma) and Shan-Thai block (Sibumasu). It is believed that southern continuation of Himalaya (Searle and Haq, 1964) and formed by collision (Mitchell, 1979) of India plate (the later closure of Neo-Tethys). In fact, the suture of Neo-Tethys extends from the Himalayas south through western Myanmar 'Mt. Victoria Belt'(Mitchell, 1979) and link up with Andaman Island and Wolya suture zone in Sumatra (Barber and Crow, 2009). In place, Mogok Belt is shifted to recent place relatively northwards motion of the India plate (including West Burma microplate) by Neogene strike-slip movement (Metcalfe, 2009), along the major right lateral Sagaing Fault (Win Swe, 1972). The Mogok Belt can be subdivided into two sub-units; 'Slate Belt' (Mitchell et al., 2004) eastern part of Mogok Belt and 'Mogok Metamorphic Belt' (Searle and Haq, 1964) western part of Mogok Belt (Figure 3). The Slate Belt is generally N-S direction from Mandalay to lower Myanmar till Myeik and composed of Carboniferous to early Permian interbedded slaty mudstone and pebbly wack, with rare quartzite and calcareous beds (Mitchell et al., 2012). Locally low-grade metamorphic rocks of schists and phyllite are also observed. Alternatively, Mogok Metamorphic

Belt is composed of Paleozoic to Mesozoic, high-temperature Kyanite-sillimanite grade metamorphic rocks dominated by meta-carbonate rocks of phlogopite- and diopside- marble but peletic rocks of gneiss, schist and quartzite are also observed occasionally. Moreover, a variety of I-type and S-type two-mica granite (Cretaceous-Paleogene) are intruded into Mogok Belt (Gardiner et al., 2015; Mitchell et al., 2012; Barley et al., 2003). I-type granitoids in Mogok Belt (Cretaceous to early Eocene) confirmed that prior to collision of India. This was followed by emplacement of syenites and leucogranite (S-type) between 35 and 23 Ma (Eocene-Oligocene) after initial collision of India and Eurasia (Barley et al., 2003). In place, Slate Belt hosted S-type granites are associated with tin-tungsten mineralization (Gardiner et al., 2015; Khin Zaw, 1990). This S-type granites from Slate Belt represent a northward extension of Central Granitoid Belt of Myanmar (Khin Zaw, 1990). With regard to Mogok Metamorphic Belt, another igneous activity is biotite granite (Kabaing granite) which emplaced by process of faulting and overthrusting in Miocene (Bertrand et al., 2001). Kabaing granite is the youngest as emplacement time and set at post tectonism.

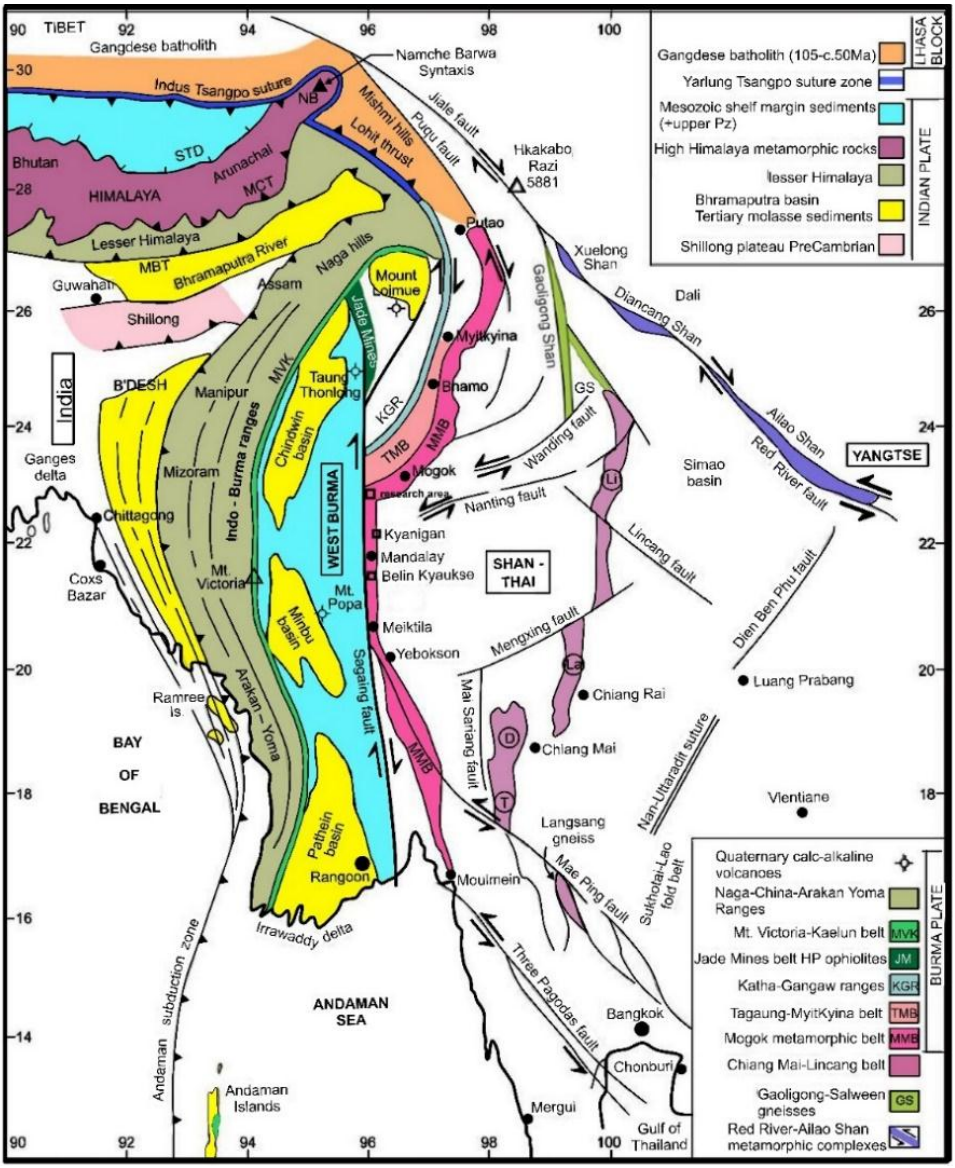

Figure 1: Regional Geological Map of Myanmar showing the principal tectonic units. (Searle et al., 2007)

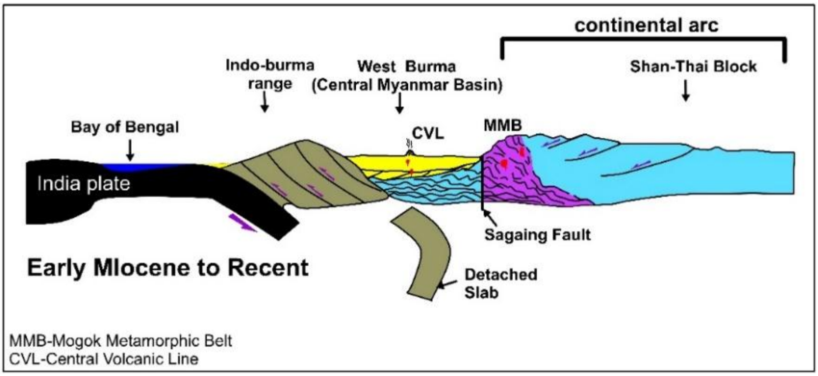

Figure 2: Principal tectonic units and their tectonic evolution setting of Myanmar (modify after G.I.A.C)

Gold Mineralization from Mogok Belt

According to tectonic emplacement, Mogok Belt is sited on continental arc setting "Fig. 2". Normally, continental arc setting are location of primary porphyry, epithermal and localized skarn gold deposits (Mitchell et al., 1999). Moreover, it would be hosted mesothermal (orogenic) gold deposits because Mogok Belt is a part of Himalayan orogeny that related with collision process of India and Eurasia plate. Generally, Gold deposits from Mogok Belt are considered as orogenic-type (mesothermal) gold deposit (Mitchell et al., 1999) but epithermal and locally skarn gold deposits could be observed. In Slate Belt (eastern part of Mogok Belt), gold mineralization has been recognized at numerous localities(Mitchell et al., 1999) such as Moditaung, Shwekyin, Meyongyi and Phayaungtaung. Mineralization occurred within quartz-pyrite stringer and veinlets whereas gold mineralization are not really associated with Cretaceous-Eocene granite intrusions, mineralization predates granite intrusions (Mitchell et al., 2004). Otherwise, gold deposits along Mogok Metamorphic Belt (western part of Mogok Belt) such as Zayetkwin-Kwinthonse, Thabeikkyin-5mile and Nweyon are mostly hosted in marble and associated with the intrusion of Createaceous I-type granite (Gardiner et al., 2015). Mineralization veins are observed as fracture filling veins and occasionally disseminated in marble where gold are associated with base metal sulfides. Some of gold deposits from Mogok Belt are shown in figure "Fig. 3".

Deposit Geology of Zayetkwin-Kwinthonse Area

Zayetkwin-Kwinthonse area is belonged by Mogok Metamorphic Belt, composed with metamorphic rocks of marble, gneiss and calc-silicate rocks where meta-carbonate rocks of marble and calc-silicate rocks (Upper Paleozoic to Mesozoic) are unconformably overlain by older gneiss unit (Lower Paleozoic). A variety of igneous rocks such as leucogranite, syenite and biotite granite (Kabaing granite) are intruded to older metamorphic rocks. The well-known N-S trending Sagaing Fault serves as western margin of research area. Interpretative NE-SW trending faults from research area are relatively parallel to the foliation of metamorphic rocks. It is probably related with Sagaing Fault system. Mineralization is hosted in marble unit and occasionally observed in gneiss which apparently acts as mineralization-hosting fracture/shear zones. Petrographically, meta-carbonate rocks are abundantly composed with calcite, phlogopite and diopsite where tremolite and diopside are common in marbles near the stocks. Small amount of actinolite, forsterite, apatite, epidote and sericite are also observed. Diopside calc-silicate occurs along the margin of igneous intrusion. The contact of intrusion is nearly parallel to the strike of this unit. Therefore, both of regional and contact metamorphism are happened in this area. Based on mineral assemblages of metamorphic rocks, it is considered that the metamorphism of research area is characterized into greenschist to upper amphibolite facies (Winkler, 1979). The geological map of Zayetkwin-Kwinthonse area is shown in Figure (4).

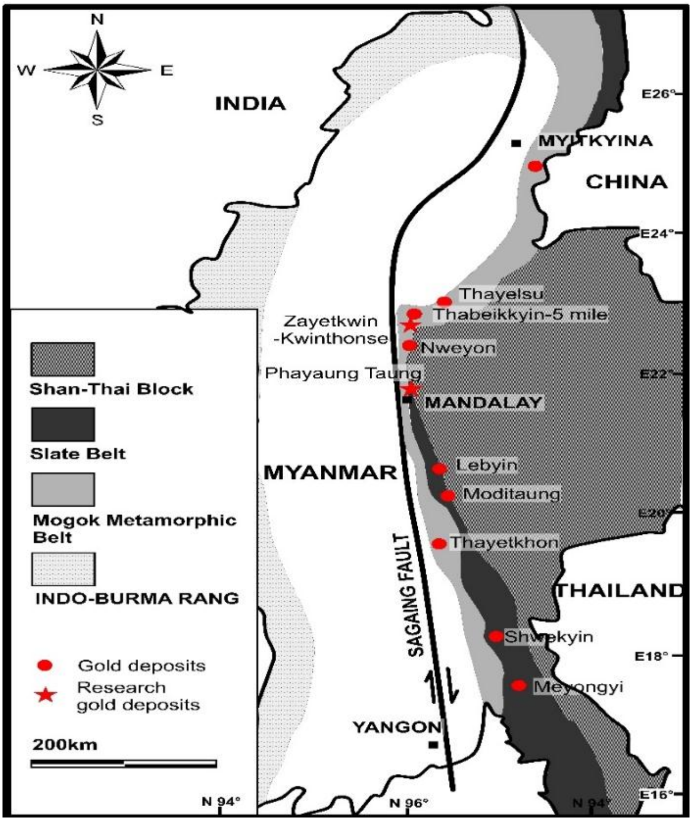

Figure 3: Some of gold deposits along Mogok Metamorphic Belt and Slate Belt

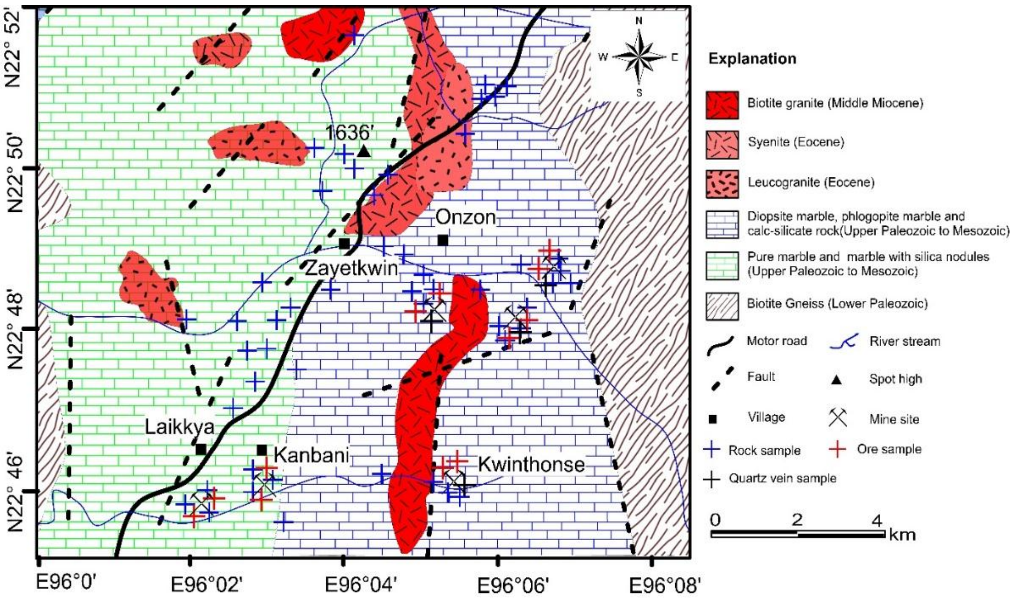

Figure 4: Simply geological map of Zayetkwin-Kwinthonse area (modify after Thein et al., 1990)

Mineralization and Ore Mineralogy

Zayetkwin-Kwinthonse area is a part of Mogok Metamorphic Belt where gold mineralization veins are mostly hosted in marbles and occasionally observed in gneiss as fracture filling veins related with fracture and shear zones. Occasionally, disseminated nature of mineralization also developed in marble. This is probably due to interaction of hydrothermal fluid and wall-rock 'marbles'. In fact, vein trends are followed the regional structural controls, mostly NE-SW in direction with steep slope (Dip= 55° to nearly vertical)where the width of veins are 0.5 to 3 meters (Figure 5). A variety of quartz vein textures such as banded, crustiform, bladed calcite, lattice, comb and cockade are observed in mineralization quartz veins especially in shallow depth of mineralization quartz veins. Banded vein nature is a common characteristic of both quartz vein and quartz carbonate vein 'Fig. 5". Banded quartz–calcite± adularia veins are also found in marble unit. In this case, gold bearing quartz veins are observed at shallow level fracture zone. Occasionally, fissure filled visible gold are observed in quartz vein.

Alteration halos are observed around the hydrothermal fracture-filling veins as laterally outgoing such as silicification, sericitization, and propylitization. Silica occurs as cryptocrystalline groundmass as well as openspace filling in vugs and veinlets. Moreover, chalcedony and amorphous silica are observed locally along the fractures. Adularia are also frequently observed as banded nature as well as cavity filling in mineralization veins.Beside silicification, narrow zone of sericitization is observed where fine-grained sericite are widely spread like dusty. But in deeper portion, this alteration zone is not developed. Propylitization zone is the outermost zone of alteration halos. In fact, some parts of propylitic alteration are not really related with hydrothermal alteration, prior to the ore deposit. It is the product of regional metamorphism (Evans, 1987) and overlapped with hydrothermal alteration.

The common ore minerals in mineralization are pyrite, galena, sphalerite, chalcopyrite, marcasite and minor arsenopyrite, native gold and electrum. Sometime more than 30% of base metal sulfides are observed in mineralization veins. Pyrite is observed as most common sulfide.In place, native gold are observed in base metal quartz-carbonate veins as fine-grained specks (< 100 µm in size) within pyrite, galena and sphalerite. Otherwise, large grained electrum (< 100 µm in size) are associated with quartz gangue and ore minerals pyrite and sphalerite in gold bearing quartz vein (Figure 6).

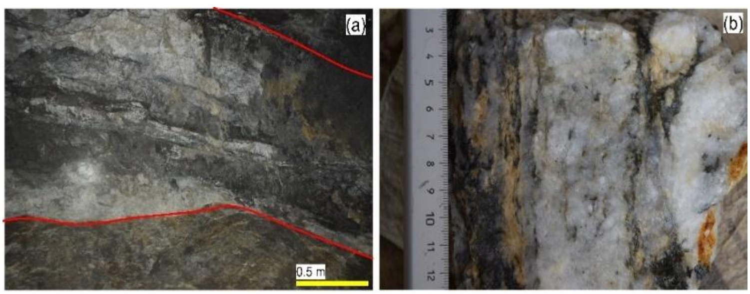

Figure 5: Photos showing fracture filling banded quartz vein(quartz-calcite ± adularia)

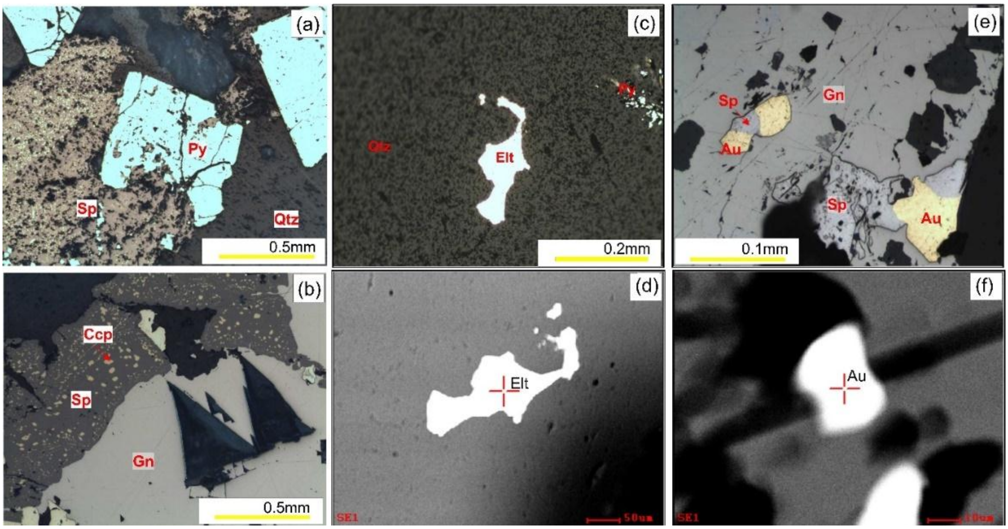

Figure 6: Photomicrographs showing (a) Euhedral pyrite (Py) replaced by sphalerite (Sp), (b) Galena (Gn) with triangular pits nature and chalcopyrite (Ccp) specks in sphalerite (Sp), (c & d) large electrum (Elt) grains in gold bearing quartz vein, and (e & f) fine grained native gold (Au) specks in base metals quartz carbonate vein.

Fluid inclusions study and interpretation

Seven of quartz vein samples were conducted for fluid inclusion study where four from quartz vein and three from quartz-carbonate vein. According to fluid inclusion petrography, there are three types of fluid inclusions are categorized based on their phase relation (1) Two-phase liquid-rich inclusion, (2) Two-phase coexisting liquid-rich and vapor-rich inclusions, and (3) Two-phase vapor-rich inclusions (Aung Tay Zar et al., 2017)(Figure 7). Most of fluid inclusions are observed in growth zones as individual inclusions or small clusters with dispersed arrays. The size range is 5 to 50 µm. In fact, two-phase fluid inclusions with coexisting liquid-rich and vapor-rich inclusions in samples are indicated that inclusions are trapped in boiling or immiscible fluid system (Bodnar, 1993). Moreover, only vapor-rich fluid inclusions are also indicator of boiling in hydrothermal system. This vapor-rich fluid inclusions assemblage indicates the intense boiling or flashing condition (Moncada et al., 2012). The temperature ranges of homogenization (*Th*) and salinity of fluid are 159 to 315°C and 0.88 to 12.73 wt% NaCl equivalent respectively. In place, salinity of fluid inclusions were calculated from (*Tm*) by using Bodnar's equation (Bodnar, 1993). According to Bodnar et al. (1985), the formation temperature of vein refers to the first peak of histogram distribution of *Th* under boiling condition. Therefore, the formation temperature of quartz vein and quartz carbonate vein are 165°C and 175 °C respectively. The formation temperature (first peak of *Th*) and salinity differences between gold bearing quartz vein and base metal quartz-carbonate vein are not too much different (Figure 8) and (Table1). It means both of these two veins are properly the same generation of vein system. A compilation of homogenization temperature (*Th*) and salinity from Zayetkwin-Kwinthonse deposit is displayed that fluid inclusions with the wide range variation of salinities and homogenization temperature. In place, the trend of increasing salinity with decrease temperature indicates boiling condition. Moreover, fluid mixing also could be happen by adding or mixing with a more or less saline solutions. On the other side, the ranges of homogenization temperature and salinity of fluid inclusions from Zayetkwin-Kwinthonse deposit are assigned to epithermal system (Figure 9).

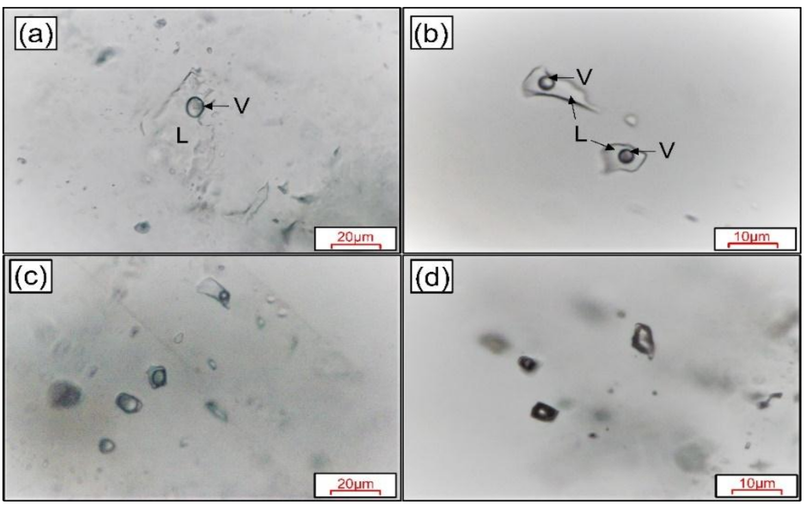

Figure 7: (a) Giant primary two-phase fluid inclusion with negative shapes, (b) two-phase fluid inclusion with consistent liquid-vapor ratio, (c) two-phase coexisting liquid-rich and vapor-rich fluid inclusion, and (d) two-phase vapor-rich fluid inclusion from Zayetkwin-Kwinthonse deposit

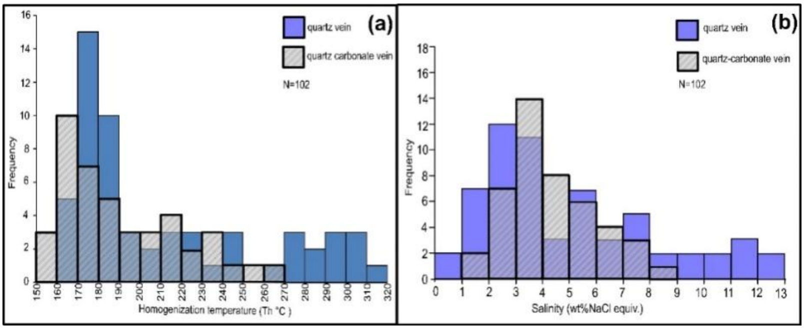

Figure 8: Histograms showing (a) homogenization temperature *Th* (°C), and (b) salinity (wt%NaCl equiv.) of fluid inclusion from Zayetkwin-Kwinthonse deposit

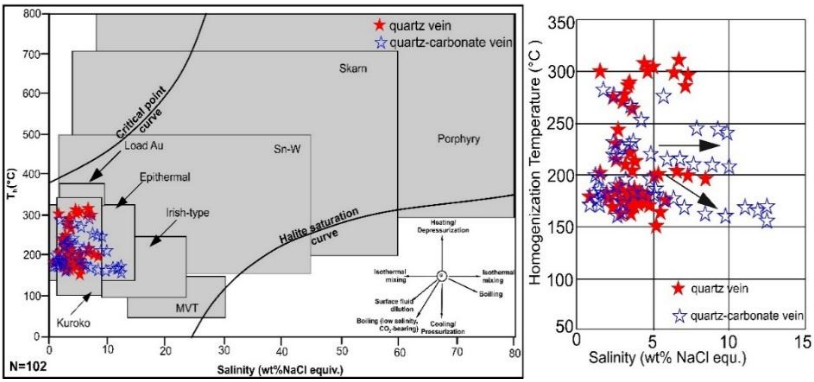

Figure 9: Homogenization temperature (*Th*)-Salinity diagram illustrating typical range for fluid inclusions from different deposit types (Wilkinson, 2001). Stars are microthermometric result of fluid inclusions from Zayetkwin-Kwinthonse deposit where *Th*-salinity space due to various fluid evolution process.

Table 1: Fluid inclusion microthermometric data of selected samples from Zayetkwin-Kwinthonse deposit

Sample ID	Vein type	Inclusion type	Homogenization Temperature (°C)	Ice melting Temperature (°C)	Salinity (wt%NaCl eqiv.)
GF-1VA, 1VB, GY-2 and 7	Quartz vein	L+V	168-315	-0.5 to -5.5	0.88-8.55
GK-F, 3, 9	Quartz-carbonate vein	L+V	159-267	-0.5 to -8.9	0.88-12.73

Deposit Geology of Phayaung Taung Area

Phayaung Taung area is the northernmost extension of the Slate Belt which is mainly composed by metasedimentary rocks such as phyllite, schist, quartzite and slightly metamorphosed limestone (Figure 10). Western part of this area is an eastern flank of Mogok Metamorphic Belt (Paleozoic to Mesozoic), consisting of mica schist and calc-silicate rock where small bodies of diorite and pegmatite intruded to mica schist. The Chaungmagyi Group (Precambrian age) occupies about half part of the research area and mainly composed with quartzite, phyllite and slate. Upper Plateau limestone of bluish grey to dark grey limestone (Carboniferous- Permian) is unconformably overlain by older Chaungmagyi Group. Gold mineralization is mainly hosted in quartzite and phyllite of the Changmagyi Group which are strongly deformed and brecciated. In fact, these rocks might be consist of interbedded sandstone and shale or mudstone beds in paleo-stratigraphy that were metamorphosed to recent metamorphic rocks during regional metamorphism. Recently, the thickness of hosted rocks ranged from 0.15 to 3 m. Phyllite, quartzite and schist were composed of low to medium grade temperature and metamorphic index minerals such as chlorite, epidote, muscovite, biotite and minor amount of garnet, staurolite and silliminite. These minerals indicate low to medium grade temperature as greenschist to amphibolite facies condition. According to deposit profile, mineralization might be related orogeny because of strong compressional and transpressional (shear) environment were clearly developed. Generally, mineralization vein trend is NE-SW in direction.

Beside the veins cut by post-mineralized E-W structures as well as normal and reverse faulting. Therefore, mineralization is strongly controlled by structures.

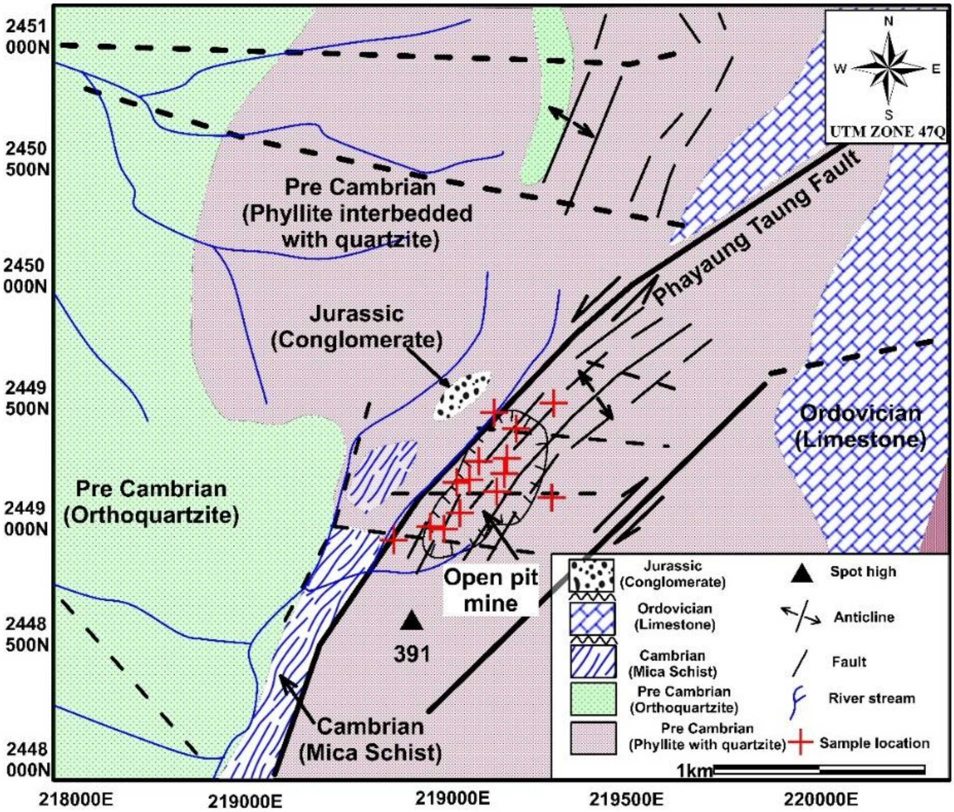

Figure 10: Geological map of Phayaung Taung gold deposit (modify after Htay et al., 1991)

Mineralization and Ore Mineralogy

The vein system of Phayaung Taung gold deposit is complicated and difficult to identify due to the strongly deformed, brecciated, and sometimes cutting by faults. The gold mineralization occurred within quartz-pyrite stringer and quartz vein/veinlets (1cm to 0.15m) which are filled along the NE-SW structural lineaments of dilational fault zone and brecciated zone. The main auriferous zones is about nearly 20 m wide and 100 m long. Two generations of vein are categorized based on structural cross-cutting and mineral content: first generation quartz vein (± black tourmaline) and late generation of disseminated sulfide (pyrite and chalcopyrite) quartz vein (Figure 11). Generally, mineralized tourmaline bearing quartz veins in the hosted rock could be seen clearly but sulfide bearing quartz veins were a rare case to find. However, it was found some kind of visible sulfides such as pyrite and chalcopyrite on the wall of some places in open pit mine. Moreover, secondary remobilized veins are frequently occurred in strongly brecciated/oxidized zone with higher Au content. It can suggest that intense supergene oxidation extend to quite depth of vein system. Mostly, vein structures are like veinlet and stringer which forming stockwork as well as some laminated nature with tourmaline. The vein mineral quartz is well developed as elongate blocky crystal/ fibrous texture in tourmaline bearing quartz vein. Moreover, the lateral breakdown of wall rock to accommodate rapidly growing crystals are observed in sulfide quartz vein. Mosaic, feathery and comb quartz textures are also observed together with open spaces filled pyrite aggregates. Boiling diagnostic vein textures of lattice, bladed, crustiform and colloform textures are absent in quartz vein.

Within and alongside the mineralized brecciated-zone, destruction of primary minerals and the wall-rock textures is incomplete. Generally, wall-rock silicic alteration by cryptocrystalline quartz or amorphous silica is dominant. In place, phyllic alteration is expressed by sericite, quartz, chlorite and pyrite with disseminated hematite. Plagioclase feldspar from bleached and silicified wall-rocks are altered to white mica (sericite) and chlorite with finely crystalline quartz. The white mica is disseminated in chlorite groundmass of strongly deformed phyllitic wall-rock which is district as micro fold texture. Fine-brecciated with disseminated calcite and pyrite next to micro-cracks filled with Fe-oxide. In outermost alteration, the original texture of host rocks has been preserved and still have to phenocryst phases. In place, white mica (sericite) and biotite flakes are partially to chlorite.

Gold occurs as small spots in tourmaline bearing quartz vein as well as sulfide bearing quartz vein in which it is associated with sulfides (pyrite and chalcopyrite) and Au-Ag-Bi-Te ore assemblages of petzite, hessite and tellurobismuth (Figure 12). Scanning electron microscopy with energy-dispersive X-ray (SEM-EDX) analyses revealed the average gold content of electrum grains, it is 75.1 at% Au and grains size range from 3-40μm. Moreover, secondary formed native gold grains were formed with hematite and iron oxides in secondary remobilized/deformed veins at strongly brecciated/oxidized zone. The association of gold and altered sulphides are suggested that gold was refractory in sulphides. It can regard that supergene oxidation extend to quite depth of mineralization veins. The Au content of such gold grains has the highest Au content; it has often almost pure condition.

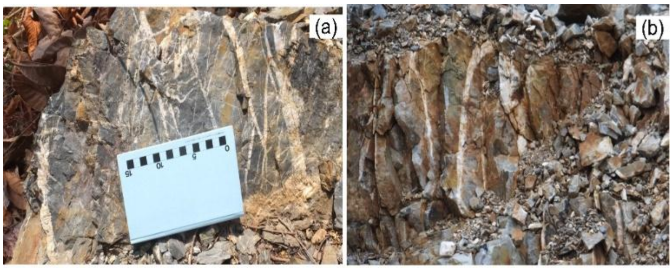

Figure 11: Photos showing (a) stockworks auriferous quartz veinlet and (b) tourmaline bearing gold- quartz veinlet

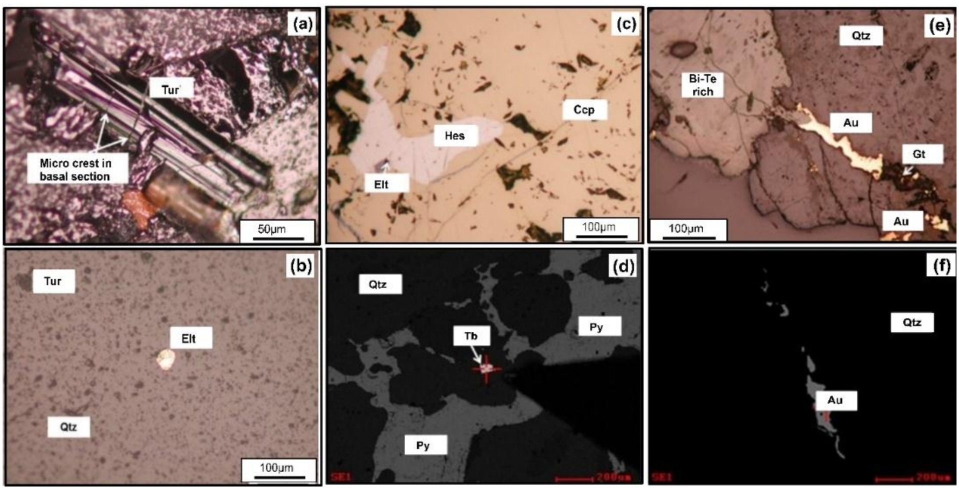

Figure 12: Photomicrographs showing (a & b) small electrum spot in tourmaline bearing quartz vein, (c & d)sulphide minerals from sulphide bearing quartz vein, and (e & f) remobilized large grains native gold in oxidized vein (Qtz=quartz, Tur=tourmaline, Au=native gold, Elt=electrum, Py=pyrite, Ccp=chalcopyrite, Hes=hessite, Tb=tellurobismuth, Bi=bismuth, Te=tellurite)

Fluid inclusions study and interpretation

A total of 4 quartz vein samples from different generation were prepared and conducted to fluid inclusion study. Basically, there are two phase fluid inclusions (liquid+vapor) are observed in both tourmaline bearing quartz veins (early stage) and sulfide bearing quartz veins (late stage) at room temperature (Figure 13). Mostly, fluid inclusions are small in size 4 to 7 µm with sub-rounded shape. The homogenization occurred into liquid dominant two-phase fluid inclusions varies from 234 to 426°C and temperatures of ice melting range between -0.2 to -5.4°C. In place, corresponding salinity range of fluid inclusions is 0.35 to 8.41wt.% NaCl equivalent [24]. The homogenization temperature of the first generation (early stage) tourmaline bearing quartz vein varies from 292-426°C. This temperature range is higher than second generation of sulfide bearing quartz vein (234-332°) but salinity ranges is not too much differences (Table 2). In nature, the second generation (late stage) of sulfide bearing quartz veins that cross-cut the first generation veins and have higher gold content. The *Th* and salinity diagram for these two generation veins is indicated that the first generation vein of tourmaline bearing quartz vein underwent 'an isothermal mixing with slightly variation salinity fluid'. Alternatively, the late generation vein is properly formed by boiling and mixing with cool low saline meteoric water. Despite the lack of fluid boiling evidence, abundant occurrence of muscovite and illite assemblage within the proximal alteration zones suggest that boiling has happen in hydrothermal system of Phayaung Taung. Therefore, we assumed the formation temperature of quartz veins as the first peaks of homogenization temperature histograms where tourmaline bearing quartz vein (370°C) and sulfide bearing quartz vein (270°C) respectively (Figure 14). In order to homogenization temperature and low to moderate saline fluid, it was possibly responsible for the development of gold ore that indicates of hydrothermal activities in mesothermal system (Figure 15).

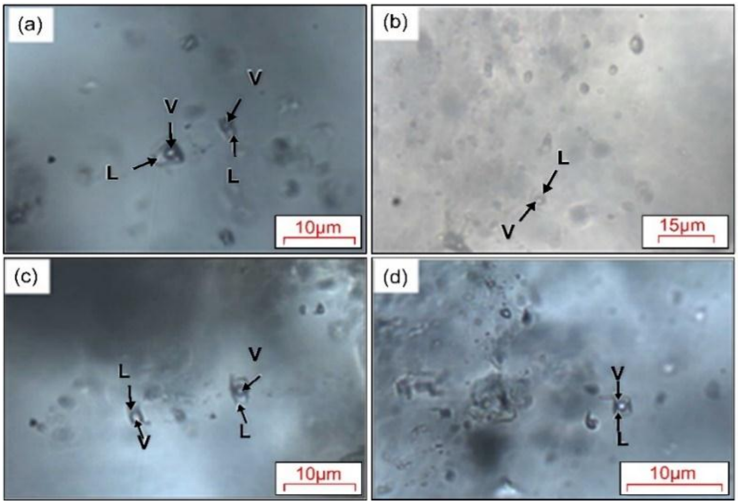

Figure 13: Photomicrographs showing two-phase fluid inclusions from Phayaung Taung deposit

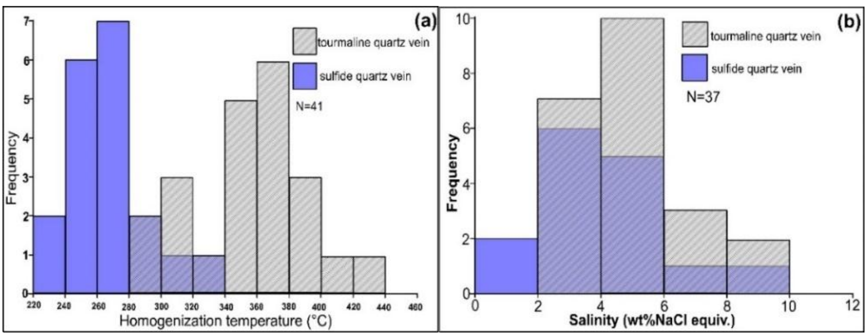

Figure 14: Histograms showing (a) homogenization temperature *Th* (°C), and (b) salinity (wt%NaCl equiv.) of fluid inclusions from Phayaung Taung deposit

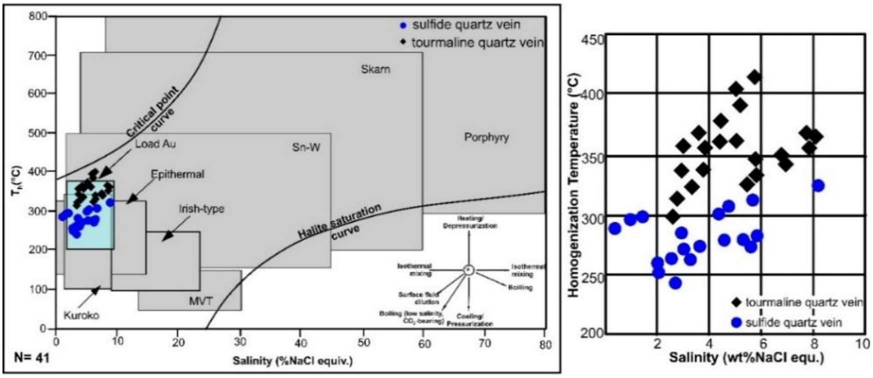

Figure 15: Homogenization temperature (*Th*)-Salinity diagram illustrating typical range for fluid inclusions from different deposit types (Wilkinson, 2001). Circles and diamonds are microthermometric result of fluid inclusions from Phayaung Taung deposit where *Th*-salinity space due to various fluid evolution process.

Table 2: Fluid inclusion microthermometric data of selected samples from Phayaung Taung deposit

Sample ID	Vein type	Inclusion type	Homogenization Temperature (°C)	Ice melting Temperature (°C)	Salinity (wt%NaCl eqiv.)
PYT Q-7,10	Sulfide quartz	L+V	234-332	-0.2 to -5.4	0.35-8.41
PYT Q-2,3	Tourmaline quartz	L+V	292-426	-2.1 to -5.3	3.55-8.28

Discussion

Although the gold deposits from Mogok Belt are considered as mesothermal (orogenic) deposits, its sub-units of Mogok Metamorphic Belt and Slate Belts have different characteristics in gold deposits. Gold mineralization from both of subunits are generally influenced by regional structural controls of faults and fractures. In place, mineralization veins from Zayetkwin-Kwinthonse gold deposit (Mogok Metamorphic Belt) are observed as fracture filling with numerous quartz vein textures. Some of vein textures such as banded, crustiform, lattice and bladed are diagnostic textures of fluid boiling (Simmons and Christenson, 1994). Moreover, hydrothermal alteration styles and mineral assemblages of quartz, calcite, adularia, sericite, illite and chlorite are look similarity of epithermal mineralization whereas calcite and adularia are characteristics of the boiling in hydrothermal system. Boiling in the conduits causes CO_2 and H_2S loss and consequent increase in pH, this condition is favored to precipitation of adularia and calcite mineral. Petrographically, coexisting of liquid-rich and vapor-rich of fluid inclusions in quartz veins are also one of indicators that happen in boiling condition of hydrothermal fluid. Furthermore, the homogenization temperature (159-315°C) and salinity (0.88 to 12.73 wt% NaCl equiv.) are also reliable that the hydrothermal system in Zayetkwin-Kwinthonse gold deposit (Mogok Metamorphic Belt) is epithermal system. Alternatively, mineralization veins from Phayaung Taung gold deposit of Slate Belt are occupied in fracture and shear zones as stockwork vein system. Gold are observed in tourmaline bearing quartz vein and sulfide bearing quartz vein. The presence of vein structure and microstructures of ductile deformation in quartz veins are indicated multiple episodes of fracturing and filling process in shear zone. It is also inferred that mineralization veins might have developed in a progressive deformation environment of ductile-brittle regime. In place, low-sulfide nature of quartz tourmaline vein and vein mineralogy of quartz, calcite, tourmaline, sericite, chlorite and sulfide minerals (pyrite, chalcopyrite) are inferred to typical of mesothermal (orogenic) gold deposit. Moreover, mineralization style and associated altered mineral assemblages of quartz, sericite (white mica), calcite, and epidote are also reliable to mesothermal (orogenic) gold deposit. Additionally, the homogenization temperature of fluid inclusions from Phayaung Taung are quite high (234-426°) that is probably deposited in mesothermal (orogenic) system.

Conclusion

Mogok Belt is one of major metallogenic belts in Myanmar with north-south general trend. It have two sub-belts from west to east (1) Mogok Metamorphic Belt and (2) Slate Belt. Both of belts are significant in gold mineralization and possess different characteristics. Case studies of each specific gold deposit from both sub-units are shown their different characteristics and natures of gold deposits. Based on available data of each gold deposits, the following conclusion can be made. In Mogok Metamorphic Belt 'Zayetkwin-Kwinthonse gold deposit', gold mineralization mainly hosted in marble units as fracture filling veins as well as disseminated in nature. A variety of quartz vein textures are observed such as banded, crustiform, bladed, lattice, comb and cockade textures. Mineralizations are controlled by regional fault system. Gold mineralization observed as large grains of electrum gold in gold bearing quartz vein and fine grains of native gold in base metal quartz-carbonate veins. Gold mineralization are basically associated with base metal sulfides of pyrite, sphalerite and galena. Hydrothermal alteration halos are also develop around narrowing zone of mineralization veins. It is overlapped to regional metamorphism of Mogok Metamorphic Belt. According to alteration minerals such as adularia, calcite, sericite, chlorite and epidote, it can conclude that it is deposited in near neutral condition of hydrothermal fluid. Vein textures of banded, lattice and bladed as well as fluid petrography of coexisting liquid-rich and vapor-rich fluid inclusions are indicated that boiling and mixing are possibly responsible for gold deposition. Moreover, microthermometric data of homogenization temperature (*Th*) 159 to 315°C and salinity 0.88 to 12.51 wt% NaCl equivalents are compatible to say deposited in epithermal system. But in Slate Belt, mineralization occurred within quartz-pyrite stringers and veinlets which forming stockwork veins. Primary gold occurs as small electrum spots in tourmaline bearing vein and sulfide bearing quartz vein. Tourmaline bearing quartz veins are the characteristics of Phayaung Taung gold deposit. Gold mineralization is associated with pyrite, chalcopyrite, petzite, hessite and tellurobismuth. Large grains secondary native gold are also formed in oxidized zone associated with hematite and iron oxide. The wall-rocks alteration are observed as silicic and phyllic with localized chloritization. There is no evidence of boiling characters within mineralization quartz vein. Microthermometric measurement of homogenization temperature and salinity range of 234 to 426°C and 0.35 to 8.41wt% NaCl equivalent are possibly responsible for the development of gold deposit from Phayaung Taung that indicates mesothermal system. Accordingly, Zayetkwin-Kwinthonse gold deposit from Mogok Metamorphic Belt shows near neutral condition of hydrothermal system with shallow level epithermal characters (possibly epithermal to mesothermal) but Phayaung Taung gold deposit of Slate Belt shows typical mesothermal characters. Such kinds of mesothermal system are elsewhere in Mogok Belt, but is not developed typical characters in Mogok Metamorphic Belt where it would be epithermal to mesothermal style.

Acknowledgements

We deeply thank to our scholar programs AUN/SEED-Net and Kizuna (JICA) for financial support to carry out our research. Additionally, we would like to gratitude to all of our advisors from Indonesia and Japan for their valuable suggestions and guide lines. Moreover, it extends to every single people who helped our field trips to carry well.

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PETROGRAPHY AND PETROGENESIS OF METAMORPHIC ROCKS EXPOSED AT MOGAUNGGYI AREA, SINGU TOWNSHIP, MANDALAY REGION

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Abstract

The Mogaunggyi area is situated in Singu Township, Mandalay Region and forms the southern continuation of highly deformed Mogok Metamorphic Belt. Based on the petrological, mineralogical and field criteria, metamorphic rocks in the study area comprise metapelites (garnet - biotite gneiss), metacarbonate (varieties of marbles and calc-silicates) and skarn. There are two main types of metamorphism affecting in this area; regional metamorphism and contact metamorphism. The metamorphic mineral such as sillimanite, garnet, diopside and forsterite, phlogopite and spinel are the evidence of regional metamorphism and belongs to the almandine-amphibolite facies with 0.4-0.8GPa and 550°C to 750°C estimated pressure and temperature respectively. The regional metamorphism was later superimposed by contact metamorphism by the intrusions of granite, biotitemicrogranite and pegmatite. Hence, the skarn rocks occurred at the marginal part. They belong to the pyroxene-hornfelsfacies and estimated pressure and temperature are between 0.1-0.2GPa and 600°C - 700°C respectively. The protolith age of the metamorphic rocks in the study area may range from Precambrian to Late Paleozoic, and the time of metamorphism of the study area is suggested to be from Oligocene to Middle Miocene.

***Keywords*;** Mogok Metamorphic Belt, metapelite, metacarbonate, skarn, facies, protolith

Introduction

The Mogaunggyi area lies in Singu Township, Mandalay Region, approximately 68 km to the north of Mandalay. It falls in one inch topographic map no. 93 B/2 and B/3.The location map of the study area is shown in Figure (1).

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Purposes of study

This research will contribute the petrological characteristics, types of metamorphism, metamorphic facies and probable P-T condition, and age of metamorphic rock in the study area.

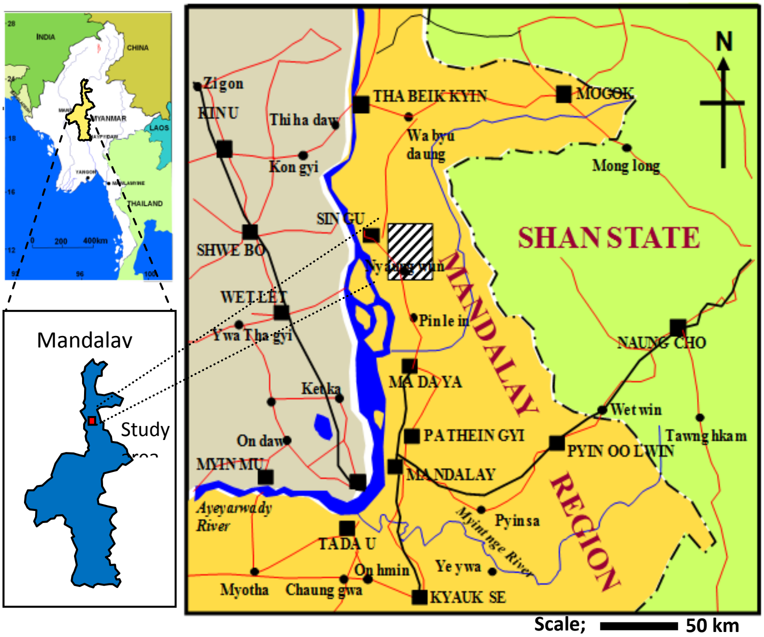


Figure 1: Location Map of the Study Area.

Methods of study

Before the field study, previous works, satellite images, and aerial photos were studied. Fieldstudy includes the systematic sampling of various metamorphic rocksand minerals to investigate the petrological characteristics and metamorphic grades.The nature of lithologic contacts, dips and strikes, foliations, joints, folds and faults were studied and measured systematically by using compass and GPS.

Detailed petrographic studies were made by using a standard binocular polarizing microscope. Type and grade of metamorphism were determined on the basis of the field studies and microscopic studies. Metamorphic facies diagrams were constructed on the basis of the characteristic mineral assemblages.

Regional Geology

Mogaunggyi area is a segment of the Mogok Metamorphic Belt and it is a southern continuation of the Himalayan Orogenic Belt and extends from north of Putao through Mogok towards Martaban in the south (Searle and Haq, 1964). The study area is situated between the Shan Plateau in the east and Central Low Land in the west and also located in the Central Granitoid Belt.Lithologically, the present investigated area is essentially made up of igneous rocks and metamorphic rocks that formed at different geological episode. Metamorphic rocks comprise metapelites (garnet-biotitegneiss), metacarbonate (various kinds of marble units andcalc-silicate rocks) and skarn rocks. Igneous rocks are biotitemicrogranite, tourmaline granite, leucogranite and pegmatite.

Regionally, the Mogok Metamorphic Belt is bounded as well as overthrusted by the Chaungmagyi Group in the east.Sagaingfault, 700 km long N-S aligned right lateral strike-slip fault that connects south to the active spreading centers in the Andaman Sea in the west. Eruptions of basaltic lava occurred around the Singu area.The regional geologic setting of the study area is shown in Figure (2).

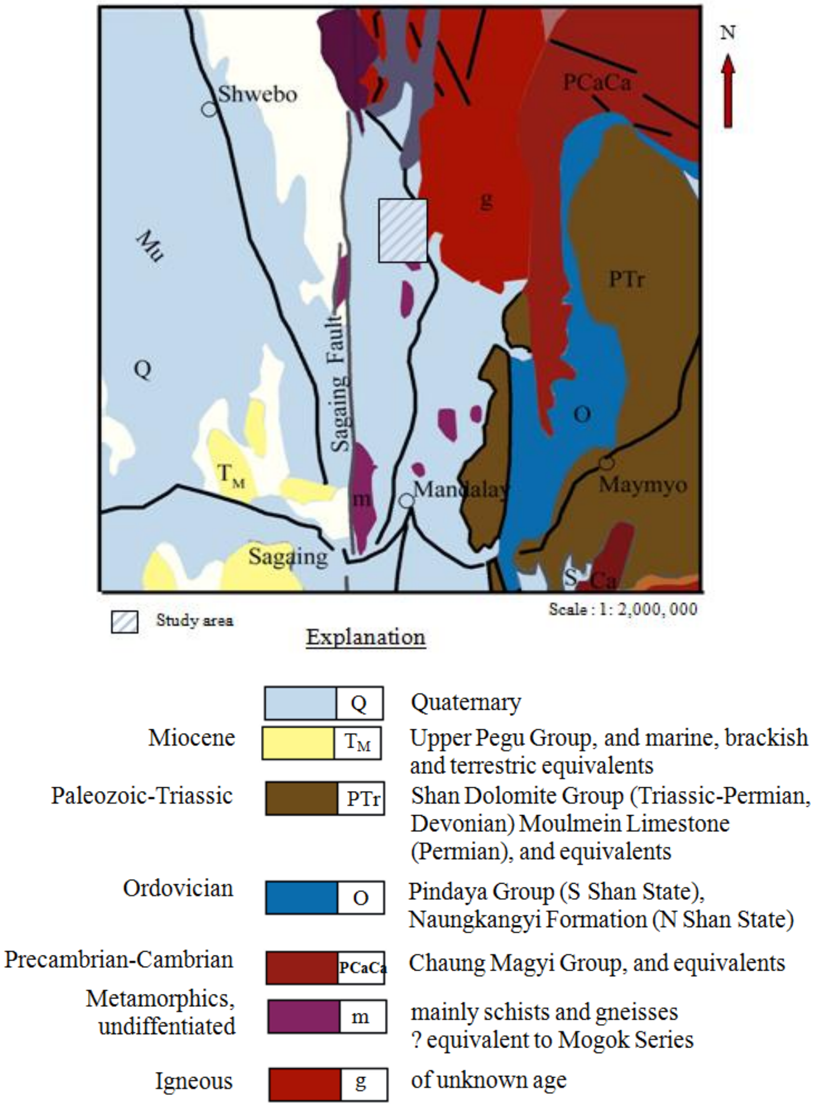


Figure 2: Regional geologic setting of the study area

Petrography

Gneiss

This unit is well exposed at the eastern part and can be subdivided into three types, viz:garnet-biotite gneiss (Figure 3A), banded biotite gneissand minor sillimanite-biotite gneiss.These rocks are well foliated, moderately banded and frequently contorted. It is the basement unit of the area.Microscopically, it is medium to coarse–grained, gneissose texture and mainly composed of orthoclase, quartz, plagioclase and biotite. Almandine occurs as important accessory mineral (Figure 4A). The minor accessory minerals are sphene and iron ores. Sillimanite occurs as tiny or minute fibres (Figure 4B).

DiopsideCalc-Silicate Rocks

Calc–silicate rock unit overlies the gneiss unit and underlies the marble unit. It is intruded by biotitemicrogranite. Differential weathering features (ridge and furrow structures) (Figure 3B), concentric folds, drag folds and boudinage have been noted in this unit. Alternating bands of dark color diopside and light color mineral such as quartz and feldspar are distinguishing feature of this unit due to metamorphic differentiation. Microscopically, it shows medium to coarse-grained, granoblastic texture and mainly composed of diopside, calcite, quartz, feldspar and other accessories. Sphene, apatite and graphite occur as minor accessory minerals.

Marble

Marble in this area has diverse mineralogy. Depending on the mineral assemblages, this unit can be subdivided into four subunits; (1) White marble, (2) Diopside marble (Figure 3C), (3) Graphite-phlogopite marble, and (4) Spinel bearing marble (Figure 3D). These are well exposed at western part of the study area. The grain size varies from medium to coarse-grained and contains diopside, spinel, phlogopite (Figure 3E), forsterite and chondrodite. Someoutcrops show hard, compact, massive nature and milky white in color.

Microscopically, it shows medium to coarse–grained, idioblastic texture. Disseminated graphite, scapolite and phlogopite can be observed in the calcite matrix.Diopside occurs as separate grains and as aggregate of small crystals (Figure 4C).

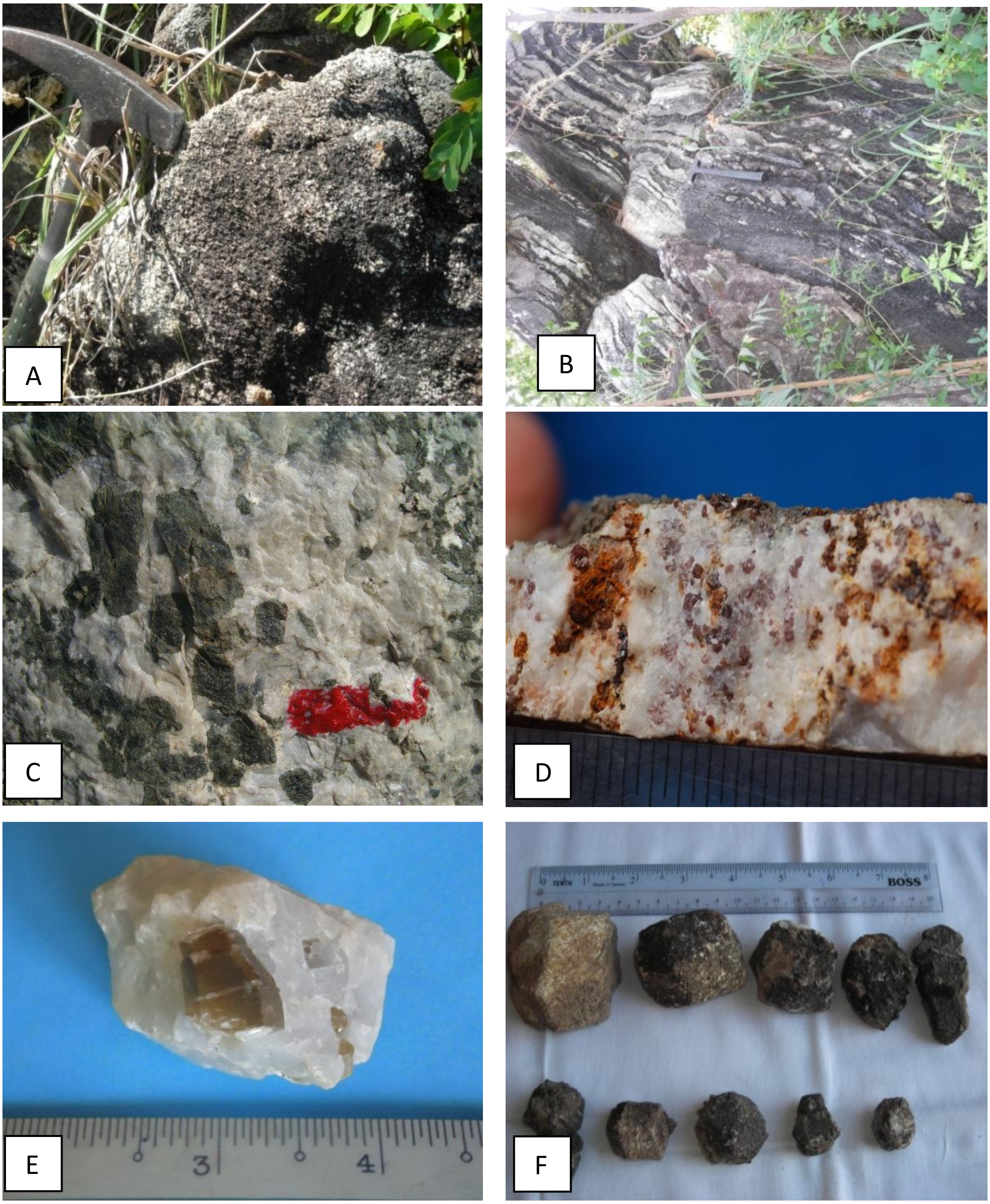


Figure 3: A. Garnet porphyroblasts in garnet-biotite gneiss B.Diopsidecalc-silicate unit is marked by banded nature as a result of compositional layering C. Diopside minerals aggregateson the fresh surface of diopside marble unit D. Spinel, phlogopite, forsterite minerals embedded in spinel bearing marble E. Phlogopite mineral embedded in the marble F.Grossular garnet crystals in skarn zone

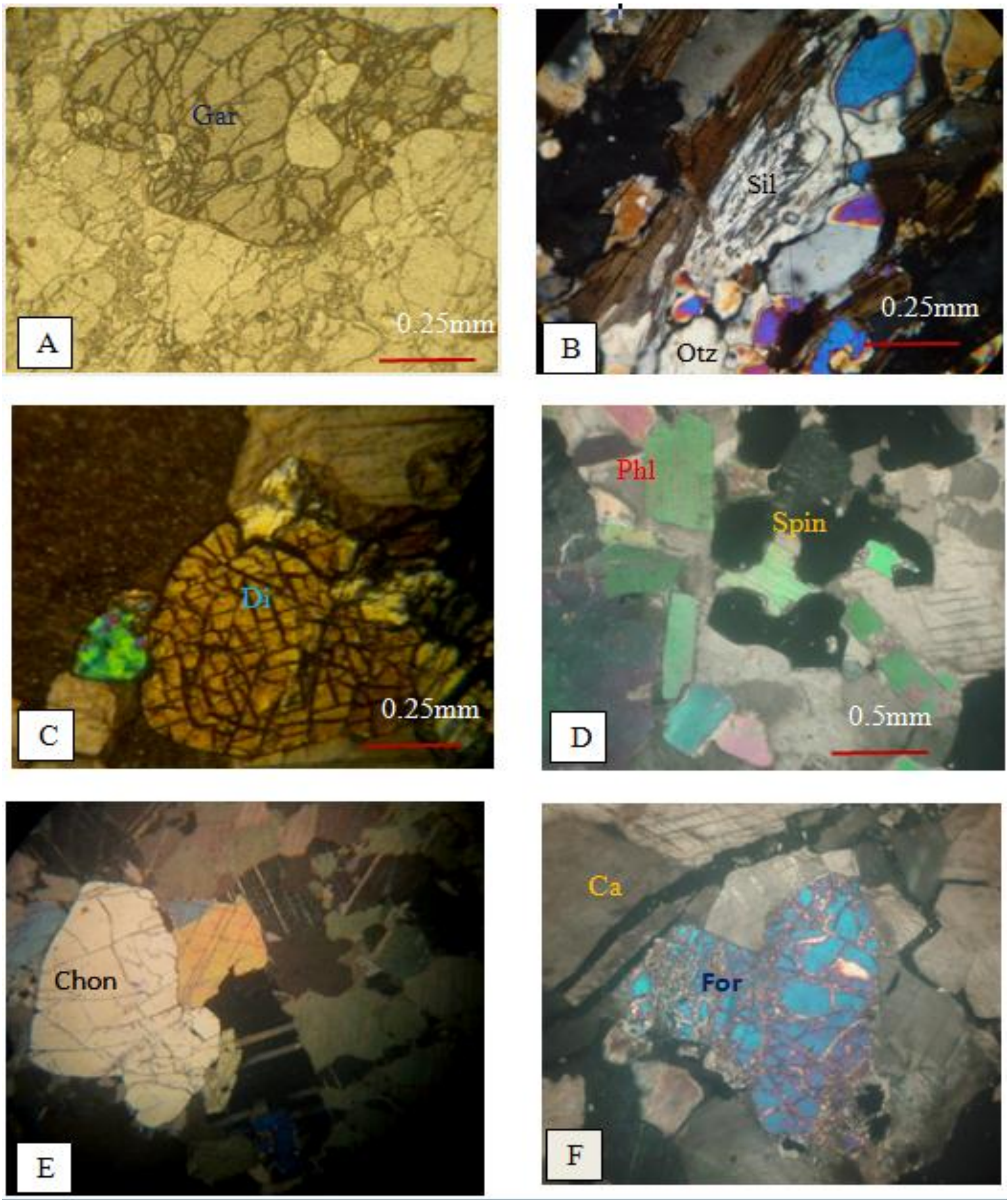


Figure 4:A. Inclusion of small quartz grains embeded in garnet crystal (Gar) resulting poikiloblastic texture, under PPLB. Small sillimanite (Sil) fibres show preferred orientation in garnet-biotitegneiss, XNC. Euhedraldiopside crystal with prominent cleavages in diopsidemarble, XN D. Mineral assemblages of spinel (Spin), phlogopite (Phl), and calcite in spinel bearing marble, XN E.Chondrodite(Chon) in spinel bearing marble, XN F.Subhedral to rounded forsterite grains with irregular fractures in spinel bearing marble, XN

Some diopside grains exhibit simple contact twin and some show polysynthetic twinning in longitudinal section. Spinels are found as octahedral idioblastic to subidioblastic crystals in the calcite matrix and irregular fractures are common (Figure 4D). The average grain size is 0.2 mm to 1.5 mm in diameter. Subhedral to rounded forsterite grains are 0.25mm to 1mm in size andirregular fractures are common. Anhedral rounded grains of chondrodite are 0.1mm to 1mm in diameterFig.4E. Partial serpentinization of forsterite is found along the cleavage plane, showing yellowish coloured serpentine and bluish green colouredforsterite (Figure 4F).

Skarn

In the study area, biotitemicrogranite bodies intrude the metacarbonate rocks. The outstanding skarn zones are (1) Diopside-tremolite bearingskarnand (2) Garnet-diopside-wollastonite bearing skarn.

This zone is essentially composed of dark green diopside, tremolite, garnet, wollastonite and calcite. Microscopically, subroundeddiopside shows colourless to pale green and partially altered to chloride.Grossular garnet occurs as subrounded grains to aggregate, pale brown in colour and commonly with irregular fractures.Radial aggregates of wollastonite show high relief and parallel extinction.

Petrogenesis

Mineral Assemblages and Metamorphic Facies

Facies classification and graphical representation used in the study area are based on Winkler (1979), Bucher & Frey (1994) and Winter (2001).

The mineral assemblages in the study area are listed in Table 1 and graphically represented by ACF and AKF diagrams in Figure (5, 6, 7 and 8). According to the petrographic studies, (23) mineral assemblages are recorded in the study area.

Table 1: Mineral Assemblages and Metamorphic facies of Mogaunggyi Area

I. Almandine – amphibolite facies

(a) Quartzofeldspathic mineral assemblages

1. Quartz + orthoclase + biotite + almandine + plagioclase
2. Quartz + orthoclase + plagioclase +biotite
3. Quartz + plagioclase + biotite + almandine + sphene
4. Orthoclase + quartz + sillimanite + plagioclase + biotite

(b) Calcareous mineral assemblages

5. Diopside + orthoclase + scapolite + plagioclase + calcite
6. Calcite + diopside + scapolite + quartz + plagioclase
7. Calcite + diopside + quartz + plagioclase + sphene
8. Calcite + diopside + quartz + orthoclase
9. Calcite + diopside + scapolite + graphite
10. Calcite + spinel + scapolite
11. Calcite + diopside + phlogopite + sphene
12. Calcite + phlogopite + graphite
13. Calcite + chondrodite + spinel
14. Calcite + diopside
15. Calcite + spinel + phlogopite
16. Calcite + phlogopite + chondrodite + spinel
17. Calcite + forsterite + chondrodite + spinel

II. Pyroxene-hornfelsfacies

(a) Skarn assemblages

18. Plagioclase + diopside + tremolite + calcite
19. Diopside + grossularite + wollastonite + quartz + calcite

20. Plagioclase + diopside + grossularite + calcite
21. Diopside + quartz + tremolite + calcite
22. Diopside + grossularite + calcite
23. Diopside + quartz + tremolite + scapolite

Types of metamorphism

The observed textural, structural, petrological and mineralogical studies indicate the present study area has subjected to two main types of metamorphism; (a) regional metamorphism and (b) contact metamorphism.

Regional Metamorphism

The indicator minerals are diopside, forsterite, phlogopite in marble and sillimanite and almandine in gneiss. Plagioclase in gneiss and calc-silicate rocks is in the range of oligoclase and andesine.

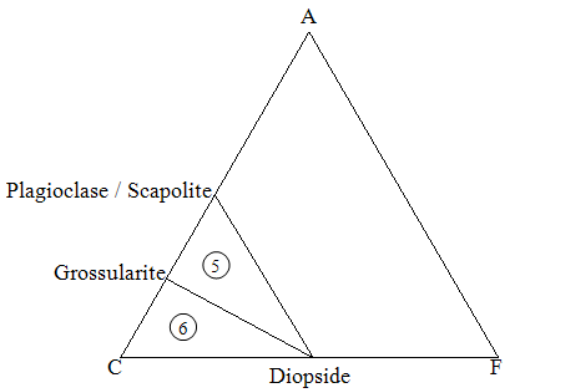
The mineral association of calcite-diopside-forsterite and calcite-diopside-phlogopite are seen in marble units. These mineral assemblages correspond to the almandine-amphibolite facies. Moreover, small amounts of sillimanite occur with orthoclase without muscovite. Hence, the mineral assemblages indicate that the study area had reached the sillimanite-almandine-orthoclase subfacies ofWinter (2001). The metamorphism took place at a temperature range between 550°C to 720°C and pressure between 0.4 to 0.8GPa.In the Mogaunggyi area, small amount of tremolite minerals occur at the northeastern part in contact with diopside marble. Diopside marble is abundant in the central part. In addition, diopside-forsterite marble is present in the southwestern part of the study area. It is inferred that the metamorphic grade in the study area increases towards the southwest.

Contact Metamorphism

The contact effects at the vicinity of granite intrusive bodies are indicative of the presence of skarn rocks. The assemblages, forsterite + spinel + phlogopite and diopside + forsterite are found in marble near the contact of biotitemicrogranite intrusive body.

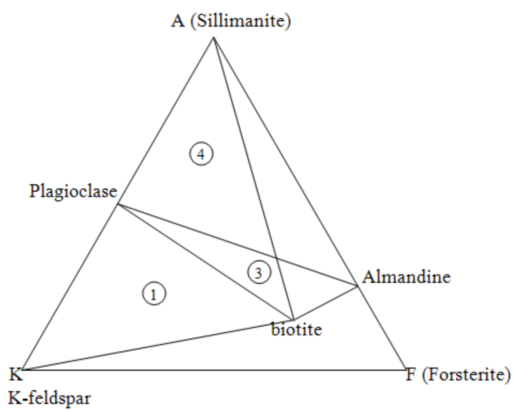
Wollastonite in the skarn rocks is associated with diopside and grossularite. The association of calcite + grossularite + diopsideskarn is also found at the vicinity of biotitemicrogranite intrusion. Forsterite commonly shows partial replacement by serpentine. The above mineral assemblages confirm that contact metamorphic grade belongs to pyroxene-hornfelsfacies. The pyroxene-hornfelsfacies is represented by the appearance of diopside with forsterite in calcareous rocks. According to this diagram, established by Winter(2001) inFig.6.The depth of metamorphism in the study area is estimated as below 2 km with the temperature of about 650°C - 700°C and pressure 0.1-0.2GPa.

A.



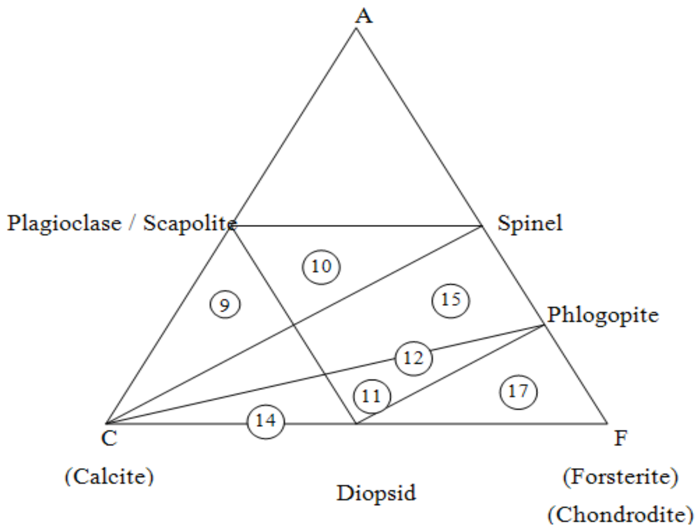
Amphibolite facies (Qtz ē)

B.



Amphibolite facies (Qtz ē)

Figure 5: ACF diagram (A), AKF diagram (B) for quartzofeldspathic and calcareous mineral assemblages of Amphibolite facies recognized in Mogaunggyi area.



Amphibolite facies (Qtzēout)

Figure 6: ACF diagram for calcareous mineral assemblages of Amphibolite faciesrecognized in Mogaunggyi area.

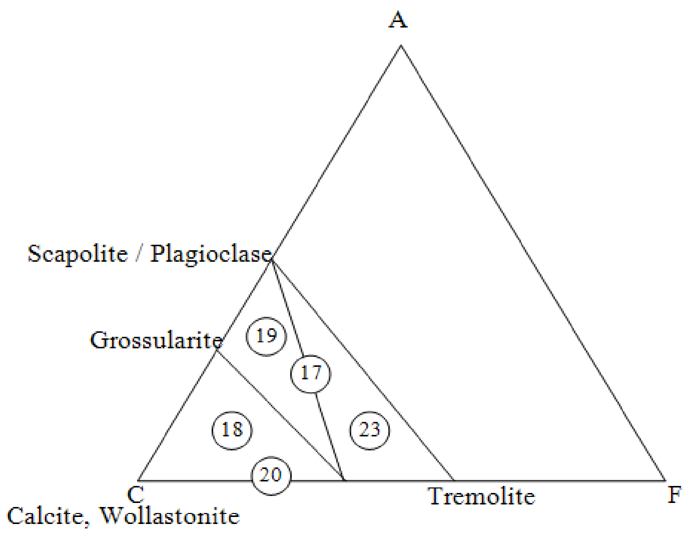


Figure 7: ACF diagram showing the mineral assemblages of Pyroxene-hornfelsfacies.

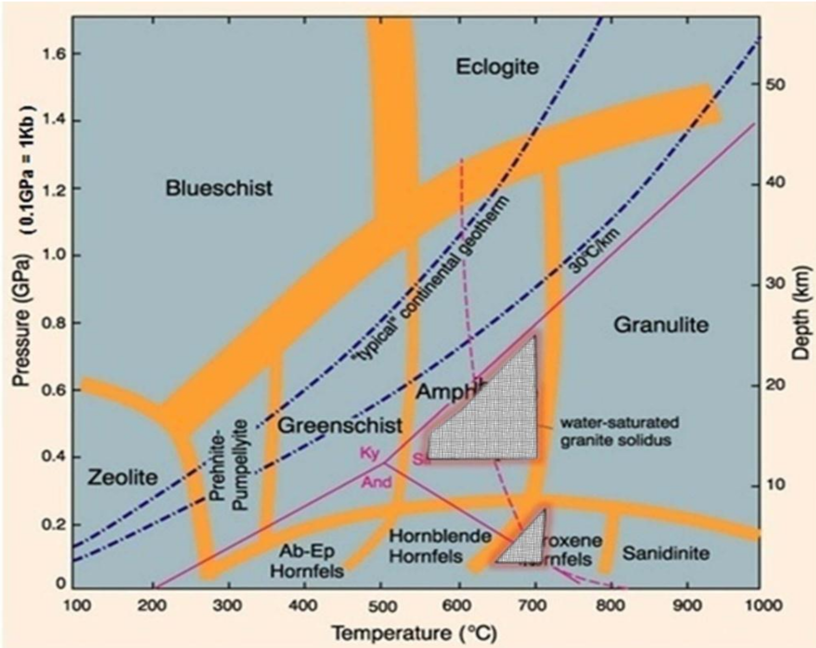


Figure 8: Temperature-Pressure diagram of the study area

(**Source:** Winter, 2001)

Time of Metamorphism

The study area is considered as the southern continuation of Mogok Metamorphic Belt and the age of metamorphic rocks in this area may be contemporaneous with the Mogok Group. Radiometric dating of a phlogopite sample from the Mogok area gives about 40 Ma. This means that the metamorphism could be the consequent event of the early Himalayas Orogeny that took place during Late Eocene (Maung Thein and Ba Than Haq, 1964).

Radiometric age determination on the MMB include an early U/Pb age on pegmatite (Searle and Ba Than Haq, 1964), K/Ar ages on augen gneiss, Rb/Srisochron ages on granite (Cobbing et al., 1992) and Ar/Ar and K/Ar ages on granitic and metamorphic rocks (Bertrand et al., 2001). All these data provide the evidence for a Lower to Middle Tertiary major thermal event.

Maung Thein (2000) suggested that the regional metamorphism of the Mogok Belt might have occurred during Late Oligocene in relation to the middle phase of Himalayan Orogeny. Win Naing (2008) proposed that the uplifting and exhumation of MMB, a consequence of India-Asia collision have taken place at Eocene to Middle Miocene.

In the study area, leucogranite sample from the Mogaunggyi area was analyzed by U-Pb zircon dating method. The age of 26.14 ± 0.37 Ma (Late Oligocene), this may interpret the crystallization age of leucogranite. In addition, sample of biotitemicrogranite from the study area were radiometrically analyzed and gives the age of 17.1 ± 0.2 Ma (Middle Miocene).

Based on the above factors, the time of metamorphism of the study area is suggested to be from 26.14 to 17.1 Ma (Oligocene to Middle Miocene).

Summary and Conclusion

The study area comprise metapelites (garnet - biotite gneiss), metacarbonate (varieties of marbles and calc-silicates) and skarn. According to the field observations, petrological studies and geochronological datas, two main types of metamorphism are recognizedviz; regional and contact. The metamorphic mineral assemblages; sillimanite, garnet, diopside and forsterite belongs to the almandine-amphibolite facies with 0.4-0.8GPa and 550°C to 720°C estimated pressure and temperature respectively. Moreover, small amount of sillimanite occur with orthoclase pointed out that the study area had reached the sillimanite-almandine-orthoclase subfacies. The metamorphic grade in the study area increases towards the southwest. The regional metamorphism was later superimposed by contact metamorphism by thegranitoids intrusion. They belong to the pyroxene-hornfelsfacies and estimated pressure and temperature are between 0.1-0.2GPa and 650°C - 700°C respectively. The age of premetamorphic rocks of the study area is probably Precambrian to Late Paleozoic, and the time of metamorphism may have taken place during Oligocene to Middle Miocene.

Acknowledgement

Special thanks are due to Professor U Hla Kyi (Part-time Professor, Applied Geology Deparement) and Professor U Thein Win (Pro-Rector. Retd., West Yangon University) for their supervision, guidance and valuable suggestions.

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PERMIAN BIOTIC ASSOCIATION FROM THE MOULMEIN LIMESTONE IN PAWTAW TAUNG, HPA-AN TOWNSHIP, KAYIN STATE

Ohnmar Soe Yin[1], Aung May Than[2] & Myo Myo Ei[3]

Abstract

The prominent rock unit, the Moulmein Limestone is well exposed in the Pawtaw Taung which is located in the northeastern part of Hpa-an Township, Kayin State. The present study recovered the coral-brachiopod-foraminifer association for the first time from the fossiliferous limestone of the Pawtaw Taung. The Middle Permian coral fauns of solitary rugose coral (*Pavastehphyllum* sp.) and compound rugose corals (*Polythecalis* sp. *and Waagenophyllum* sp.) are dominated. These corals are typically Tethyan. The occurrence of brachiopod fauna (*Retimarginifera* sp. *Stereochia* sp. and *Spiriferella* sp.) and the fusuline fauna (*Parafusulina* sp., *Eopolydiexodina* sp. and *Yangchienia* sp.) are regarded as an indicative of the transitional biotic province of Shan-Thai Terrane. From the paleobiogeographical point of view, it is assumed that the coral-brachiopod-foraminifer association of the Moulmein Limestone, including the present study area, represents the western part of Sibumasu Block, as a whole, are treated as a mixed transitional fauna (Gondwanan and Cathaysian fauna affinities) which flourished in warm temperate conditions during Middle Permian time.

Key words: Moulmein Limestone, Coral-brachiopod-foraminifer association, Sibumasu, Middle Permian

Introduction

The study area, Pawtaw Taung which is located in the northeastern part of Hpa-an Township, Kayin State. The Permian rocks of Kayin State including Pawtaw Taung are dominantly limestone that commonly exhibit isolated karstic landforms and have been formalized lithostratigraphically as the Moulmein Limestone. The Moulmein Limestone gradationally overlies the clastic rocks of the Taungnyo Group. It is mainly composed of well-bedded dark grey limestone and silicified argillaceous limestone. The biotic association such as coral, brachiopod and foraminifera occurs in light to dark grey fossiliferous limestone and micritic limestone. The samples and data are systematically collected at five localities situated on the eastern and

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western foot hill of the Pawtaw Taung. The location and topographic maps of the research area are shown in figure (1).

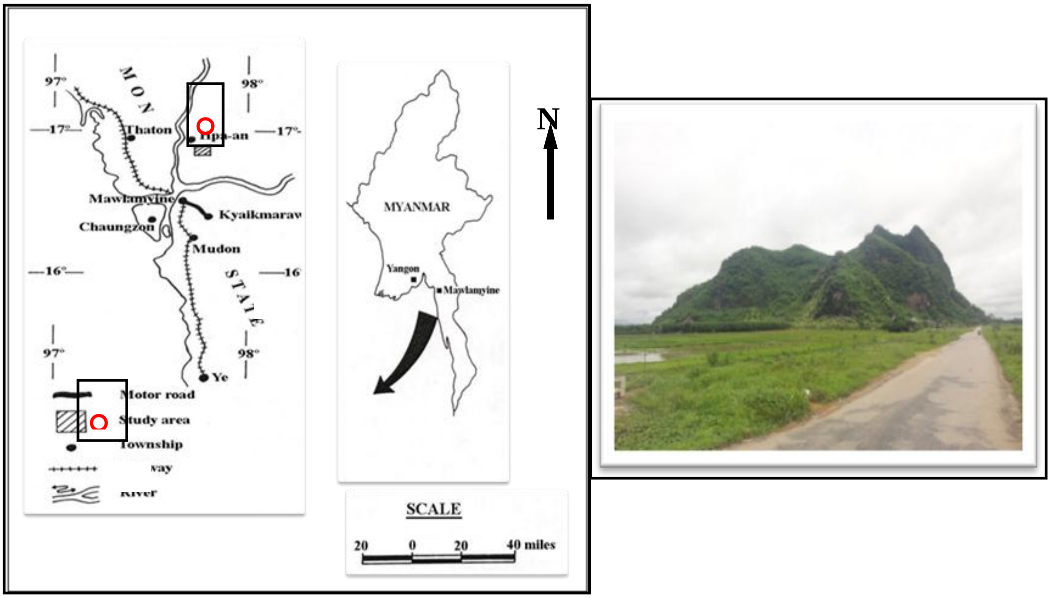


Figure 1: Location map and panoramic view of the Pawtaw Taung cropping out in the low-lying alluvial plain

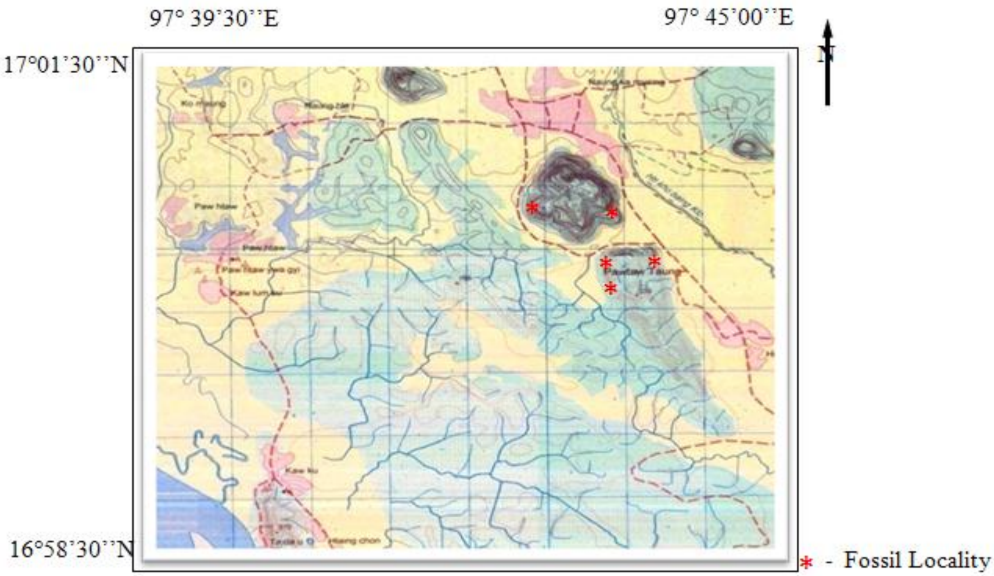


Figure 2: Map showing the localities of fossil of the study area (From UTM index no: 1797-12 and 1697-09)

Previous Studies

A few previous studies have been reported Permian fossils in Moulmein Limestone in Hpa-an area. Tin Tin Latt et al. (2014) mentioned the presences of Middle Permian Cimmerian foraminifers (*Parafusulina, Minojapanella, Yangchienia, Chenella*) in the Zwekabin Range.

Moulmein Limestone

The prominent rock unit, the Moulmein limestone of Permian age is well exposed in the study area. T. Oldham (1856) firstly proposed the name Moulmein system for widespread clastics and limestones. It was later designated as Moulmein Limestone (Brunschweiler, 1970) representing a middle Permian age. The stratigraphic classification of the Hpa-an Township (Cited from Maung Thein, 2014) is shown in below.

Stratigraphic Units	**Geological Age**
Moulmein Limestone	Permian
…..…gradational…….	
Taungnyo Formation	Carboniferous-Early Permian

In the study area, Moulmein Limestone includes two different lithologies of the fossiliferous limestone and micritic limestone. The fossiliferous limestone unit of the Moulmein Limestone is exposed in the southwestern and eastern parts of the Pawtaw Taung (Figure 2). It is medium-to thick-bedded, fine-to medium-grained, gray to black coloured limestone. The rock unit is highly fossiliferous and foraminifera, brachiopods and rugose coral are the observed fossils (Figures 3-7). The micritic limestone unit also occurred in the western part of the Pawtaw Taung. It is well-bedded, fine-grained, reddish brown coloured on weathered surface and gray in fresh coloured (Figure.8) This unit is mostly hard and compact, calcite veinlets and fusulinid and small foraminifera are present. Genera of large Fusulinidae, such as *Parafusulina*, *Eopolydiexodina*, and *Yangchienia* which are associated with small foraminifers as *Palaeotextularia* sp., *Endothyra* sp. *Climacammna* sp. and *Tetrataxis* sp., corals (*Pavastehphyllum, Waagenophyllum*, *Polythecalis*) and brachiopods (*Retimarginifera, Steochia and Spiriferella*) are collected from the Pawtaw Taung.

Figure 3: Fossiliferous limestone of the Moulmein Limestone, at the Pawtaw Taung

Figure 4: Solitary rugose coral from the Moulmein Limestone, at the Pawtaw Taung

Figure 5: Calyx of solitary rugose coral from the Moulmein Limestone, Pawtaw Taung

Figure 6: Solitary rugose coral from the Moulmein Limestone, Pawtaw Taung

Figure 7: Brachiopod from the Moulmein Limestone, at the Pawtaw Taung

Figure 8: Micritic limestone of Moulmein Limestone Group, at the Pawtaw Taung

Fossil Distribution in Moulmein Limestone, Hpa-an Area

Moulmein Limestone exposures are exposed at the Pawtaw taung, the Kamawnyaw taung, the Daungkala taung and the Zwekabin Range in the Hpa-an area (Figure 9). The present research area, the Pawtaw taung which is located in northeastern part of the Hpa-an township, is composed of thick-bedded to massive limestone containing rugose coral (*Pavastehphyllum* and *Polythecalis*) (Figures,10 and 11), brachiopod fauna (*Retimarginifera*, *Steochia*, *Spiriferella*) (Figures, 12,13,14) and fusuline fauna (*Parafusulina*, *Eopolydiexodina*, *Yangchienia*) (Figures 15-17) with a small foraminiferal fauna (*Tetrataxis* sp., *Palaeotextularia* sp., *Endothyra* sp. *Climacammna* sp.) (Figures 18-21).

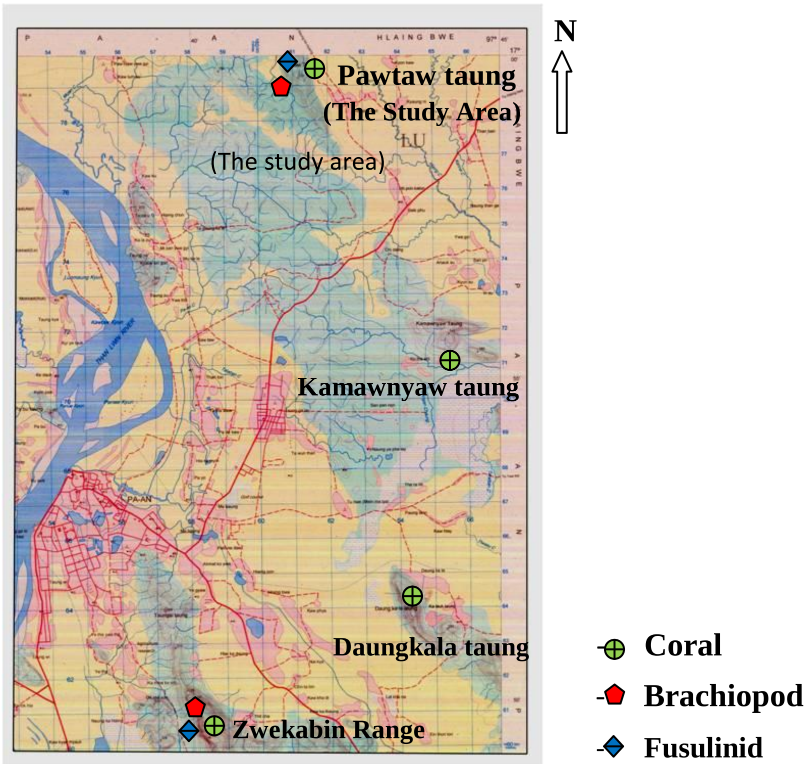
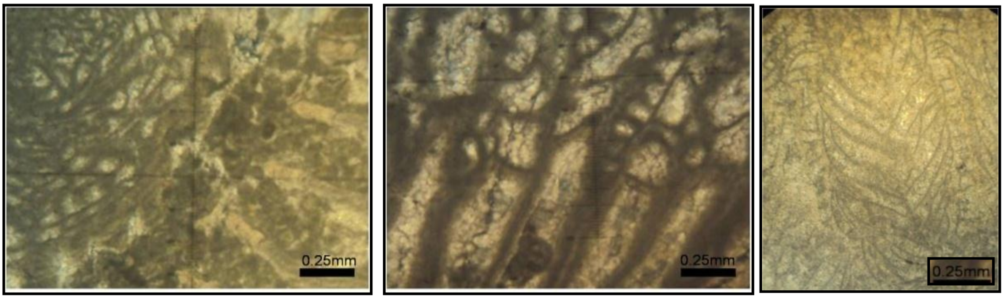


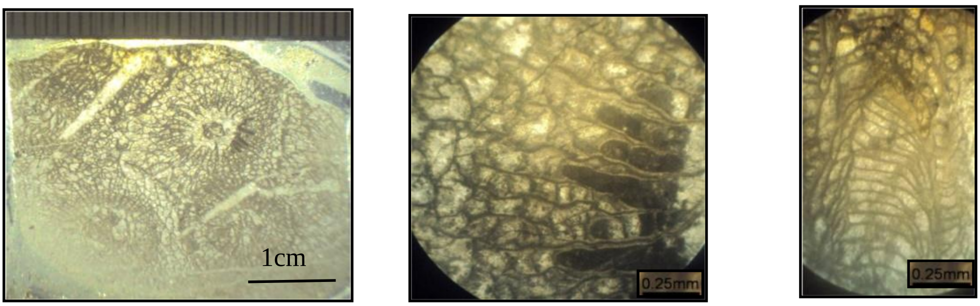
Figure 9: Fossil Distribution in Moulmein Limestone, Eastern part of the Hpa- an area

At Kamawnyaw taung, northeastern part of the Hpa-an township, grey colored, thickly bedded to massive limestone contains colonial rugose coral (*Waagenophyllum*) (Figure 22) but some are almost completely destroyed by recrystallization.



(i) (ii) (iii)

Figure 10: (i) Transverse section of well constructed axial structure of *Pavastehphyllum*, (ii) Rhopaloid major septa and distinct carine of *Pavastehphyllum*, (iii) *Pavastehphyllum* sp. Longitudinal section showing steep inclined tabulae



(i) (ii) (iii)

Figure 11: (i)*Polythecalis* sp. Transverse section showing small globose to somewhat circular dissepiments, (ii) *Polythecalis* sp. Transverse section showing septa are wavy or zigzag at the periphery, (iii)*Polythecal-is* sp. Longitudinal section showing transverse tabulae

Figure 12: *Retimarginifer sp.*, ventral external valve

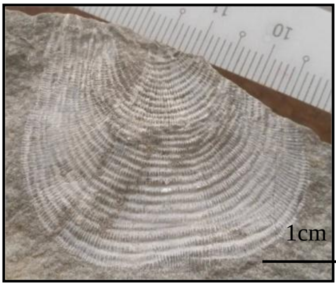
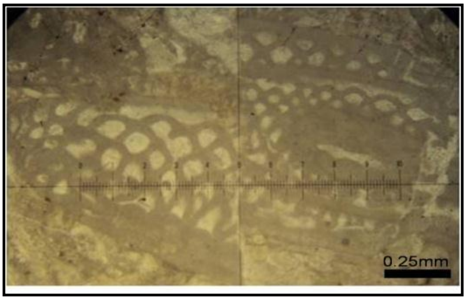
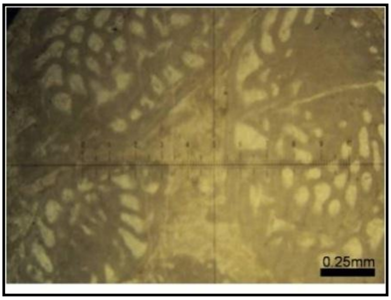


Figure 13: *Steochia sp.*, dorsal external valve

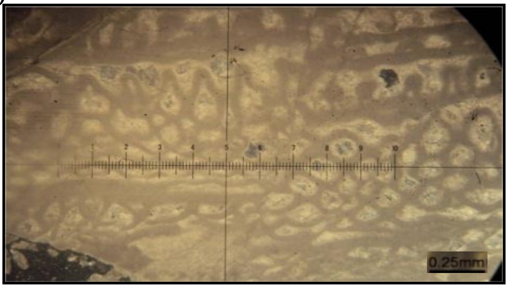
Figure 14: *Spiriferella sp.*, ventral external valve



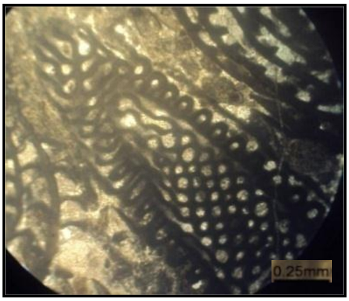
(i)



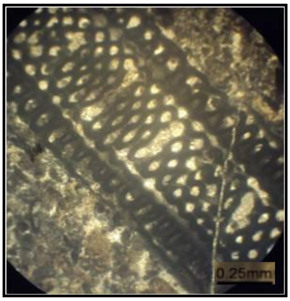
(ii)



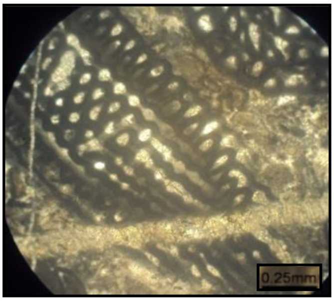
(iii)



(iv)

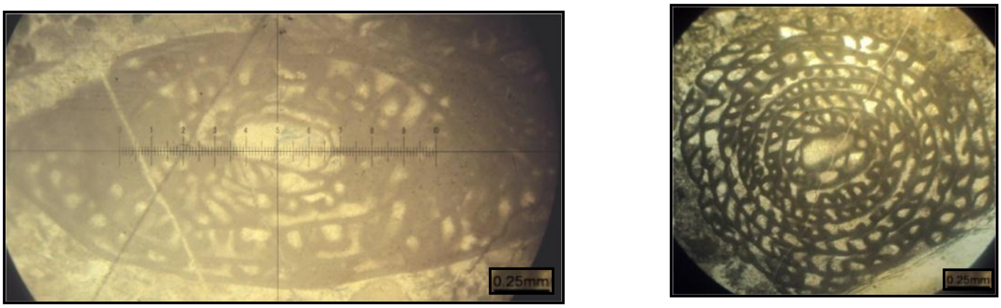


(v)



(vi)

Figure15: (i-vi) *Parafusulina* spp. showing elongate species, septal fluting in advanced stage with cuniculi present.



(i) (ii)

Figure 16: (i) *Eopolydiexodina* sp. showing axial section, septa are intensely fluted and folds of septa divide the early part of chambers into small chamberlets ; (ii) showing sagittal section, proloculus large

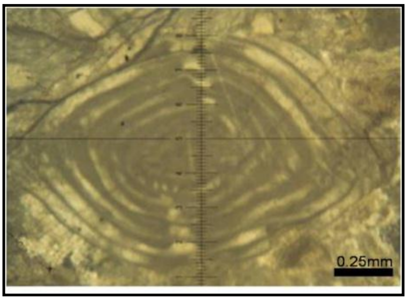


Figure 17: *Yangchienia* sp. showing axial section, distinct chomata in the fusiform whorls

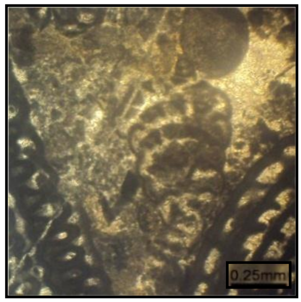
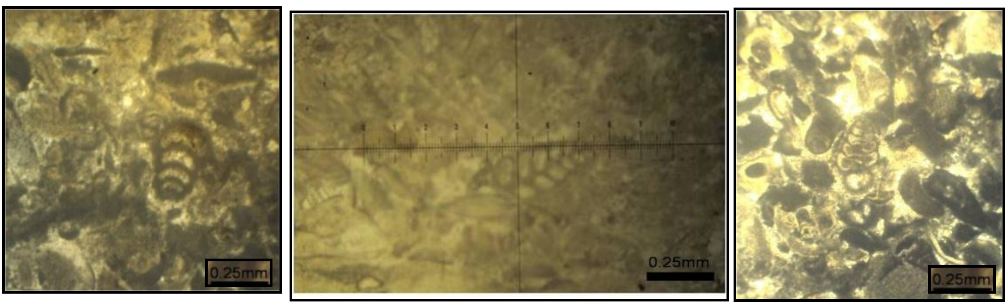


Figure 18: *Tetrataxis* sp. showing chambers strongly overlapping on the umbilical side



(i) (ii) (iii)

Figures 19: (i) *Palaeotextularia sp.* showing uniserial chamber, (ii&iii), showing biserial chamber

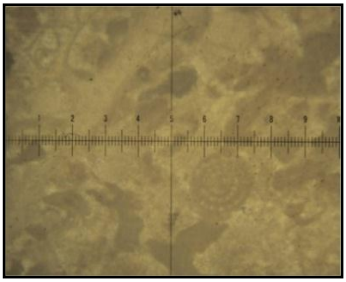
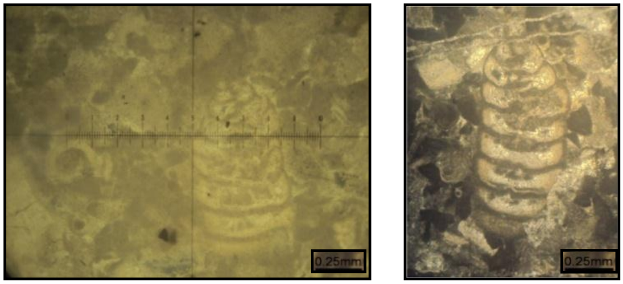


Figure 20: *Endothyra sp.* showing partially involute and planispiral.



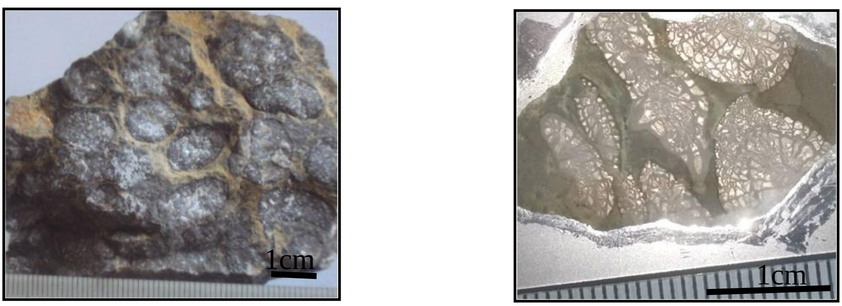
(i) (ii)

Figures 21: (i,ii) *Climacammna* spp. showing biserial stage followed by a uniserial stage,

At the southeastern part the Hpa-an Township, a large hill, Daungkala taung which is composed of grey colored, bedded limestone contains colonial rugose coral (*Polythecalis*) (Figure 23).

At Zwekabin Hill, southern part of the Hpa-an Township, grey colored, well bedded to massive limestone is partly dolomitized, but elsewhere contains Brachiopods (*Orthotetes*, *Neospirifer*, *Kutorginella*) (Figures 24-26), solitary rugose coral (? *Cyathoxina*) (Figure 27), colonial tabulate coral (*Syringopora*) (Figure 28) and fenestrate bryozoans. These rugose coral *Cyathoxina* faunas, which are typically composed of small, solitary and non-dissepimented rugose, occur in the Early Permian of the Lhasa block belong to the Cimmerian continent. (Wang *et al*., 2001)

The localities mentioned up to now in this research belong largely to the Permian and mainly to Early-Middle Permian.



(i) (ii)

Figure 22: (i) Megascopic view of Waagenophyllum (ii) transverse section showing thin corallite walls and a comparatively small axial column

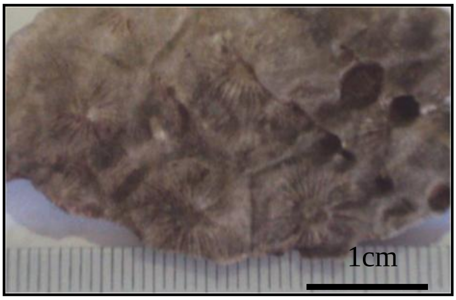
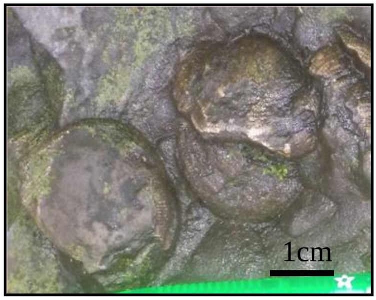


Figure 23: Megascopic view of *Polythecalis* showing the corallum is compound, massive and cerioid and some calicular pits.



Figures 24: *Orthotetes* sp. showing internal dorsal moulds

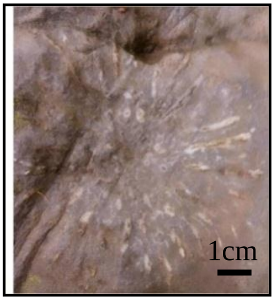
(i)

(ii)

Figures 25: (i and ii) *Neospirifer* spp. showing external moulds of ventral valves

Figures 26: *Kutorginella* sp. showing internal moulds of ventral valve

Figures 27: ?*Cyathoxina* of rugose coral



Figures 28: *Syringopora* sp. of tabulate coral

Faunal Affinity and Paleobiogeography of Hpa-an Area Including Pawtaw taung

The Pawtaw taung fauna consists mainly of Middle Permian foraminifers, corals and brachiopods occurring in the Moulmein Limestone. A small foraminiferal fauna is known from the Moulmein Limestone and includes *Palaeotextularia* sp., *Endothyra* sp. *Climacammna* sp. and *Tetrataxis* sp. A low diversity fusulinacean fauna occur in the Pawtaw Taung. This fauna is dominated by genus *Parafusulina* and is associated with *Eopolydiexodina, and Yangchienia*. The genus *Eopolydiexodina* is considered as one of the most typical taxa during the late Middle Permian of the Cimmerian continent (Wang *et al.*, 2001). The Tethyan realm contained relatively fusulinid genera of *Parafusulina* and *Yangchienia* is restricted to Tethyan-Boreal trends of fusulinides.

Three indeterminate coral species were recovered from the Moulmein Limestone of Pawtaw Taung, Kamawnyaw taung and Daungkala taung. They are *Pavastehphyllum* sp., *Waagenophyllum* sp. and *Polythecalis* sp.(Ezaki., 1991). *Pavastehphyllum* occur widely in the Middle Permian of the Cimmerian continent such as West Sumatra, Peninsular Thailand, Shan States of Burma and Baoshan (Fontaine *et al.*, 2002). In the study area of Pawtaw taung, *Pavastehphyllum* occur associated with *Parafusulina* but it seems never accommodate taxonomically higher neoschwagerinids. The occurrence of *Waagenophyllum, Pavastehphyllum* and *Polythecalis* indicate some paleobiogeographic link of the Sibumasu coral fauna during Middle Permian. The Middle Permian coral faunas in the Sibumasu Terrane are dominated by both solitary and compound Waagenophyllidae. The latter is a common element in the Cathaysian continent (Shi and Archbold, 1998)

A few diverse brachiopod fauna from the study area were described and named *Retimarginifera* sp., *Steochia* sp. and *Spiriferella* sp. The presence of *Retimarginifer* from the Pawtaw Taung is substantially different from the coeval cold and poorly diversified assemblages of Gondwana regions.

Summing up the above faunal association of the study area clearly exhibits Tethyan aspects and the Middle Permian faunas of the Sibumasu show mixed affinities to Cathaysia and Gondwana in terms of corals and brachiopods (Metcalfe, 1998). Occurrence of some distinctive species such as *Waagenophyllum*, *Polythecalis* and *Parafusulina* in Pawtaw taung indicate paleobiogeographic independence of the Sibumasu Block from Cathysia.

Conclusion

Moulmein Limestone are well exposed in the Pawtaw taung. It consists dominantly of well-bedded, fine to medium grained fossiliferous limestone and hard, compact reddish brown coloured micritic limestone. The collected samples at five sample localities were examined for coral-foraminifer-brachiopod study. The occurrences of biotic associations are *Pavastehphyllum, Waagenophyllum, Polythecalis, Paleotextularia, Endothyra, Climacammna, Tetrataxis, Eopolydiexodina, Parafusulina, Yangchienia*, *Retimarginifer, Steochia and Spiriferella*. Based on above these fauna, the Moulmein Limestone of the study area can be dated as Middle Permian (Wordian to Capitanian) in age. From the paleobiogeographical point of view, it is assumed that the study area includes in the mixed Gondwanan-Cathaysian fauna of the Sibumasu province.

Acknowledgements

We wish to express my sincere gratitude to Dr Mya Mya Aye, Rector of Hpa-an University and Dr Daw Than Myint, Pro-Rector of the same University for their permission to do this research. We extend our special thanks to Professor Dr Aung May Than, Head of Geology Department, Hpa-an University, for her advice and encouragement in preparing this research.

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STUDY ON SPELEOTHEMS FROM GEOHERITAGE SITES OF THE LIMESTONE CAVES AT THE HPA-AN TOWNSHIP, KAYIN STATE, MYANMAR

Aung Kyaw Myat, Aung May Than

Abstract

The research area is located at the vicinity of the Hpa-an Township, Kayin State, Myanmar. In Hpa-an area, there are so many historical limestone caves with beautiful speleothem, such as Ba-yint-nyi cave, Ya-thae-pyan cave, Kawtgon cave, Sadan cave, Waè-byan cave, Hlaing-kawt-pya cave, Kawt-ka-thaung cave, Badom cave, Linno cave and Thayar-shwe cave. Among them, Ba-yint-nyi cave, Ya-thae-pyan cave, Kawtgon cave, Sadan cave and Linno cave are distinct and famous for tourism. These limestones caves are composed of micritic limestone, dolomitic limestone and brecciated limestone of the Moulmein Limestone Formation (Permian in age). According to morphology of speleothems by Hill and Forti (1997), at least 17 kinds of speleothems can be classified as the cave deposits of Ba-yint-nyi cave, Ya-thae-pyan cave, Kawtgon cave, Sadan cave and Linno cave in this study. All of the speleothems formations are mainly controlled by the five hydrological mechanisms such as dripping, flowing, seeping, pooled water and splashing water. Thermogene travertines form from carbon dioxide sources which receive most of their carrier CO_2 from thermally-driven processes in this area because of the sub-tropical climate condition. The preservations of these beautiful limestone caves are important for geotourism as geoheritage sites. Moreover, these caves act natural ornaments for our country.

Keywords: Speleothem, limestone cave, tourism, geoheritage, geotourism

Introduction

A "speleothem" is a secondary mineral deposit formed in a cave by a chemical reaction from a primary mineral in bedrock or detritus, (Moore, 1952). "The term "speleothem" refers to the mode of occurrence or shape of a mineral deposit.

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The research area, Hpa-an Township, has so many historical limestone caves with beautiful speleothem, such as Ba-yint-nyi cave, Ya-thae-byan cave, Kawtgon cave, Sadan cave, Waè-byan cave, Hlaing-kawt-pya cave, Kawt-ka-thaung cave, Badom cave, Linno cave and Thayar-shwe cave. Among them, Ba-yint-nyi cave, Ya-thae-byan cave, Kawtgon cave, Sadan cave and Linno cave are distinct and famous for tourism.

Location and Accessibility

The research area is located at the vicinity of the Hpa-an Township, Kayin State which is bounded between North Latitude 16°44' to 16°56' and East Longitude 97°33' to 97°43'. According to the Universal Tranverse Mercator Map Index, this area lies within 1697-9, 10, 13 and 14. The area coverage is 378 km^2 and the cave distribution area is 16 km^2.

The research area is easily accessible by car, train and various kinds of vehicle because most of the areas are lowlying topography and fairly good condition of bedrock for road constructions.

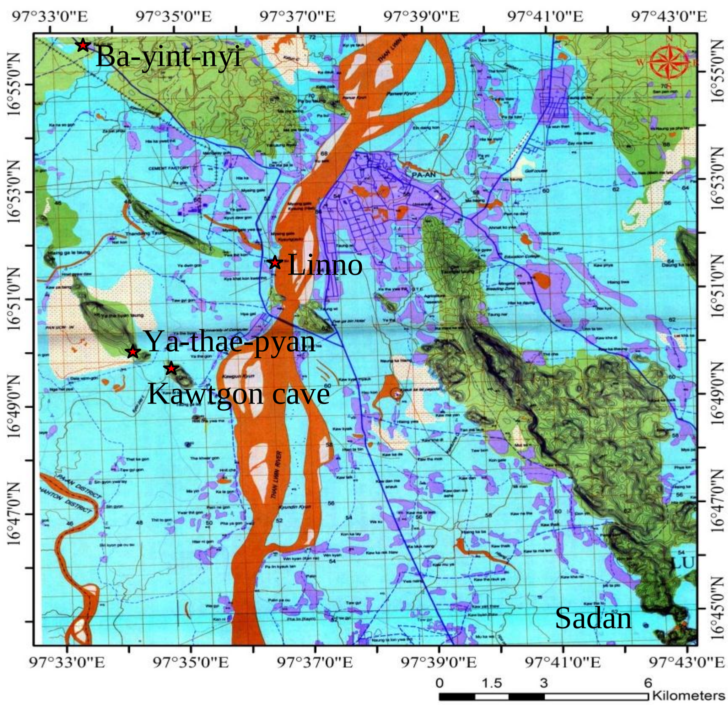


Figure 1: Location map of the research area

Physiography and Drainage

Physiographically, isolated hills with steep slopes, mountain ranges and flat plain are observed in the study area. The study area lies within the western part of the Shan-Tanintharyi Block.

Elevated hilly regions occur only at the south-eastern and north-western part of this area and most of the areas are flat-plain with isolated hills shown in Figure (2). The highest elevation of the research area is Zwekabin Range with 401-503 meter.

In the research area, Thanlwin River and its tributaries flow from north to south. The major influence streams are Kawyin Chaung and Binnlaing Chaung that mainly affect to the Ba-yint-nyi Cave and Ya-thae-pyan Cave. Besides, three main drainage patterns occur in this area such as dentritic pattern, subparallel pattern and centripetal pattern, (Figure 3).

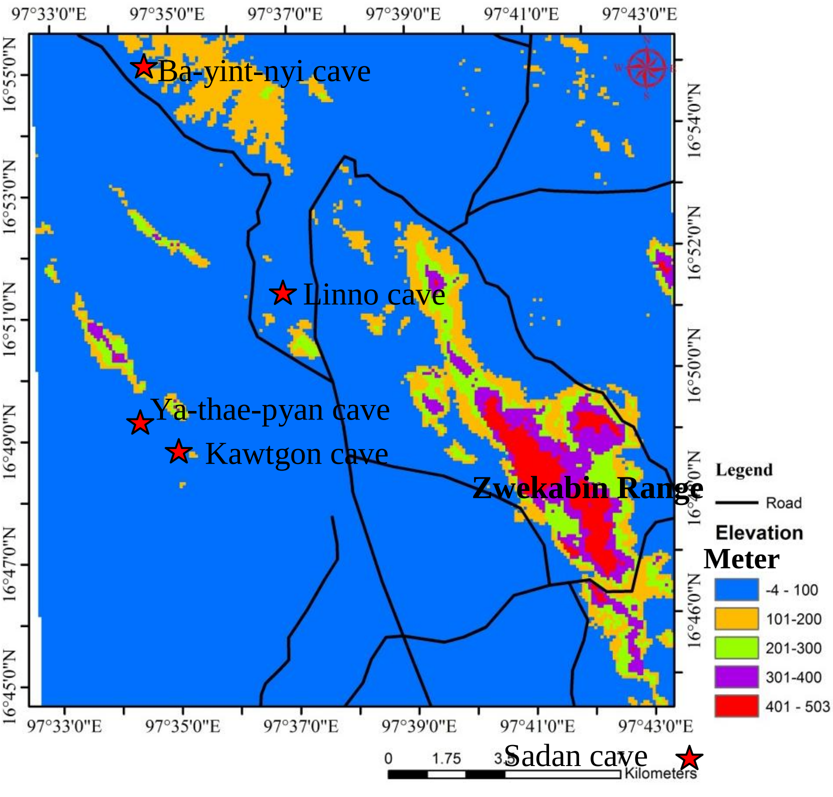


Figure 2: Physiography of the research area

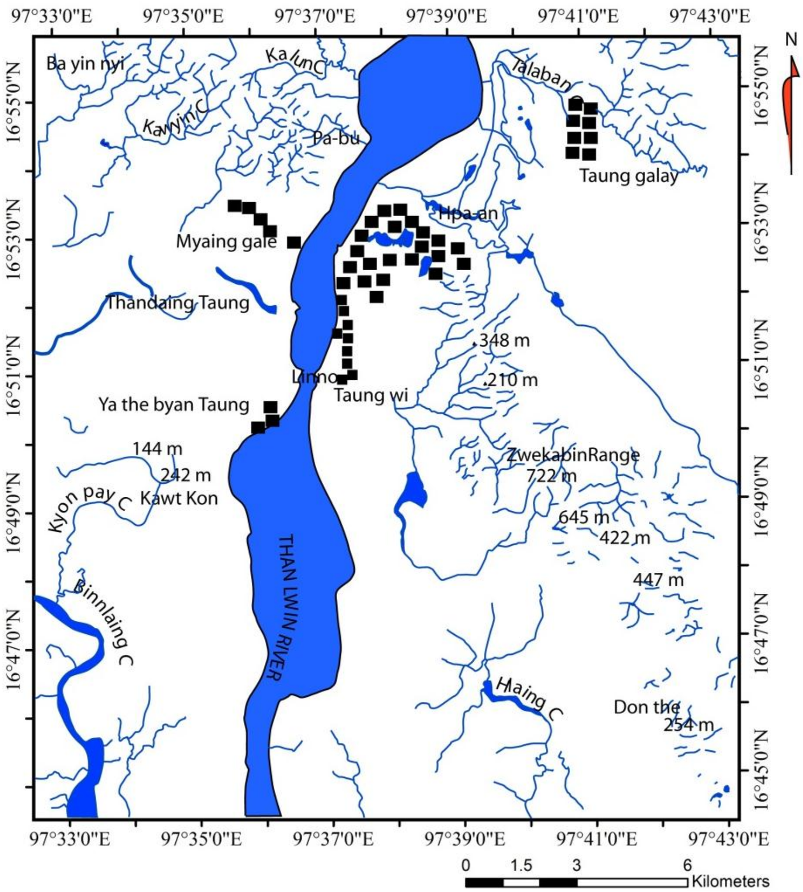


Figure 3: Drainage map of the research area

Geology of the Research Area

The rocks of Taungnyo Formation (Carboniferous to Early Permian), Moulmein Limestone (Middle to Late Permian) and Alluvium (Quaternary) cover the study area with different relief.

The rocks of the Taungnyo Formation are exposed at the northern part of the Zwekabin Range and southern part of the Hpa-an Town. The rocks are mainly composed of clastic units; thin bedded, whitish grey to pinkish colored siltstone intercalated with thinnly laminated shale, partly fine grained nodular sandstone which is shown in Figure (4).

Moulmein Limestone is mostly composed at the Zwekabin Range with gentle dipping. The other isolated hills with karst topography are also composed of Moulmein Limestone. The rocks consist of medium to thick bedded, light grey to grey colored micritic limestone, dolomitic limestone and brecciated limestone of the Moulmein Limestone. (Figures 5, 6 & 7)

Most of the flatplains are covered by reddish brown to yellowish brown colored, thick alluvial soils. (Figure 8)

Figure 4: Thin bedded, whitish grey to pinkish colored siltstone intercalated with thinnly laminated shale, partly fine grained nodular sandstone of Taungnyo Formation at the northern part of Zwekabin Range

Figure 5: Medium to thick bedded, light grey to grey colored micritic limestone of the Moulmein Limestone at the entrance of Ba-yint-nyi Cave

Figure 6: Medium to thick bedded, grey to dark grey colored dolomitic limestone of the Moulmein Limestone at the exit of Ya-thae-pyan Cave

Figure 7: Medium to thick bedded, grey to dark grey colored brecciated limestone of the Moulmein Limestone at the western part of the Zwekabin Range

Figure 8: Reddish brown colored lateritic soil of the Alluvium at the north-eastern part of the Hpa-an Town

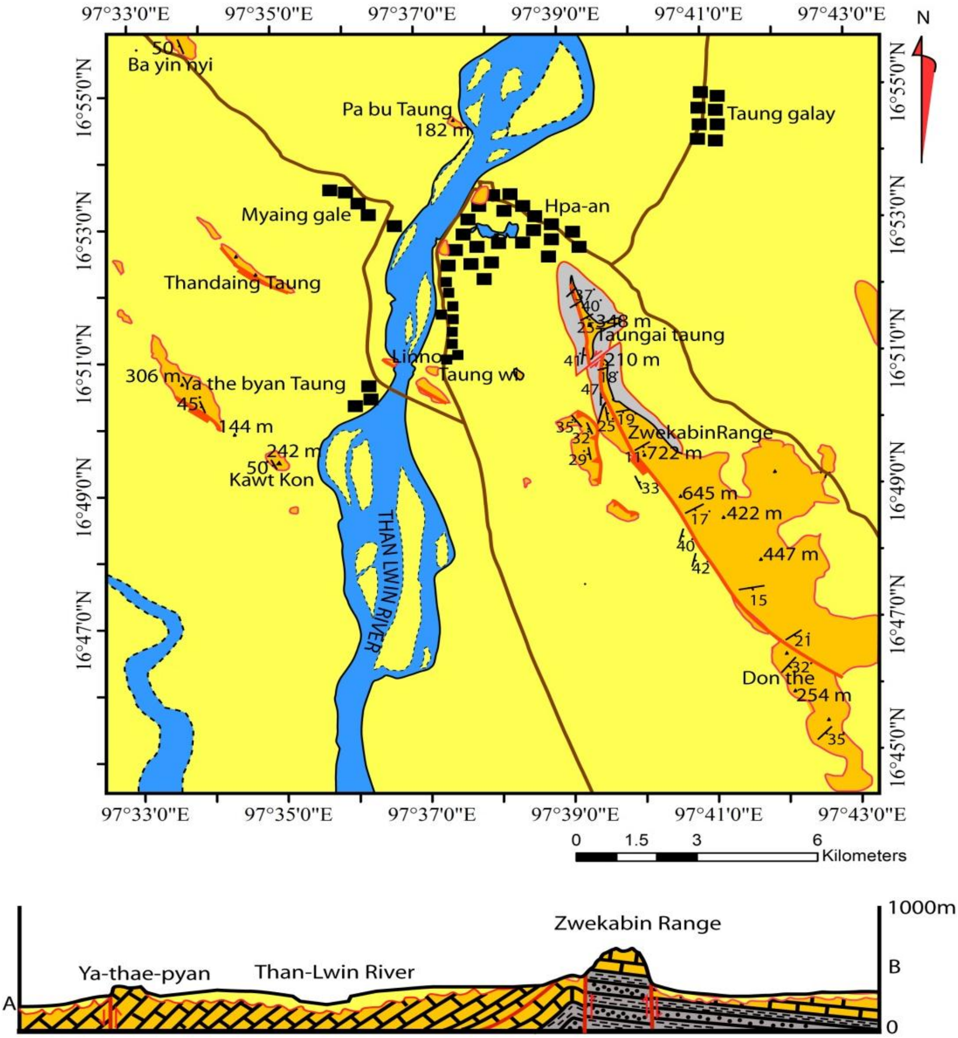
Geological Structures

The research area is mainly characterized by NNW-SSE trending stratigraphic units in eastern part and NW-SE trending in central and western part. Besides, the major longitudinal fault with normal sense occurs at the western flank of the Zwekabin Range which is trending nearly north-south in direction. (Figure 9) Another thrust fault is also trending parallel to the normal fault. (Figure 10) Other minor faults are trending nearly NW-SE direction which occurs as the normal faults at the western part of the research area which are shown in Figure (11). Moreover, the anticlinal fold occurs with NNW-SSE trending at the western part of the Zwekabin Range. The geological map of the research area is illustrated in Figure (12).

Figure 9: Normal fault scarp at the western part of the Zwekabin Range

Figure 10: Thrust sheet at the west of the Zwekabin Range

Figure 11: Normal fault scarp at the western part of the Ba-yint-nyi Cave



Geology by Aung Kyaw Myat and Aung May Than (2017)

Explanation

Alluvium (Quaternary)

Moulmein Limestone (Middle to Late Permian)

Taungnyo Formation (Carboniferous to Early Permian)

Figure 12: Geological map of the research area

Methodology

It has been done by the study and collection of all available geological Thesis and Papers (Iyer, 1938; Clegg, 1953; Chhibber, 1934; Brunnschweiler, 1970; Zaw Win and Kyaw Htin Khine, 2006; Win Swe, 2012; Maung Thein, 2014; Aung May Than, 2014; Saw Naing Tint Oo; 2015) and text books and papers of traventine (Allen, 2005; Caroll and Paolo, 1995; Fairchild, et al., 2006).

Topographic map interpretation is plotted on the UTM map no. 1697-9, 10, 13 and 14 of Survey Department (Ministry of Environmental Conservation and Forestry). Topographic units as features, elevation contrast and topographic trends, drainage systems in relation with structural controlled features are described in these studies.

By using the Arc GIS 10.1 (GIS software), the terrain analysis of the research area was done on the DEM image with 30 meter resolution.

And then, tape and compass traverse method compiled with distance meter measurement was used to draw the outcrop mapping and detail cave morphology.

The collection of water samples made by Saw Naing Tint Oo (2015) in each caves have been carried out to test the chemical composition of water and to know the water qualities.

The identification and analysis of cave deposits were done by the classification of Hill and Forti, 1997. Moreover, the mechanisms and processes of cave developments were followed by the Allen Pentecost, 2005.

Results and Discussions

Formation of Speleothems

The development of big cave system with dozens or hundreds of meters in length begins with micro-karst cavities. And then larger pores, pits, shafts and small caverns are developed by the opening of bedding planes, fissures, joints and faults which gradually integrate and expand into channels that collect the water flows. Finally, cave system comes into existence when many such channels are connected.

On the other hand, the speleothems are formed by the following processes. When rainwater seeps through the soil, it absorbs carbon dioxide (CO2) given off by plant roots, soil animals and decaying matter. This carbon dioxide makes the water acidic and able to dissolve limestone (calcium carbonate).

These limestone caves in Hpa-an area were formed, related with micritic limestone, dolomitic limestone and brecciated limestone of the Moulmein Limestone (Permian in age). These rocks dissolve in the acidic water as it finds its way through tiny cracks such as joints, fractures, etc in the rock. When the water reaches the cave, it loses carbon dioxide to the cave air. Water is now less acidic and unable to hold the same amount of limestone. Tiny crystals of calcium carbonate are deposited slowly to make the decoration to the caves with speleothems.

Classification of Speleothems

Hill and Forti (1997) classified the speleothems depend on the five hydrological mechanisms such as dripping, flowing, seeping, pooled and splashing water. They classified into 31 kinds of speleothems based on their forms and water conditions. (Figure 13A & B)

Among them, the common types of speleothems are stalactite, stalagmite, column, flowstone and rimstone dam. They are formed by the following processes.

Stalactite

When a soda straw is forming, the solution will also deposit calcite along the inner part of the tube as it travels through it. Eventually, the straw will become solid. At that point, as the solution continues to enter the cave, it is forced to the side of the tube, then runs down outside. Over time, the result looks like an icicle.

Stalagmite

As the watery solution falls from the ceiling, it lands on the floor or a ledge where it splashes or runs over an area, leaving the remaining calcite in its wake. The continued deposits build into a mound.

Column

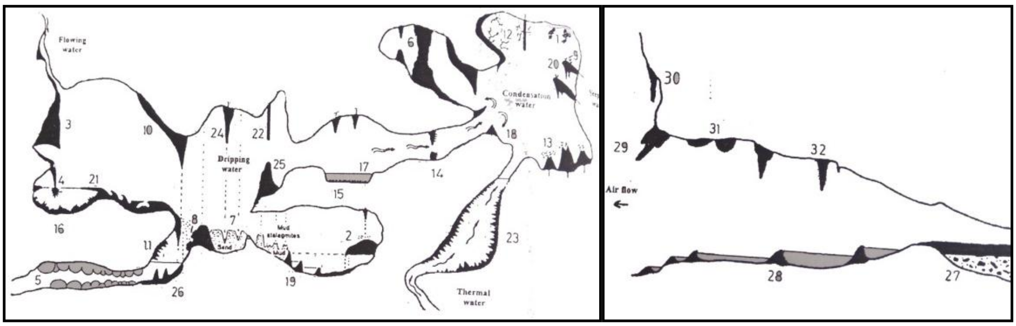
As usual, a stalagmite is directly below a stalactite. Over much time they may finally meet. As calcite continues to run down the length of the stalactite, it now continues to run down the connected stalagmite smoothing the connection point. Some columns have been together for so long that it is hard to tell where the two formations first joined.

Flowstone

It is similar to the formation of a stalagmite. However, the area receiving the deposit has a slope to it, so the water runs down the slope in a wide spread. A flowstone can cover a large area.

Rimstone Dam (also known as Gours in Europe)

Depressions in the cave floor may collect saturated water. The calcium in the solution will deposit around the edge of the pool. Eventually the deposits build up so high that more and more water can be held. The calcite deposits act as a dam.



(A) (B)

Figure 13: Diagram of speleothem type (after Hill and Forti, 1997)

(A) (1) Anthodites, (2) Baldacchino canopy, (3) Bell canopy flowstone, (4) Bottle brush stalactite, (5) Cave clouds, (6) Column, (7) Conulites in sand, (8) Coralloids, (9) Cups, (10) Drapes, (11) Folia, (12) Helictites, (13) Geysermites, (14) Oriented popcorn, (15) Pearls, (16) Pool spar, (17) Raft/floe, (18) Rims, (19) Rimstone dams, (20) Shields, (21) Shelfstone, (22) Soda straw stalactite, (23) Spar, (24) Stalactite, (25) Stalagmite, (26) Tower cones

(B) (27) Clastic traventine under stalagmite floor, (28) Dam, (29) Phototropic stalactite, (30) Remora or aussenstalactit and (31) Roof boss.

Identification of Speleothems at the Ya-thae-pyan Cave

The Ya-thae-pyan cave is 433 meter long and its alignment is NW-SE in direction. The rocks are made up of micritic limestone, dolomitic limestone and brecciated limestone of the Moulmein Limestone. There are 16 kinds of speleothems according to Hill and Forti (1997) which is shown in Figure (14-19).

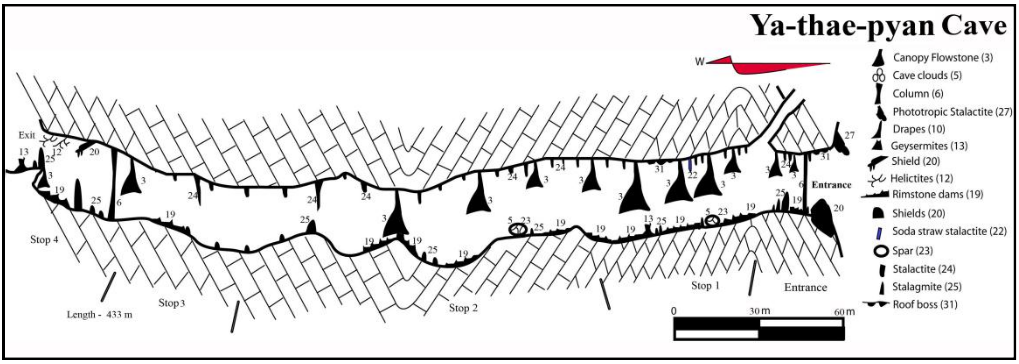


Figure 14: Morphology of speleothem with cross-sectional view at the Ya-thae-pyan cave

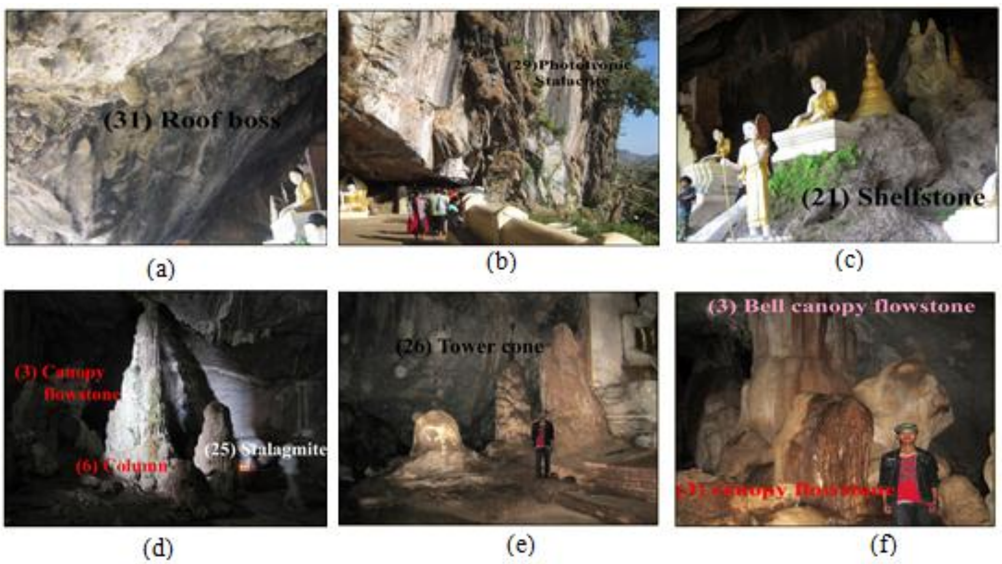


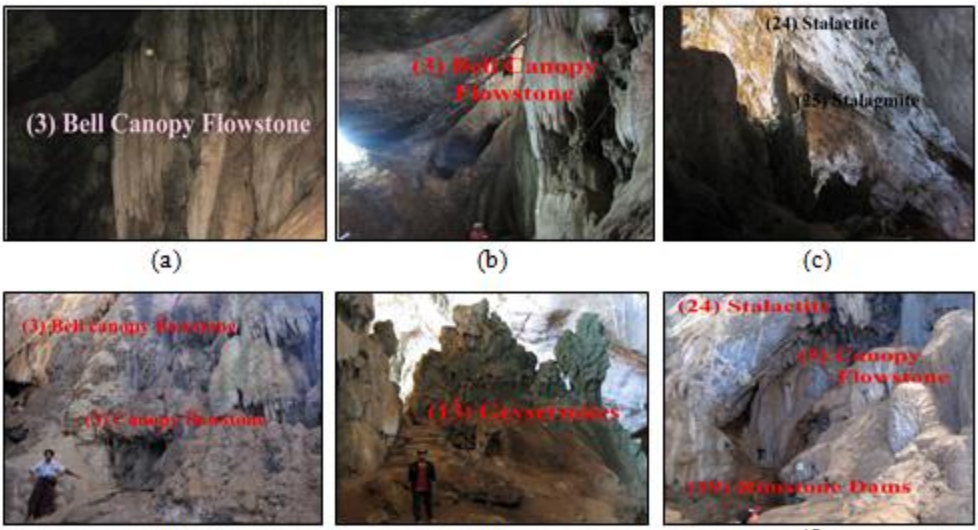
Figure 15: (a-f) Types of the speleothem at the entrance of Ya-thae-pyan cave

(a) (b) (c)

Figure 16: (a-c) Types of the speleothem at the (Stop 1) of Ya-thae-pyan cave

(a) (b) (c)

Figure 17: (a-b) Types of the speleothem at the (Stop 2) of Ya-thae-pyan cave



(a) (b) (c)

(d) (e) (f)

Figure 18: (a-f) Types of the speleothem at the (Stop 3) of Ya-thae-pyan cave

Figure 19: (a-c) Types of the speleothem at the (Stop 4) of Ya-thae-pyan cave

Identification of Speleothems at the Ba-yint-nyi Cave

The Ba-yint-nyi cave is 205 meter long and its alignment is also NW-SE in direction. The rocks are made up of micritic limestone and dolomitic limestone of the Moulmein Limestone. There are 14 kinds of speleothems according to Hill and Forti (1997) which is shown in Figure (20-26). Among these speleothems, stalactite, stalagmite, flowstone and rimstone dam are commonly occurred along the cave.

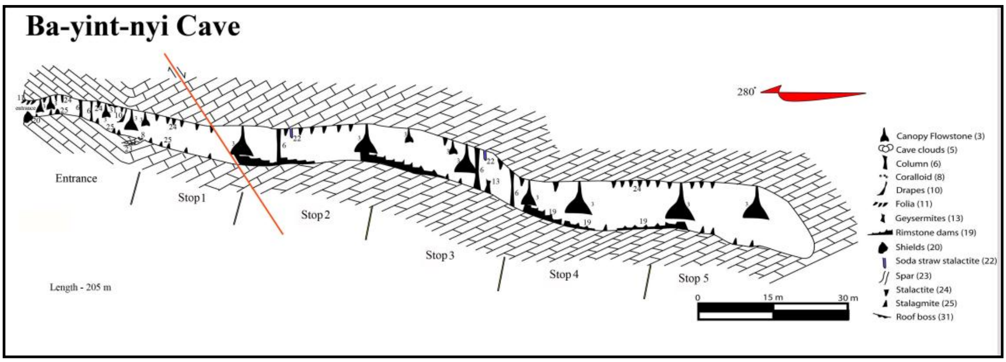
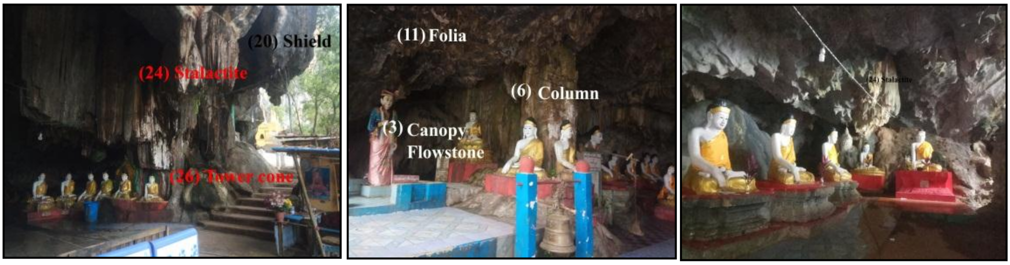


Figure 20: Morphology of speleothem with cross-sectional view at the Ba-yint-nyi cave



(a) (b) (c)

Figure 21: (a-d) Types of the speleothem at the entrance of Ba-yint-nyi cave

(a) (b) (c)

(d) (e)

Figure 22: (a-e) Types of the speleothem at the (Stop 1) of Ba-yint-nyi cave

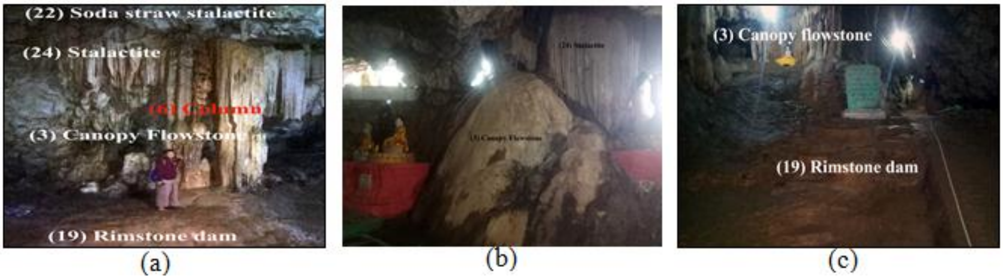


Figure 23: (a-c) Types of the speleothem at the (Stop 2) of Ba-yint-nyi cave

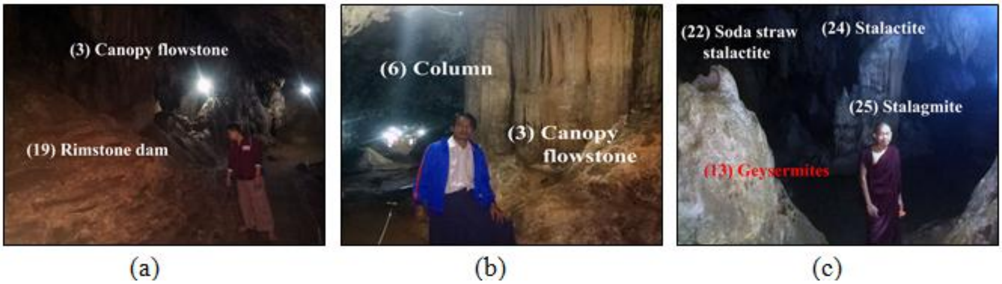


Figure 24: (a-c) Types of the speleothem at the (Stop 3) of Ba-yint-nyi cave

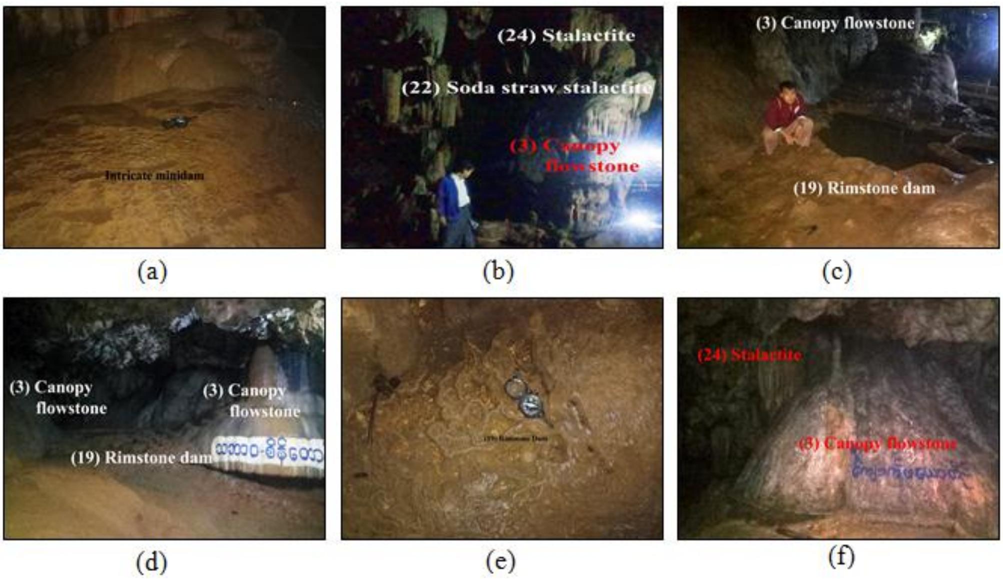


Figure 25: (a-f) Types of the speleothem at the (Stop 4) of Ba-yint-nyi cave

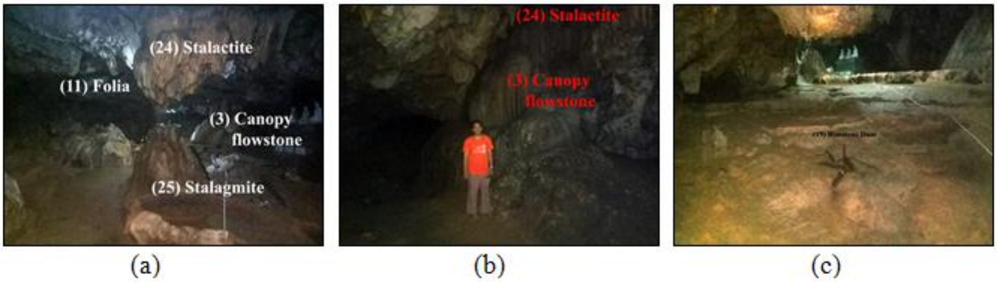


Figure 26: (a-c) Types of the speleothem at the (Stop 4) of Ba-yint-nyi cave

Identification of Speleothems at the Kawtgon Cave

The Ba-yint-nyi cave is also 70 meter long and it is trending nearly NNW-SSE in direction. The rocks are made up of micritic limestone and dolomitic limestone of the Moulmein Limestone. There are 9 kinds of speleothems according to Hill and Forti (1997) which is shown in Figure (27-29). Among these speleothems, stalactite, stalagmite, flowstone and rimstone dam are commonly occurred along the cave.

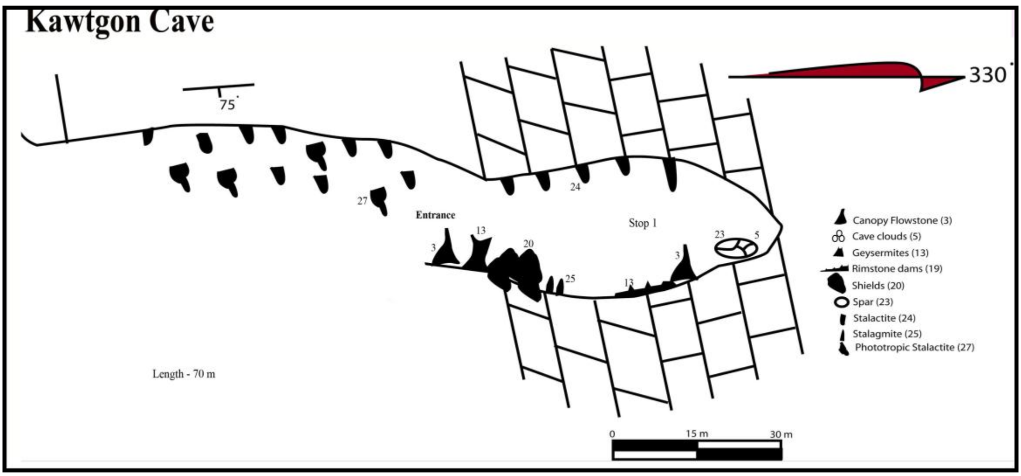


Figure 27: Morphology of speleothem with cross-sectional view at the Kawtgon cave

Figure 28: (a-c) Types of the speleothem at the entrance of Kawtgon cave

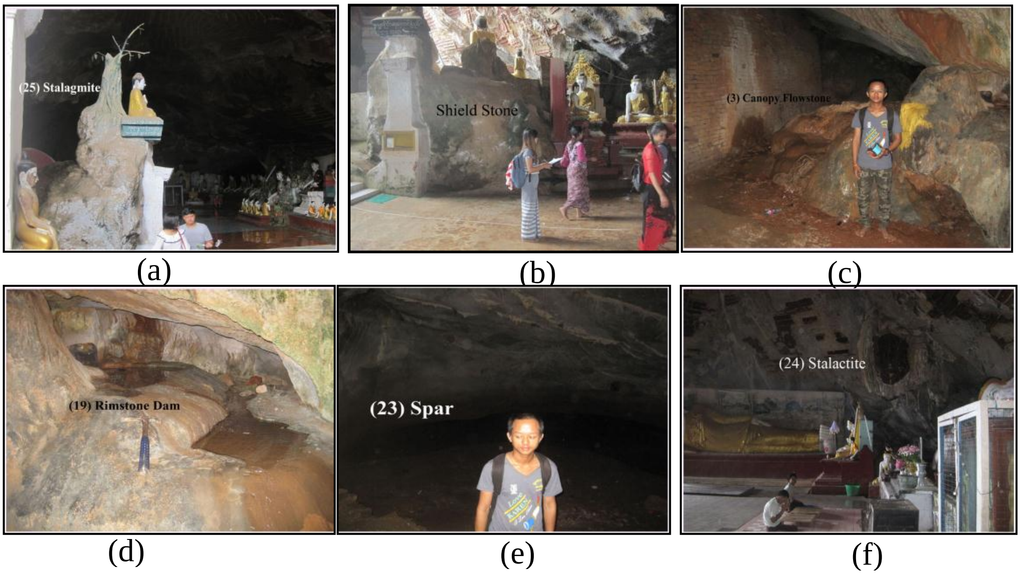


Figure 29: (a-f) Types of the speleothem at the (Stop 1) of Kawtgon cave

Identification of Speleothems at the Sadan Cave

This cave is the longest cave with beautiful speleothems and 800meter long, trending nearly N-S in direction. The rocks are made up of micritic limestone, brecciated limestone and dolomitic limestone of the Moulmein Limestone. There are 13 kinds of speleothems according to Hill and Forti (1997) which is shown in Figure (30-36). Among these speleothems, stalactite, stalagmite, flowstone, column and rimstone dam commonly occur along the cave.

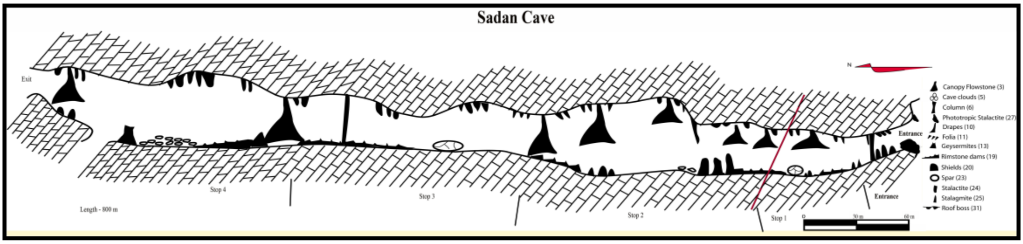


Figure 30: Morphology of speleothem with cross-sectional view at the Sadan cave

(a) (b) (c)

Figure 31: (a-c) Types of the speleothem at the entrance of Sadan cave

(a) (b) (c)

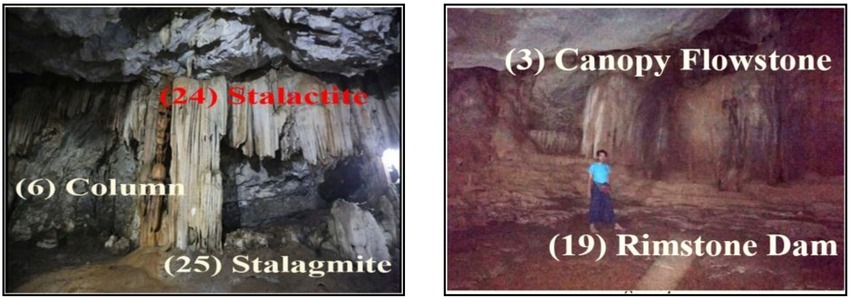
Figure 32: (a-c) Types of the speleothem at the (Stop 1) of Sadan cave

(a) (b) (c)

Figure 33: (a-c) Types of the speleothem at the (Stop 2) of Sadan cave

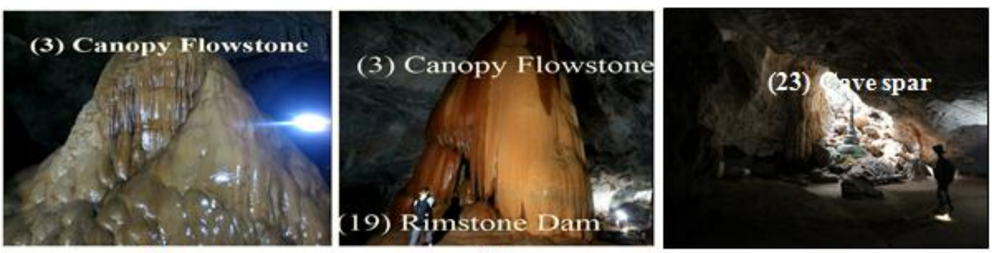
(a) (b) (c)

Figure 34: (a-c) Types of the speleothem at the (Stop 3) of Sadan cave



(a) (b)

Figure 35: (a-b) Types of the speleothem at the (Stop 4) of Sadan cave



(a) (b) (c)

Figure 36: (a-c) Types of the speleothem at the (Stop 5) of Sadan cave

Identification of Speleothems at the Linno Cave

The Linno cave is not favourable for conservation because the cave is also home for many bats. The cave is 67 meter long and it is trending nearly NW-SE in direction. The rocks are made up of cherty limestone of the Moulmein Limestone. There are 5 kinds of speleothems according to Hill and Forti (1997) which is shown in Figure (37-41). Among these speleothems, stalactite, stalagmite, flowstone and rimstone dam commonly occur along the cave. Besides, the landslide, rockfall occurs at the entrance of the Linno cave.

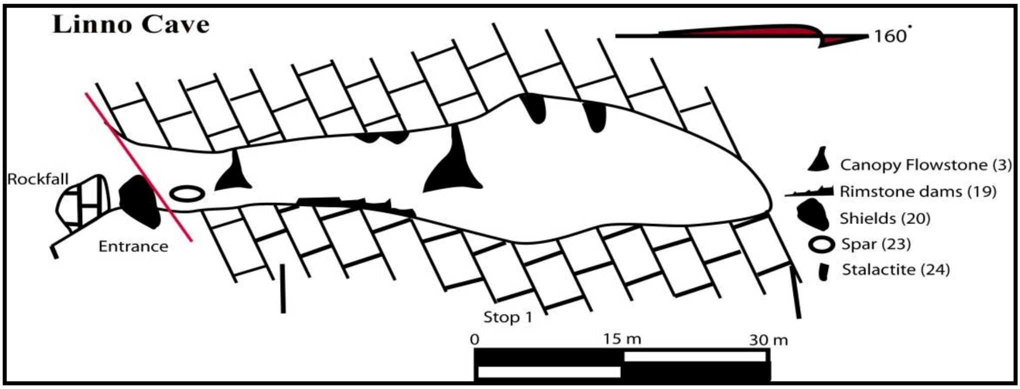


Figure 37: Morphology of speleothem with cross-sectional view at the Linno cave

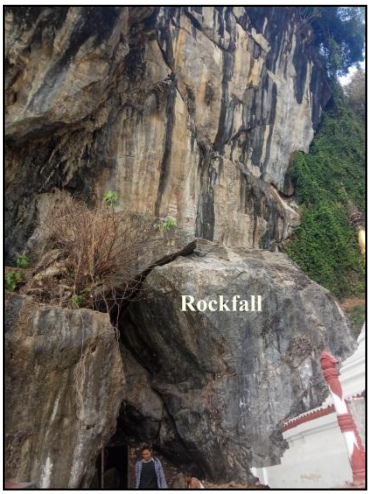


Figure 38: Photograph showing nature of landslide at the entrance of Linno cave

Figure 39: Photograph showing nature of fault, landslide and type of speleothem at the entrance of Linno cave

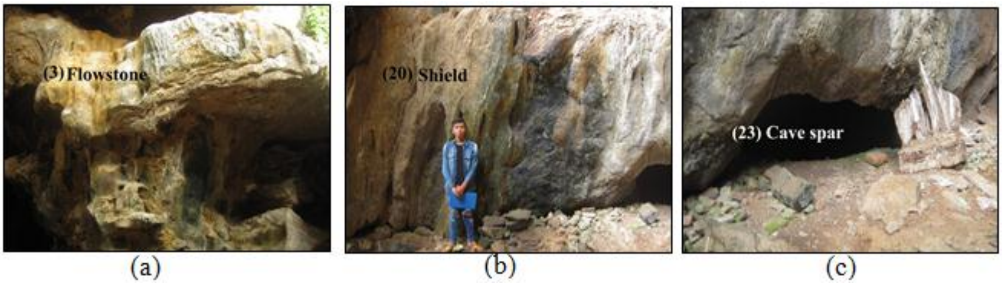


Figure 40: (a-c) Types of the speleothem at the entrance of Linno cave

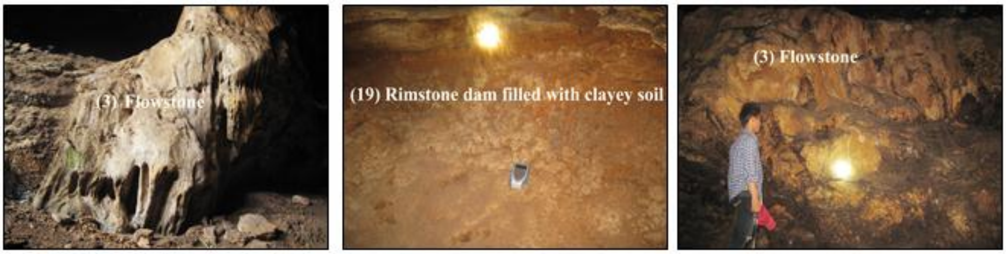


Figure 41: (a-c) Types of the speleothem at the (Stop 1) of Linno cave

Controlling Factors in the Formation of Speleothems

In the limestone terrain, the water condition, opening of rocks such as joints, cracks, bedding plane and faults and inclination of wall rocks are the main controlling factors in forming the speleothems. Besides, the amount and rate of water flowage can also influence on the shape and size of the speleothems. The water condition with their related types of speleothems is as follows in Table (1).

Table 1: The relation between water condition and types of speleothems

Water condition	Types of Speleothems
Dripping	(2) Baldacchino canopy, (4) bottle brush stalactite, (6) Column, (7) conulites in sand, (13)Greysermites , (14) oriented popcorn, (15) pearls, (22) Soda straw stalactite, (24) stalactite, (25) stalagmite, (29) Phototropic stalactite, (30) Remora or aussenstalactit
Flowing	(3) Bell canopy flowstone, (5) cave cloud, (8) coralloids, (18) Rims, (19) Rimstone dams, (23) spar, (26) Tower cones, (27) dam
Seeping	(1) Anthodite, (9) Cups, (10) Drapes, (11) Folia, (12) Helictites, (20) shield, (31) Roof boss
Pooled water	(16) Pool spar, (17) raft/toe, (21) shelfstone, (26) clastic traventine under stalagmite floor
Splashing water	Few

Source Water Chemistry

In this study, hydrogen ion concentration (pH), electrical conductivity (EC), bicarbonate (BC), calcium (Ca) and temperature (T) analysis containing the water in each cave have been carried out by the laboratory test which is described in Table 2 and Figure 42-46. According to these results, all caves have good condition in pH. Some high contents of calcium occur where calcium content is more than 75 mg/l of WHO standard. Besides, among the temperature test results, water in Ba-yint-nyi cave has high temperature that is affected by hot spring in there.

Groundwater precipitation from which traventine in the cave varies greatly in their chemical composition. According to the chemical composition of source water after Allan (2005), Calcium hydroxide waters may have in excess undetectable levels of CO_2 and a low ionic strength while thermogene springs may have pH range from less than 6 to more than 12. Moreover, under high temperature and pressure, aqueous solutions of CO_2 are very reactive and capable of dissolving large amounts of carbonate. So, thermogene travertines form from a range of carbon dioxide sources and receive most of their carrier CO_2 from thermally-driven processes in this area because of the sub-tropical climate condition.

Table 2: Chemical composition of water in each cave

Cave name	pH	EC	BC (mmol/L)	Ca (mg/l)	T (C°)
Ba Yint Nyi	7.5	132	3.4	246	38.6
Kyauk Gon	7.85	387	4.8	80	27.5
Ya Thet Pyan	7.04	613	7.5	122	27.8
Sadan	7.69	327	4.1	74	25.6

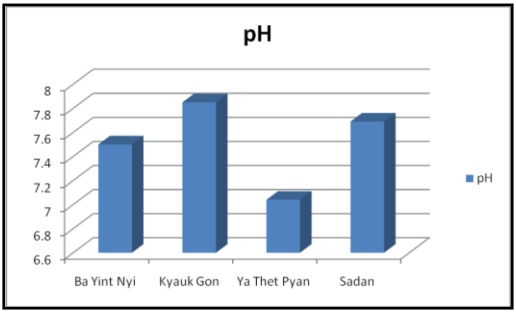


Figure 42: Comparative study of hydrogen ion concentration (pH) in caves

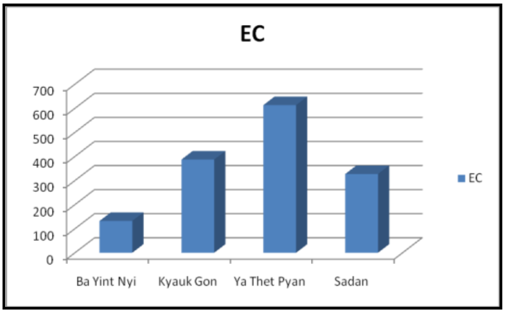


Figure 43: Comparative study of electrical conductivity (EC) in caves

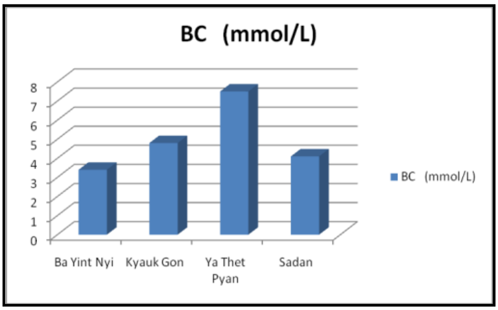


Figure 44: Comparative study of Bicarbonate (BC) in caves

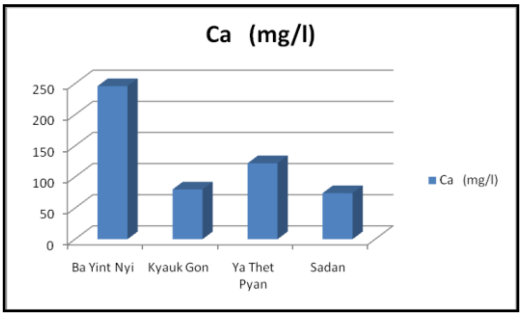


Figure 45: Comparative study of Calcium (Ca) in caves

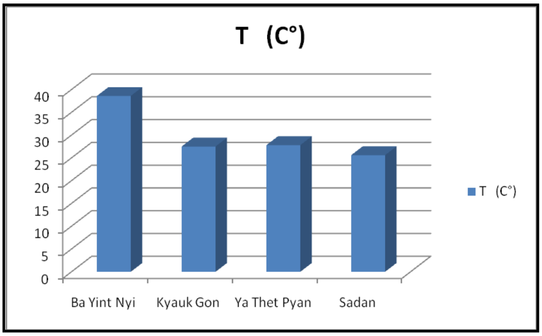


Figure 46: Comparative study of Temperature (T) in caves

Conclusions

The research sites are in the Ba-yint-nyi cave, Ya-thae-byan cave, Kawtgon cave, Sadan cave and Linno cave in Hpa-an Township, Kayin State, Myanmar. This area is mostly composed of the sedimentary rocks such as siltstone with laminated shale and nodular sandstone of the Taungnyo Formation (Carboniferous to Early Permian), micritic limestone, dolomitic limestone and brecciated limestone of the Moulmein Limestone (Middle to Late Permian) and Alluvium (Quaternary). Moreover, the caves in this study are mainly composed of the rocks of Moulmein Limestone with beautiful speleothems.

According to the classification of speleothems after Hill and Forti (1997), there are at least 17 kinds of speleothems in these caves. These speleothems are formed by the controlling of five hydrological mechanisms such as dripping, flowing, seeping, pooled water and splashing water. Moreover, the other controlling factors in forming speleothems are opening of rocks such as joints, cracks, bedding plane and faults and inclination of wall rocks. The amount and rate of water flowage also influence the shape and size of the speleothems.

According to the laboratory test results for water chemistry, all caves have good condition in pH. Some high contents for calcium occur where calcium contents is more than 75 mg/l of WHO standard. Besides, among the temperature test results, water in Ba-yint-nyi cave has high temperature that is affected by hot spring in there. According to the chemical composition of source water after Allan (2005), Calcium hydroxide waters may have in excess undetectable levels of CO_2 and a low ionic strength while thermogene springs may have pH range from less than 6 to more than 12. Moreover, under high temperature and pressure, aqueous solutions of CO_2 are very reactive and capable of dissolving large amounts of carbonate. So, thermogene travertines form from a range of carbon dioxide sources and receive most of their carrier CO_2 from thermally-driven processes in this area because of the sub-tropical climate condition.

The beautiful limestone caves are not only difficult in formation but also rare in Myanmar. So, these caves are important for preservation as geoheritage sites as well as geopark because of the geotourism. Moreover, these caves act natural ornaments for our country.

Acknowledgements

The author would like to express his gratitude towards Dr. Mya Mya Aye, Rector in-charge, Hpa-an University for her permission to carry out the present research work.

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MICROFACIES ANALYSIS OF SILURIAN CARBONATE ROCKS IN THE AREA BETWEEN YATSAWK AND BAWSAING, SHAN STATE (SOUTH)

Aye Aye Han[1], Myittar[2], Win Naing[3], Thida Than[4], Khin Hnin Swe[5]

Abstract

Carbonate microfacies analysis was systematically carried out focusing on the sedimentological characters for the rock units exposed in the area between Yatsawk and Bawsaing, Yatsawk township, Shan state (south), Myanmar. It lies between latitude 21° 03' N and 21° 07'N, longitude 96° 45' E and 96° 55'E, representing one inch topographic map index of 93 C/16. Most of the exposed rock units are limestone and dolomite with different lithologic characters in different geological age, with minor amount of clastic rocks. Detailed sedimentological analysis and interpretations are carried out for the Linwe Formation. It consists of purple, pink and grey, medium to thick bedded phacoidal limestones, fine-grained, poorly jointed, wavy and discontinuous laminated, argillaceous limestone, bluish-grey calcareous shale and calcareous mudstone. Based on the partical component, texture and sedimentary structure six microfacies such as lime mudstone, bioclastic lime mudstone, biointraclastic wackestone, bioclastic wackestone, bioclastic lithoclasticpackstone and bioclastic packstone are recognized. By the microfacies analysis, Linwe Formation can be subdivided into four different facies associations falling into four main depositional environments, namely, foreslope, open sea shelf, deep shelf margin and basin by identifying their grain type, physical, biologic and sedimentary structures.

Keywords: Shan State, Linwe Formation, foreslope, open sea shelf, deep shelf margin, basin, microfacies, facies association

Introduction

The research area lies between the latitude 21° 03' N to 21° 07' N and longitude 96° 45° E to 96° 55' E. This area occupies between Yatsauk and Bawsaing. Location map of the research area is as shown in Figure (1). Stratigraphically Bawsaing range is covered with the rocks of the Chaungmagyi Group (Precambrian), the Pindaya Group (Ordovician), the

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Mibayataung Group (Silurian), the Zebingyi Formation (Early Devonian) and the plateau Limestone Group (Permian to Early Triassic) (National Committee, I.G.C.P., 1980). This research comes out from the microfacies analysis of the Silurian carbonate rocks of the Linwe Formation in this investigated area. At least 6 microfacies can be distinguished from the rocks of Linwe Formation.

Terminology and classification for microfacies is according to Dunham (1962) and Wilson (1975). Terminology of Folk (1965) for carbonate crystal shapes is also adopted for this research.

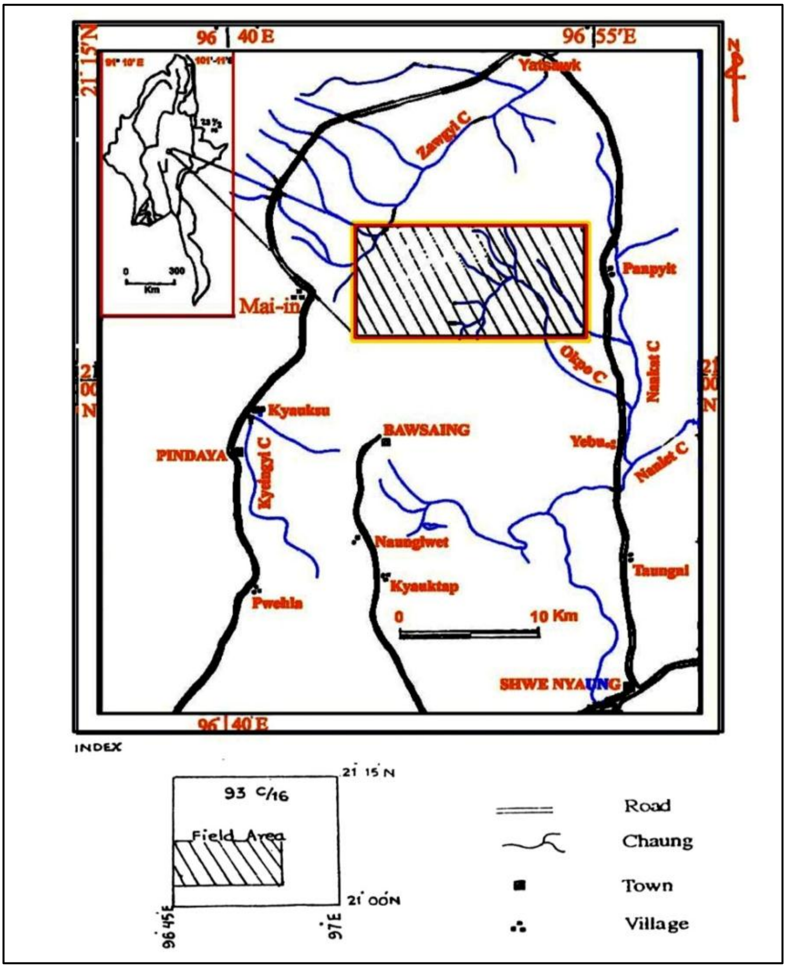

Figure 1: Location map of the research area

Methods of Study

- Tracing lithologic contact from one inch topographic map and aerial photographs
- Field investigation and collecting the samples
- Microscopic examination
- Staining Analysis

Microfacies Analysis of the Silurian carbonate rocks, Linwe Formation

The Linwe Formation is widely distributed in this area. The rocks of the Linwe Formation can be classified into six microfacies based on the particle component, texture and sedimentary structure. These microfacies are –

(1)	lime mudstone	(L-1)
(2)	bioclastic lime mudstone	(L-2)
(3)	biointraclastic wackestone	(L-3)
(4)	bioclastic wackestone	(L-4)
(5)	bioclastic-lithoclastic packstone	(L-5)
(6)	bioclastic packstone	(L-6)

Petrographic plots of the Linwe Formation based on the orthochem and allochem compositions are as shown in figure (2).

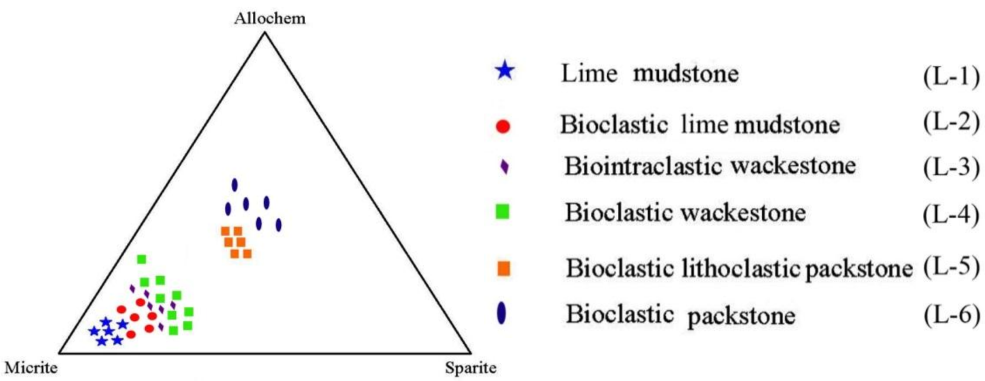

Figure 2: Petrographic plots of the Linwe Formation based on the orthochem and allochem content.

Microfacies 1: Lime mudstone (L-1)

Microfacies description

This microfacies consists of planar laminated (lamination is maximum 4cm), grey, thin to medium bedded argillaceous limestone with bluish grey calcareous shale. The rocks of this microfacies occupy the lower and middle part of measured section. The rock consists of dense, dark grey, organic rich micrite and argillaceous lime mudstone.

Microfacies interpretation

There is no evidence for high current energy. High micrite accumulation reflects low energy condition. The fact that the rock has lack of fossil evidence indicates the environment of deposition is not hospitable for marine life. Most fine-grained sediments are largely deposited by suspension. Thinly, flat laminated limestone and its fine-grained nature of this facies strongly suggests slow rate of sedimentation in low energy quiet water environment.

Microfacies 2: Bioclastic lime mudstone (L-2)

Microfacies description

It is composed of grey to buff coloured, medium bedded, thickening upward in bedding and lamination, argillaceous limestone with shale. Thickness of intercalated shale lamination is about 3mm to 5mm.

The rock comprises bioclasts such as ostracods 4-5%, crinoids 3-5% and thin bivalve shells 1% by volume which are well packed by microcrystalline carbonate mud (Figure 3). Unbroken bioclasts are more common than broken one and filled with sparry calcite mosaic. Their size is 0.1mm in diameter, and moderately to well sorted. Interparticle pores are filled with microcrystalline carbonate mud same as matrix. Microstylolites are locally common; along which clay materials are observed. Scattered pyrite bits are 0.025mm to 0.075 mm in size containing less than 1% by volume. They are idiotopic fabric with rectangular outline (Figure 4).

Microfacies interpretation

High content of lime mud is evidence for lower energy condition. Parallel lamination indicates the low energy condition and medium bedded nature shows slow rate of sedimentation. Limestone with intercalated argillaceous layer suggests the alternate deposition of clastic rich sediments and carbonate-rich sediments with fluctuation in current energy condition. Bioclasts are possibly derived from up slope.

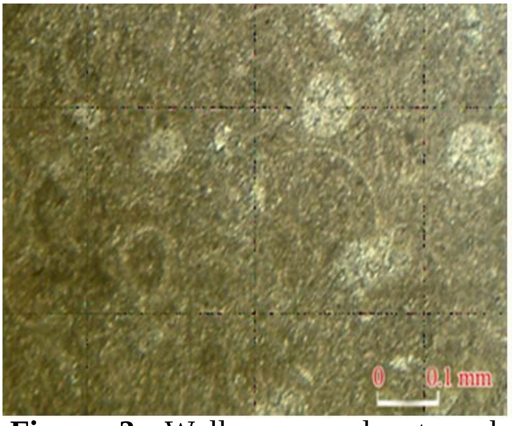

Figure 3: Well preserved ostracod shells (o) are well packed by microcrystalline carbonate mud (m) in bioclastic lime mudstone microfacies (MF-2) PPL.(S.No.A 12)

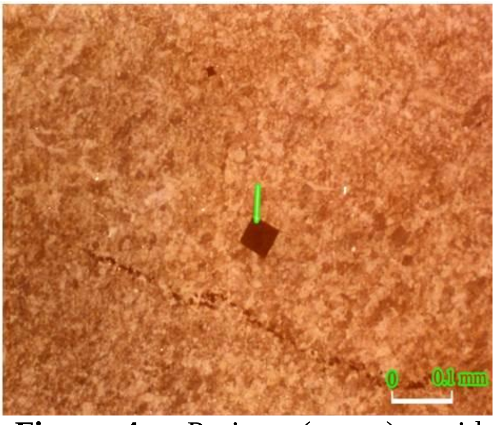

Figure 4: Pyrite (arrow) with rectangular outline scattered in bioclastic lime mudstone showing reducing environment. PPL. (S.No. B.7)

Microfacies 3: Biointraclastic wackestone (L-3)

Microfacies description

This rock is made up of buff coloured, thinly bedded and very fine-grained, limestone. Argillaceous content is higher upward and slump feature is common.

This rock consists of bioclasts about 1-2% by volume and slightly lithified intraclast 20%. Intraclasts are 1mm in maximum diameter. They are roughly equidimensional, not well sorted, but sub-rounded in appearance and clayey material coated (Figure 5). Matrix is bioclastic mudstone. Intraclasts and matrix are same. Interparticle pores are filled with microcrystalline calcite mud.

Microfacies interpretation

High micrite accumulation reflects low energy condition. Previously lithified intraclasts are transported by current from up slope and probably deposited in unstable inclined slope. Subrounded appearance of intraclasts shows slight wave energy condition.

Microfacies 4: Bioclastic wackestone (L-4)

Microfacies description

This rock consists of light grey to pinkish or purple, medium to thick bedded, fine-grained, poorly jointed, wavy discontinuous laminated argillaceous limestone. Phacoidal structure is also developed and nodular bedding is common. Crinoid fragments are locally scattered on weathered surface. This microfacies is widely distributed throughout the measured section.

The rock consists of bioclasts such as echinoids up to 20%, ostracods about 4-10%, gastropods 10%, brachiopod 5% by volume. Bioclasts are not sorted in size and shapes. Interpartical pores are filled with microcrystalline carbonate mud. Internal sediments of the bioclasts is same as micrite matrix. Types of bioclasts are diverse. Aggraded neomorphosed bioclast is shown in (Figure 6). Degraded neomorphosed Brachiopod shell is shown in (Figure 7). Drusy calcite cement filled the interparticle pores (Figure 8). Amplitude of microstylolite (Figure 9) ranges from 0.1mm to 0.3 mm. This microfacies can be correlated with S.M.F 9 (Wilson, 1975).

Microfacies interpretation

Low energy condition is suggested by high content of lime mud accumulation. Wavy discontinuous argillaceous laminations indicate slight current condition within sufficient supply of fine clastic sediments by intermittent storm. Diverse shelly fauna reflects oxygenated normal marine salinity with adequate water circulation. The fact that unbroken shells are more than broken bioclasts suggests that shells were not influenced by wave action and they are well packed by micrite.

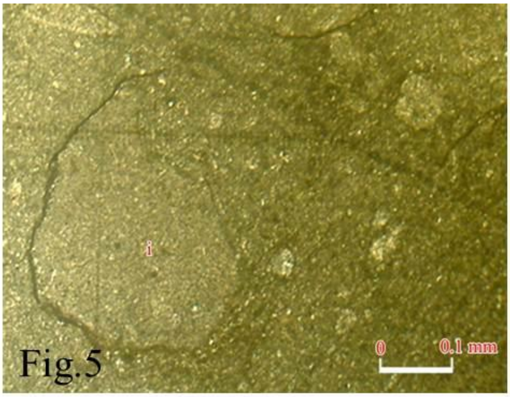

Figure 5: Previously lithified intraclasts (i) which are same as matrix in biointraclastic wackestone microfacies in lower part of measured section. PPL. (S.No . A.29)

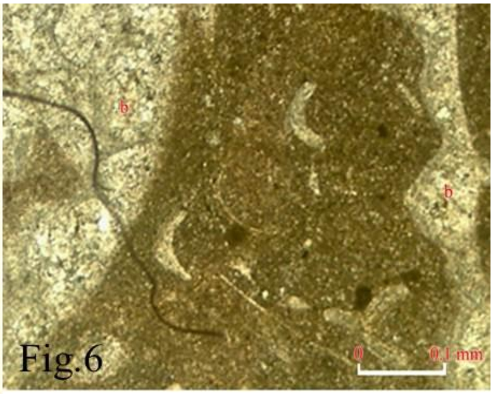

Figure 6: Bioclastic wackestone in which bioclasts (b) are aggrading neomorphosed, middle part of measured section PPL. (S.No. A.42)

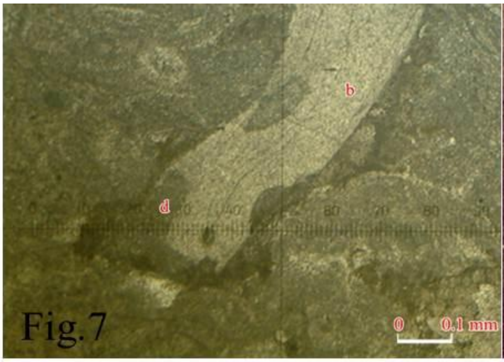

Figure 7: Degrading neomorphism (d) in brachiopod shell fragments (b) in bioclastic wackestone, lower part of measured section PPL. (S.No. A2)

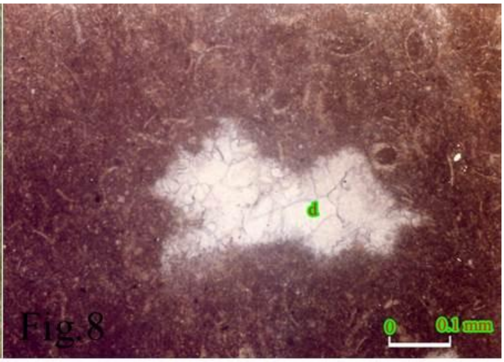

Figure 8: Drusy calcite cement (d) filled in the interparticle pores in the bioclastic wackestone microfacies, PPL. (S. No. B.9)

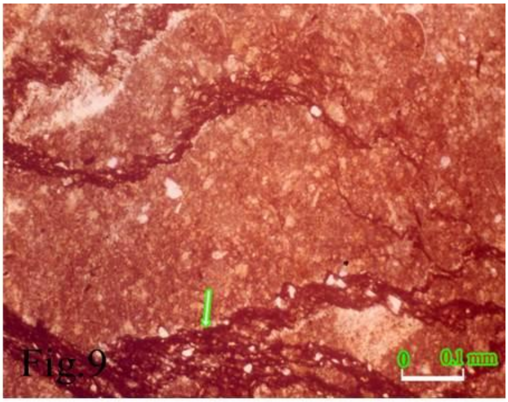

Figure 9: Network type microstylolite (arrow) due to pressure solution in late diagenetic process, bioclastic wackestone. PPL. (S. No. B. 11)

Microfacies 5: Bioclastic-lithoclastic packstone (L-5)

Microfacies description

This rock comprises buff coloured, micaceous, soft, thin to medium bedded, poorly exposed limestone with shale and silt intercalation.

This rock composed of bioclastic lithoclasts fragments 50% by volume and previously lithified lithoclastic fragments (Figure 10). Bioclasts and lithoclasts are coated, subrounded and poorly sorted. Size of bioclastic grains is up to 0.2mm in diameter. This microfacies can be correlated with S.M.F 4 of by Wilson, 1975.

Microfacies interpretation

Dominant particles are of high energy environment and have moved down to local slopes to be deposited. Coarse shell fragments may be derived from up slope by slight energy current velocity. Abundant occurrence of lithoclasts in various size and rock type strongly suggests the rocks are made up entirely of marine talus and coarser debris probably derived by submarine slumping or turbidity current.

Microfacies 6: Bioclastic packstone (L-6)

Microfacies description

This rock is greenish to pinkish, medium to coarse crystalline, thick bedded wavy laminated, poorly jointed, nodular limestone. Crinoids stems commonly occur on the bedding plane and weathered surface. The rocks are composed of bioclasts more than 50% by volume. Matrix is microcrystalline carbonate and clayey materials. Crinoids are most abundant bioclasts in this microfacies. Some bioclastic grains are 0.2mm in diameter. Bioclastic grains are poorly sorted, rounded. Grains are showing syntaxial overgrowth, later subjected to micritisation (Figure 11). This microfacies coincide with S.M.F 5 by Wilson, 1975.

Microfacies interpretation

This microfacies with high diversity large amount of fauna strongly suggests good current circulation and normal marine salinity with well oxygenated condition. Wavy discontinuous lamination reflects the slight current condition with intense wave activities above normal wave base. Some coarser shell fragments were probably derived from up slope by current transportation.

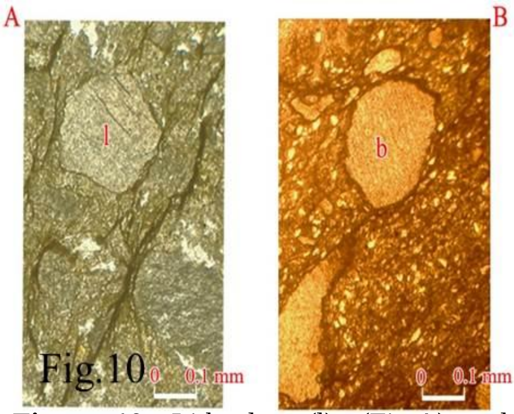

Figure 10: Lithoclast (l), (Fig.A) and corroded bioclastic lithoclast(b), (Fig.B) in bioclastic lithoclastic packstone microfacies. Notice that there is no grain to grain contact showing lack of deep burial compaction. PPL. (S. No. A40)

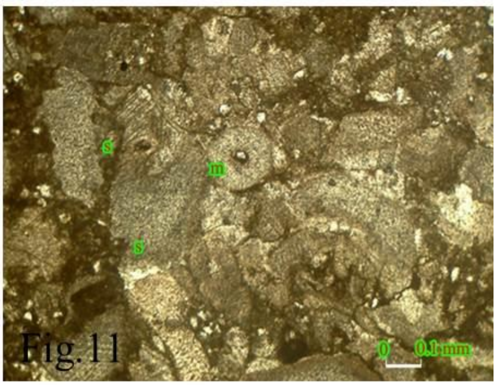

Figure 11: Bioclastic grains cemented by syntaxial overgrowth (s),later micritization occur. Bioclastic packstone microfacies PPL.(S.No. A.44)

Microfacies Association and Depositional Environment

The rocks of the Linwe Formation can be categorized into six microfacies. These microfacies are grouped into four main facies associations for four different depositional environments, such as, basin, open sea shelf, deep shelf margin and fore slope environment respectively. Table (1) describes-microfacies association, their depositional environment and respective characteristic features. Table (2) shows four main depositional environments identified by microfacies analysis of the Linwe Formation based on grain type, physical, biologic and sedimentary structure putting into (Wilson, 1975 and Reckmann & Friedman, 1981) modal.

Table 1: Depositional environment and characteristics features of the Silurian carbonate rocks, Linwe Formation

Micro facies No	Microfacies	Environment	Characteristic features
1.	Lime mudstone	Basin	▪ Lime mudstone with some calcisilt
2.	Bioclastic lime mudstone		• Low energy, rhythmic bedding
			• Some shale, fine clastic
3.	Biointraclastic wackestone	Deep shelf margin	❖ Slump, talus
			❖ Regular bedding
			❖ Low energy
			❖ Slightly lithified intraclast
			❖ Organism rolled particle
4.	Bioclastic wackestone	Open sea shelf	✓ Wackestone, diverse fossil, nodular bedding
5.	Bioclastic-lithoclastic packstone	Foreslope	➢ Lime sand,
			➢ Abundant organism
			➢ Lithoclast
6.	Bioclastic packstone		o High energy

Table 2: Characteristic Features of Depositional Environment for microfacies of the Silurian carbonate rocks, Linwe Formation

Depositional Environment / Characteristic Features	Basin		Open Sea Shelf	Deep Shelf margin	Foreslope	
Microfacies	1	2	4	3	5	6
Bedding						
Regular	—	—	—	—		
Irregular					—	—
Texture						
Mudstone	—	—		—		
Wackestone			—			
Packstone					—	—
Particles						
Bioclast		—	—	—	—	—
Intraclast				—		
RLithoclast					—	
Special Features						
Nodular bedding			—			—
Slumping					—	—
Organism Preservation						
Whole			—			
Broken		—		—		—
Rolled				—	—	—
Sedimentary structure						
Planar lamination	—	—				
discontinuous wavy			—			—
Energy						
Low	—	—	—	—		
High					—	—

Summary and Conclusion

The investigated area is situated in the west of Yatsawk- Shwenyaung motor road, Yatsawk Township, southern Shan State. This area is demarcated by latitude 21° 03' N to 21° 07' N and longitude 96° 45' E to 96° 55' E with one-inch to pographic map sheet No.93C/16.

Silurian carbonate rocks, Linwe Formation can be classified into 6 microfacies which fall into 4 different facies association. Lime mudstone (L-1) and Bioclastic lime mudstone (L-2) are probably deposited in basin environment. Characteristic feature of basin environment possessed in these microfacies are low energy lime mudstone, rhythmic bedding, some shale and fine clastics.

Biointraclastic wackestone (L-3). May be deposited in deep shelf margin due to the presence of regular bedding, slump, low energy condition and rolled particle organism and slightly lithified organism.

Bioclastic wackestone (L-4) having the characteristic features of diverse fossil, nodular bedding, discontinuous wavy lamination, is accumulated in open sea shelf environment.

Foreslope facies association contains bioclastic-lithoclastic packstone (L-5) and bioclastic packstone (L-6). These microfacies possess the characteristic features such as lime sand, abundant organism, lithoclast, high energy condition..

Sedimentation of the Linwe Formation may be brought about transitionally on foreslope, deep shelf margin, open sea shelf and basin at the time of Silurian.

Acknowledgement

The author is deeply indebted to Dr. Myint Thein (Retired Rector, Sagaing Institute of Education), Dr. Win Naing (Rector, University of Dagon) and U Myittar (Part-time Professor, Department of Geology, University of Yangon) for their helpful suggestions and valuable discussions.

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LITHOFACIES AND DEPOSITIONAL ENVIRONMENT OF OKHMINTAUNG FORMATION IN KYUNCHAUNG AREA, PAKOKKU DISTRICT, MAGWAY REGION, MYANMAR

ThidaThan[1], Day Wa Aung[2], Aye Aye Han[3], Khin Hnin Swe[4], Hayman Thawthar Nyein[5]

Abstract

The Kyun Chaung area is situated in Pakokku District, Magway Region in Central Myanmar. The study area is composed essentially of Cenozoic rock sequences of Lower Pegu Group (Oligocene – Miocene) and Irrawaddy Formation. The rock sequences of the Lower Pegu Group are Padaung Formation, Okhmintaung Formation, (Lower-Upper Oligocene). The detailed petrographic analysis is carried out for the sandstones of the Padaung and the Okhmintaung Formation to obtain the modal compositions of the rock units, diagenetic imprints and provenance study. From the petrographic analysis, sandstones of the Okhmintaung Formations can be regarded as lithic arkose in composition. According to the lithofacies analysis, at least five different lithofacies type can be recognized in Okhmintaung Formation. They are Sand-Mud interlayer facies, Bluish Grey Shale facies, Bioturbated Sandstone facies, Fossiliferous Sandstone facies, and Ripple Sandstone facies. The depositional pattern of Okhmintaung Formation shows a typical cyclic sedimentation pattern occurred in near shore environment. The main economic interest of the KyunChaung area is petroleum extraction from reservoir.

Keywords: Pegu Group, Okhmintaung Formation, lithofacies, depositional environment

Introduction

The Kyun Chaung area is situated in Pakokku District, Magway Region in Central Myanmar. The vertical grid number is (69) to (74) and the horizontal grid number is (05) to (12) in one inch topographic map. Topographic map No is 84 K/16, Burma Survey Department. The study area lies between North Latitude 21˚ 9’ 00" to 21˚ 11’ 30" and East Longitude 94˚ 44’ 30" to 94 ˚ 49’ 00". The coverage of investigated area is (12) square miles; 4 miles in E-W direction and 3 miles in N-S direction. It consists of Kyun

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2. Dr, Professor and Head, Department of Geology, University of Yangon
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4. Demonstrator, Department of Geology, Bago University
5. Demonstrator, Department of Geology, Bago University

Chaung, Letpangyaung, Myozo and Pauktaw villages. Location map of research area is as shown in figure (1).

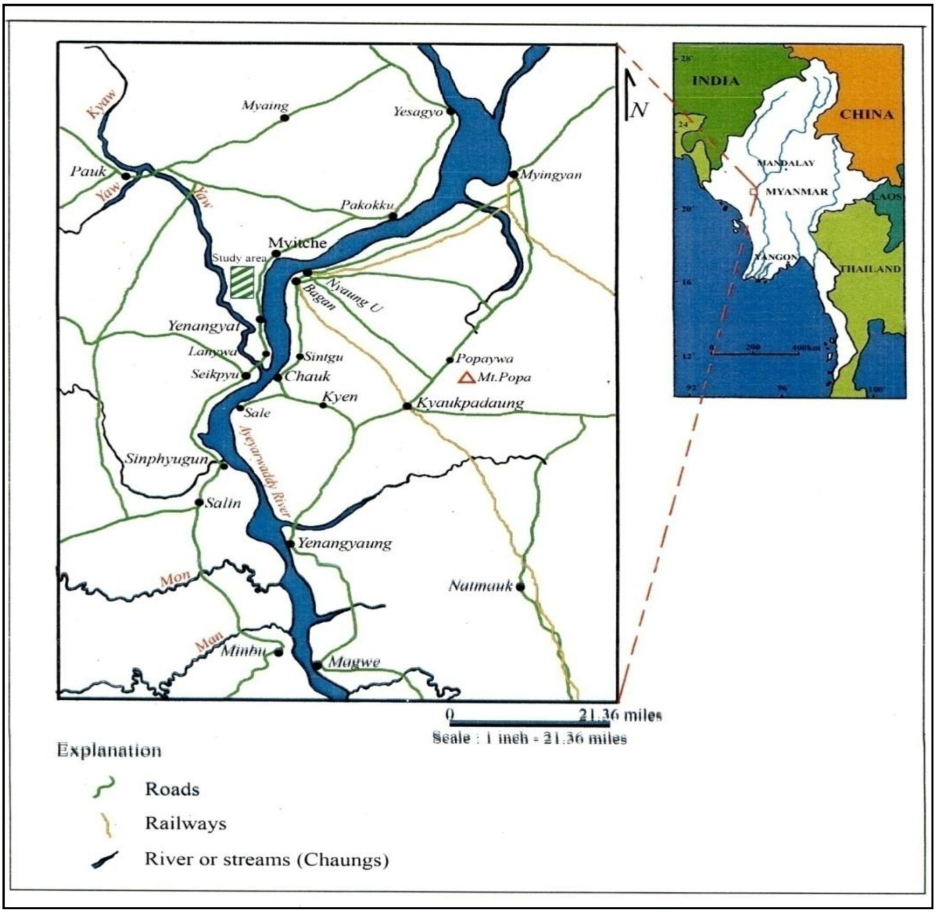

Figure 1: Location map of the research area

Methods of Investigation

- Provide Topographic map 84/K16 scale used for location and enlarge up to four times used as based field map.
- Detailed measurement of lithologic boundaries, thickness and dominant character of the rock unit.
- Good exposure views are obtained as a photographic data with facing.
- Compass can be used for finding the location and for measuring the dipping of the rock units.

Laborotory Methods

- Firstly, according to the procedure of the defrosting, grainding of rock chips and gluing the use of Canada balsam are made.
- Compositions of rocks, grain size variation, physical and chemical character of sandstone (well cement) were studied.
- Taking photomicrographs of rock slides under the microscope.
- Writing up the detailed petrography of rock unit.

Regional Geological Setting

The research area lies within the Eastern Highland and the Western Ranges. It is rather interesting for the accumulation of oil and natural gas.

Regional Geology

The present area is composed essentially of Cenozoic rock sequences of Lower Pegu Group (Oligocene-Miocene) and Irrawaddy Formation (Miocene-Pliocene). Regionally, in the southeast of the area mainly Cenozoic volcanic rock (Mt.Popa Volcano) is exposed. The rock sequences of the lower Pegu Group are Shwezetaw Formation, Padaung Formation, Okhmintaung Formation, (Lower-Upper Oligocene).

Regional Geological Structures

Asymmetrical anticlinal fold is a prominent structure in this research area. It is a strongly asymmetry, steeply dipping east limb and gently dipping west limb. Dip amount of the eastern part is 68-70 and western part is 17-40. This anticline is Yenangyat-Chauk anticline. It is north plunging anticline. Yenangyat-Chauk thrust occurs in the eastern part of the research area. It extends nearly N-S position and down throw to the west. These structures are situated at the east of the Salin syncline in central basin. There are cross faults trending to NNE-SSW direction and early perpendicular to the strike of rock units.

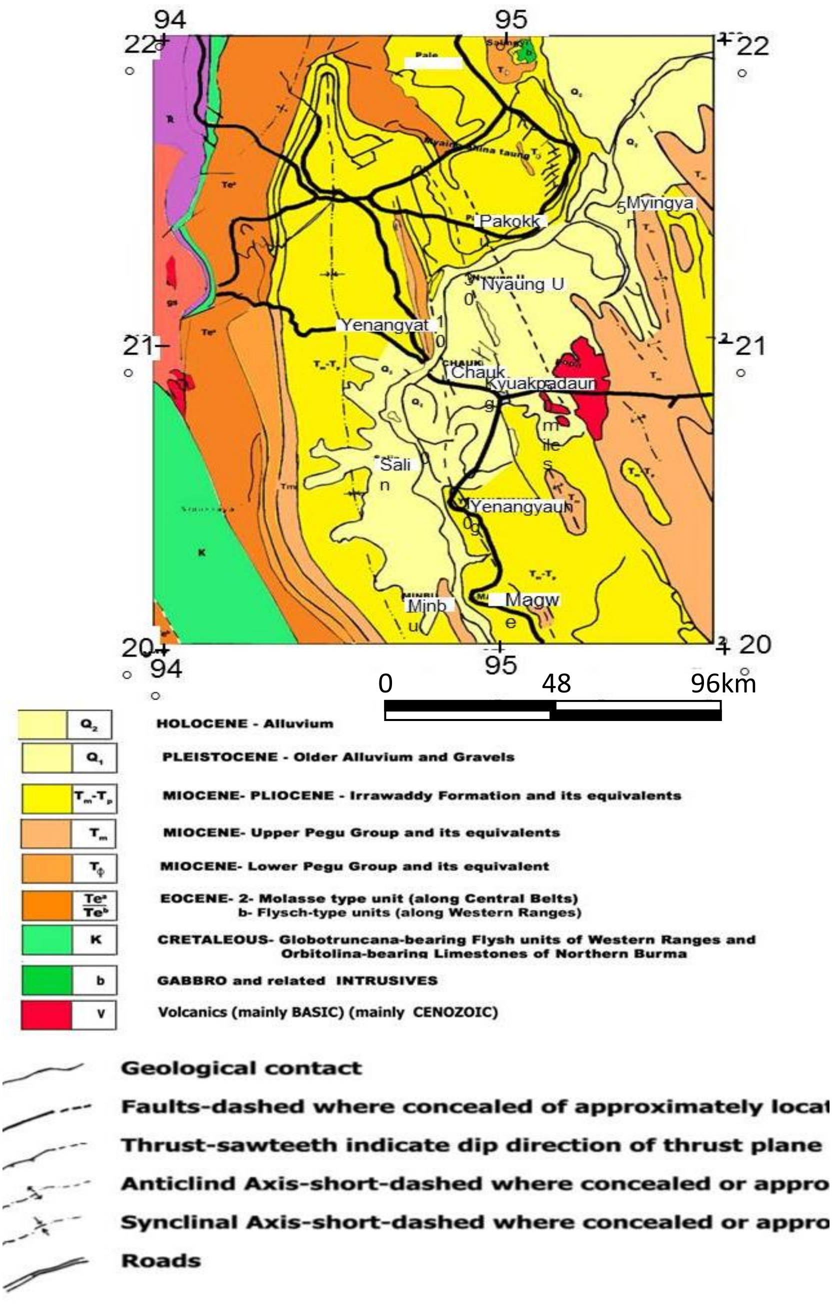

Figure 2: Regional geological map of the research area (Modified after Million scaled Geological Map of Union of Myanmar, 1977)

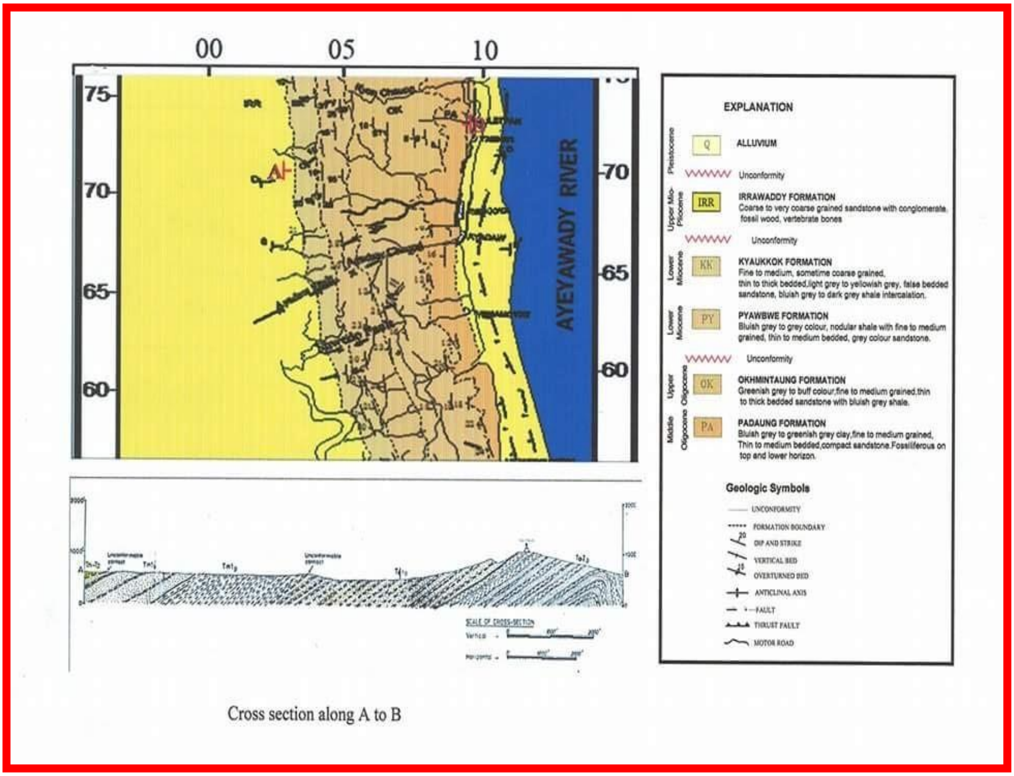

Figure 3: Geological map of Kyun Chaung area (Modified after U Than Htut, MOGE, 1995)

Stratigraphy

General Description

The research area is situated at the Minbu Basins, Central Cenozoic Belt of Myanmar. The Tertiary rock sequences are well exposed in the area especially, Pegu Group (Oligocene-Miocene) and the Irrawaddy Formation (Miocene to Pleistocene). There are two parts of Pegu Group and of each part into three lithologic units of Formation rank was described by Aung Khin and Kyaw Win (1969).The stratigraphic classification used in the research area is that of MOGE, which is as displayed in table (1).

Table 1: The general stratigraphic sequence of the Minbu Basin

Subdivision		Age
Irrawaddy Fm		Upper Miocene- Pliocene
	Unconformity	
Obogon Fm		Middle Miocene
Kyaukkok Fm		Lower Miocene
Pyawbwe Fm		Lower Miocene
	Unconformity	
Okhmintaung Fm		Upper Oligocene
Padaung Fm		Lower Oligocene

Okhmintaung Formation

General Description

It was named as "Okhmintaung Sandstone" by Lepper (1933) from Okhmintaung ridge. It is later named as "Okhmintaung Formation" by Aung Khin and Kyaw Win (1969).

Lithology

This formation has buff to yellowish brown in fresh colour, grayish brown in weather colour, thick bedded to massive, argillaceous and conglomeratic sandstone with sandy shales and locally bands of hard shelly limestone.

Outcrop description

This formation is especially exposed eastern and western part of the Kyun Chaung Section. In the Ngaku Chaung section, this formation can be found eastern and western flank of the area. Normal fault structure can be found in this formation.

Stratigraphic Description

Transitional boundary is occured the lower part of the formation with Padaung Formation and unconformable contact at the upper part of the formation to Pyawbwe formation.

Sedimentary Structure

In the massives and stone, the sedimentary structures of medium-scaled troughcross-beds and sigmoidal can be seen. Mud drapes are also present. Flaser bedding, lenticular bedded, sand-mud interlayers, ripple bedding and cross-stratification are found to be locally. Boiturbation also occur.

Fauna and Age

Pelecypods, gastropods and foraminifera are occurred in this formation. Ageof the Formation is Late Oligocene (Chattian). The total thickness of the Formation isabout 2200ft.

Figure 4: Reddish brown color of Okhmintaung Sandstone with gypsum content & concretion at Kyun Chaung section, Kyun Chaung Village

Figure 5: Thin to medium bedded of buff color Okhmintaung Sandstone with shale interlayer that is faulted at Kyun Chaung section, Kyun Chaung Village

Figure 6: Buff colored Sandstone of Okhmintaung Formation with iron concretions at Kyun Chaung section, Kyun Chaung Village

Geological Structure

General Statement

In the research area, the most prominant features is fold which related to the regional structural framework. It occupies at the Minbu Basin, the Central Cenozoic Belt of Myanmar. Regionally, Tangyi Taung and its environs is essentially the southern part Yenangyat–Chauk anticline which is trending north – south and is elongated strongly asymmetric with a steeply dipping east limb and a gently dipping west limb. The eastern limb of this anticline is cut into many segments by a series of thrust faults and eastern flank of the anticline is affected by Yenangyat–Chauk Thrust, trending north-south.

Folds

Asymmetrical anticline fold is present at the eastern part of the research area. At the eastern limb of the anticline, the general dip of the rocks inclines at a high angle (about 75˚) while western limb have a moderate in inclination (about 35˚). The anticlinal axis is trending nearly north-south and plunging towards north. In the eastern part of the research area, Padaung formation is mainly exposed and it also occupies the crestal portion of the anticline and where mainly bluish grey colored shales are exposed. This formation is flanked by Okhmintaung Formation. The eastern limb of the anticline (in the eastern part of the research area) is deeply eroded by weathering and nearly vertical beds are exposed. The continuation of this anticlinal fold is also exposed at a stream-cut section in Kyun Chaung valley and also along the foot path. At the northern part, the anticlinal axis is cut by NE-SW trending strike-slip fault.

Faults

There are two strike-slip faults in the present research sarea. These faults are recognized along the stream valleys such as Paungkatot Chaung in the western part and Kyun Chaung in the eastern part of the research area. These strike slip faults are trending NE-SW direction. They cut across the fold axis of N plunging anticline, which is mainly composed of Padaung Formation.

Thrust Fault

This fault is also called Yenangyat–Chauk thrust (Khin, 1991), eastern part of the area. At this thrust exposed the rocks of Irrawaddy Formation dip randomly towards various directions with varying dip amounts?

Depositional Environment

According to the lithofacies analysis, at least five different lithofacies can be recognized in Okhmintaung Formation:

1. Sand –Mud interlayer facies
2. Bluish Grey Shale Facies
3. Bioturbated Sandstone Facies
4. Fossiliferous Sandstone Facies
5. Ripple Sandstone Facies

Figure 7: Photograph showing the Sand-Mud interlayer Facies of Okhmintaung Formation

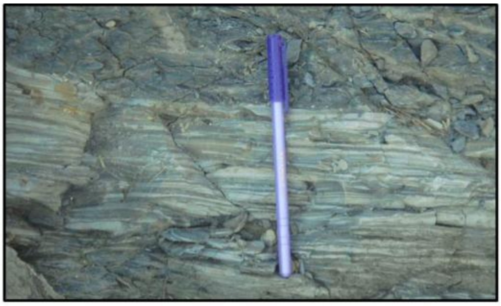

Figure 8: Photograph showing Bluish grey Shale Facies of Okhmintaung Formation

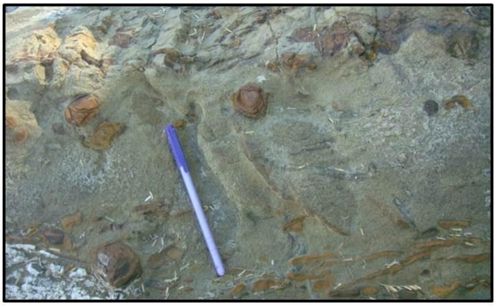

Figure 9: Photograph showzing Bioturbation Sandstone Facies of Okhmintaung Formation

Figure 10: Photograph showing Fossiliferous Sandstone Facies of Okhmintaung Formation

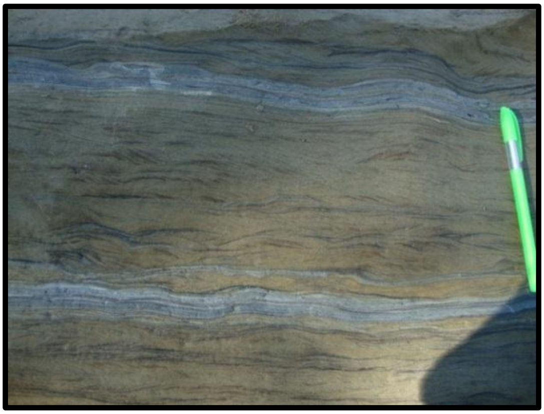

Figure 11: Photograph showing Ripple Sandstone Facies of Okhmintaung Formation

The medium to coarsed grained sediments with high energy bed forms and internal structures characterized the lower shorefacies (or) subtidal area as depositional environment.

Table 2: Lithofacies and depositional environment of Okhmintaung Formation in research area.

Fm	No	Facies Name	Distincts Sedimentary attribute	Possible depositional environment
OKHMINTAUNG FORMATION	1	Sand –Mud interlayer facies	Yellowish brown color sand and dark grey color shale. Medium grain sand size can be found.. Upper part of the sand is thicker than the lower part of this facies. Average thickness of this facies is 2m.	mixed intertidal flat
	2	Bluish Grey Shale Facies	Bluish grey color shale. Nodular bluish grey shale is friable with a small amount of sand. Average thickness of this facies is 2m.	prodelta offshore area
	3	Bioturbated Sandstone Facies	Yellow color sand and medium grain sandstone. The primary sedimentary structure can be occurred in this facies mainly that bioturbation. Mud drapes and iron-concretions are found in this facies. Average thickness of this facies is 3m.	shallow marine
	4	Fossiliferous Sandstone Facies	Light grey color & medium sand. Fossiliferous is found at the top of the bed and mud clasts are also found. The size of the mud clasts are 0.5cm to 1cm in diameter. Average thickness of this facies is 7m.	beach or shore area
	5	Small Scale Cross Bedded Sandstone Facies	Yellow color sand with many micro-cross bedding and medium grain sandstone. The primary sedimentary structure can be occurred in this facies mainly that trough type cross-beddding. The cross-bedded is distributed in this facies. The size of the cross-bedding is 1cm in length and it is shown bidirection. Average thickness of this faices is 3m.	Channel

Summary and Conclusion

The research area is situated in the Pakkoku district, Magwe Region of Central Myanmar. It is composed of clasticmolassic sedimentary rocks of Upper Pegu Group of Oligocene- Miocene age. The research area occupies the eastern parts of the Minbu Basin which is one of the Tertiary Basins in Central Cenozoic Belt. Besides, it is located in forearc basin. Stratigraphically, Oligocene of Padaung and Okhmintaung Formations (Rock units of Lower Pegu Group) unconformity overlain by Early Miocene Pyawbwe and Kyaukkok Formation (Rock Units of Upper Pegu Group) which in turn Mio-Pliocene Irrawaddy Formation unconformably overlain on the Pegu Group. By the petrographic analysis, the sandstones of the Okhmintaung Formations can be regarded as lithic arkose in composition. The Okhmintaung Formation yields Sand –Mud interlayer facies, Bluish Grey Shale Facies, Bioturbated Sandstone Facies, Fossiliferous Sandstone Facies, and Ripple Sandstone

Facies are deposited in intertidal and subtidal environments. The main economic interest of the Kyun Chaung area is petroleum extraction from sand reservoir.

Acknowledgement

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FACIES ANALYSIS OF PYAWBWE FORMATION EXPOSED AT PYAWBWE - MINHLAGYIN AREA, MINBU DISTRICT, MAGWAY REGION, MYANMAR

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Abstract

Pyawbwe – Minhlagyin area is located in Minbu Township, Magway Region. It is situated between North Latitude 19˚ 57′ to 20˚ 02′ and East Longitude 94˚ 37′ to 94˚ 43′ in one inch topographic maps of 84 L/12 and 85 I/9. The Pyawbwe Formation is characterized by thin to medium bedded, pale brown to bluish grey shale and mudstone with subordinate sandstone interbedded with buff coloured loose sand, laminated to large scaled cross-bedded, greenish grey silty clay and occasionally intercalated with hard sandstone bands. Gypsum, shell beds, lenticular and concretions are also observed. Pyawbwe Formation of the research area consists of at least 11 lithofacies and they are grouped into four lithofacies association: fan delta association, delta plain association, delta front association and prodelta association. Fan delta association is usually coarse grained resulting in higher sedimentation rate. Delta plain association may have occurred in swamp, marsh, lake and distributary channel area where are filled by overbank spilling of fine-grained material from the river during flood stages with quite energy condition. Delta front associations are present distributaries channel, subaqueous levee and distributary mouth bar. Prodelta is an environment where finer particles settle out from suspension and disperse over wide area by basinal processes. The lower part of Pyawbwe Formation is occupied by the wave and tidal influence delta front association. These include wavy laminated sandstone, laminated siltstone and clay, flaser and lenticular bedding of sandstone and shale. The middle and upper parts of Pyawbwe Formation are occupied by delta plain and prodelta. These include massive clay bearing burrow structure, shale intercalated with fossiliferous sandstone and sandstone intercalated with shale bearing gypsum.

Keywords: Minbu Township, Magway Region, Pyawbwe Formation**.**

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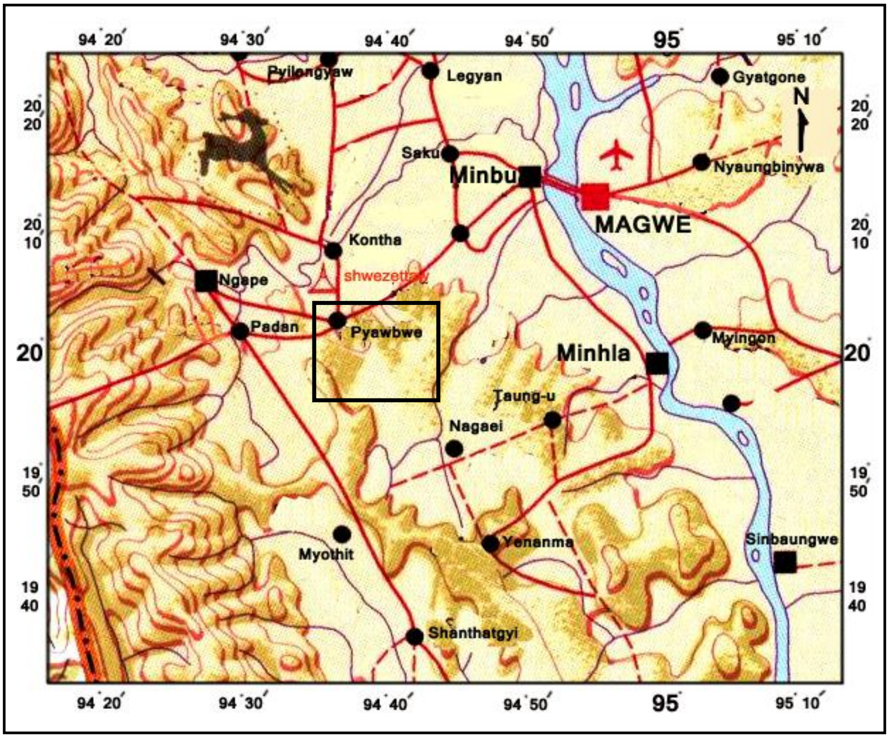
Introduction

Location, size and accessibility

The research area is situated between North Latitude 19° 57′ to 20° 02′ and East Longitude 94° 37′ to 94° 43′. It extends about 10.4 km from east to west and 9.3 km from north to south, covering approximately 96.72 km^2 in area. It is situated in Minbu Township, Magway Region and falls in one-inch topographic maps of 84 L/12 and 85 I/9. The location map of the research area is shown in Figure (1).



Car-road
Stream
Village
Research Area

Figure 1: Location map of the Pyawbwe-Minhlagyin Area

Topography

The research area is represented by the rolling terrain topography and ranges of small hills are running from NNW-SSE direction.

Purposes of study

The purposes of the present investigation are as follows:

(1) To describe detail geological map of the area

(2) To carry out the facies analysis of the Pyawbwe Formation

(3) To study the sedimentary structures of the area

(4) To interpret the depositional environments and geological history of the area

Methods of study

Tape and compass method, Jacob staff and Brunton Compass method were used to measure thickness of individual beds, joints, folds and faults. The certain locations of outcrops were attained by GPS navigator and checked by intersection method. Both sandstone and shale samples and diagnostic fossils were collected, properly marked and carefully packed for detailed laboratory investigation. The observed datas were plotted on the base map and geological map was drawn by using field data and lithologic evidence. Finally the columnar section of Pyawbwe Formation was drawn manually with convenient vertical scale. The photos taken in the field are chosen for the interpretation of field evidence. Detailed studies of fossils were made to determine probable age of rock unit. The lithofacies were classified according to the facies code modified from (Miall, 1978 in Walker, 1992) on the basis of grain size, primary sedimentary structures and lithologic signatures.

Regional Geologic Setting

The research area is situated in the Central Cenozoic Belt of Myanmar (Maung Thein, 1976), a down faulted block (graben) in which several depositional basins and uplifts are found. The Central Cenozoic Belt can be subdivided into three basins: Chindwin Basin, Minbu Basin and Ayeyarwaddy Embayment; and four uplifts; Kumon Ridge Uplift, Wuntho Uplift, Salingyi

Uplift and Bago Yoma Uplift (Maung Thein, 1983). The basins are indeed broad structural basins (synclinal basins) which are separated from each other by the latitudinal highs, viz., N 22° high and N 19° high. The research area is located in south western part of the Minbu Basin of Central Cenozoic Belt. It has few hills which are of rolling terrain. Structurally, Minbu Basin is a south plunging syncline (Salin Syncline), measuring approximately 200 km in length, north south oriented and about 70 km in width. In the research area, the rocks are Oligocene to Miocene in age. The strata are trending NNW-SSE and dipping towards NE direction. Major tectonic structures are arranged parallel with the regional strike of the strata. The Miocene rocks of Upper Pegu Group are buff and light brown to grey hard sandstones and bluish-grey clay and also consist of fossiliferous sandstone band. Regional geologic setting of the study area and it's environ is shown in Figure (2).

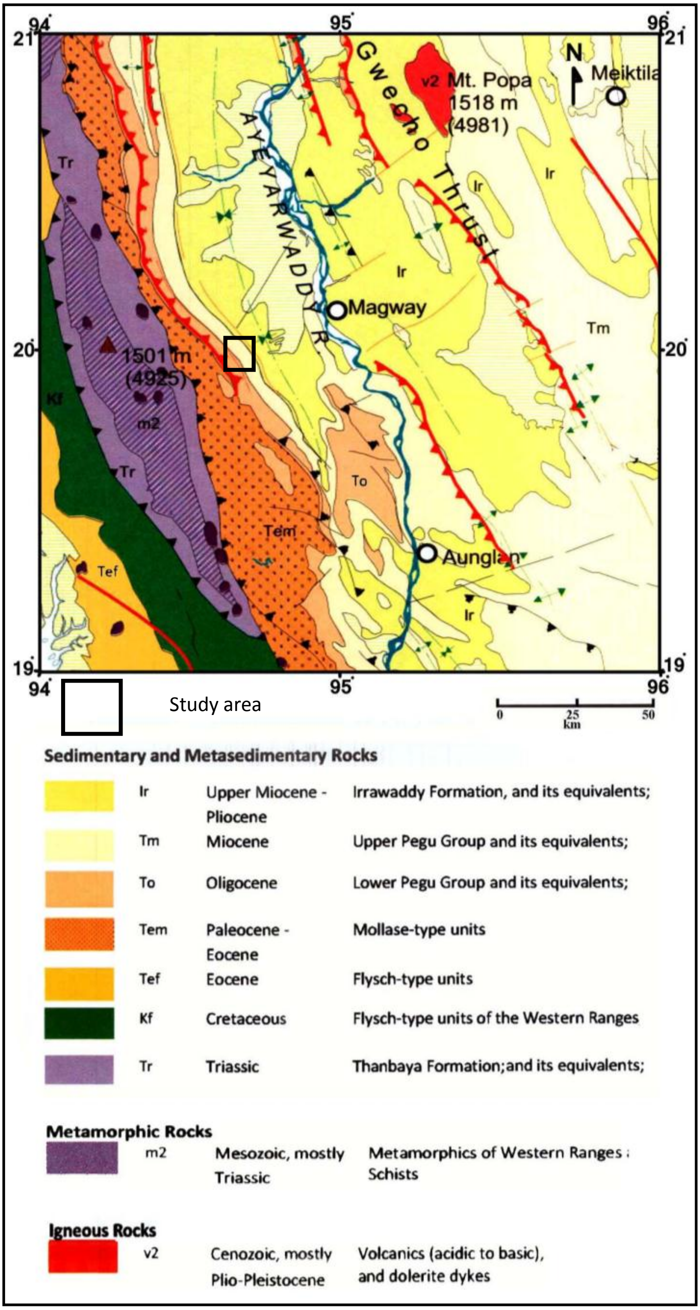


Figure 2: Regional Geologic Setting of the research area and its environs

Source: Geological Map of Myanmar (M.G.S, 2014)

Stratigraphy of Pyawbwe Formation

Name derivation

The term “Pyawbwe Clays” was first introduced by Lepper in 1933 for a succession with crops out near the Pyawbwe village (Lat. 20° 01′ N, Long. 94° 38′ E) in the Minbu Township, Magway Region. It is constituted of bluish grey sandy clays with subordinate sandstones and some conglomerates and disseminated gypsum plates. Later, Aung Khin and Kyaw Win (1969) gave the name "Pyawbwe Formation" on the basic of the same lithostratigraphic unit.

Distribution and thickness

The research area consists of the type locality of the Pyawbwe Formation. The rocks of Pyawbwe Formation are well exposed Pyawbwe village and along Padaung Chaung, in central part of the research area. The upper part of Pyawbwe Formation is cropped out near the Kayu Kan village (Kan thar ya ywathit). The lower part of this formation is observed near the Pyawbwe village. The correlation of the stratigraphic units of the research area with those of the other areas is shown in Table (1). Geological map of the research area is shown in Figure (3).

Table 1: Correlation of the stratigraphic unit of the research area with those other area

Age		Taungtalon area, Kyaukse District Myint Thein (1966)	The area between Padan & Kyaukpon Khin Aung Than (1983)		Chindwin Basin Maung Thein (2014)	Minbu Basin	
						Aung Khin & Kyaw Win (1969)	Pyawbwe-Minhlagyin Area (2015)
Pleistocene					Terraces		Maw Gravels
Pliocene		Thittawpya Sandstone			Irrawaddy Formation (Mingin Fm)	Irrawaddy Formation	Irrawaddy Formation
Miocene	L						
	M	Kabo Sandstone Moza Formation	Upper Pegu Group	Obogon Formation	Shwethamin Formation	Obogon Formation	Obogon Formation
	E	Taungtalon Sandstone		Kyaukkok Formation	Natma Formation	Kyaukkok Formation	Kyaukkok Formation
		Shwetaung Clay		Pyawbwe Formation	Letkhat Formation	Pyawbwe Formation	Pyawbwe Formation
Oligocene	L	? ? ?	Lower Pegu Group	Okhmintaung Formation	Tonhè Formation	Okhmintaung Formation	Okhmintaung Formation
	E			Padaung Formation		Padaung Formation	Padaung Formation
				Shwezettaw Formation		Shwezettaw Formation	Shwezettaw Formation

Explanation

Break in the geologic time

Not exposed

Unconformity

Conformity

Uncertain

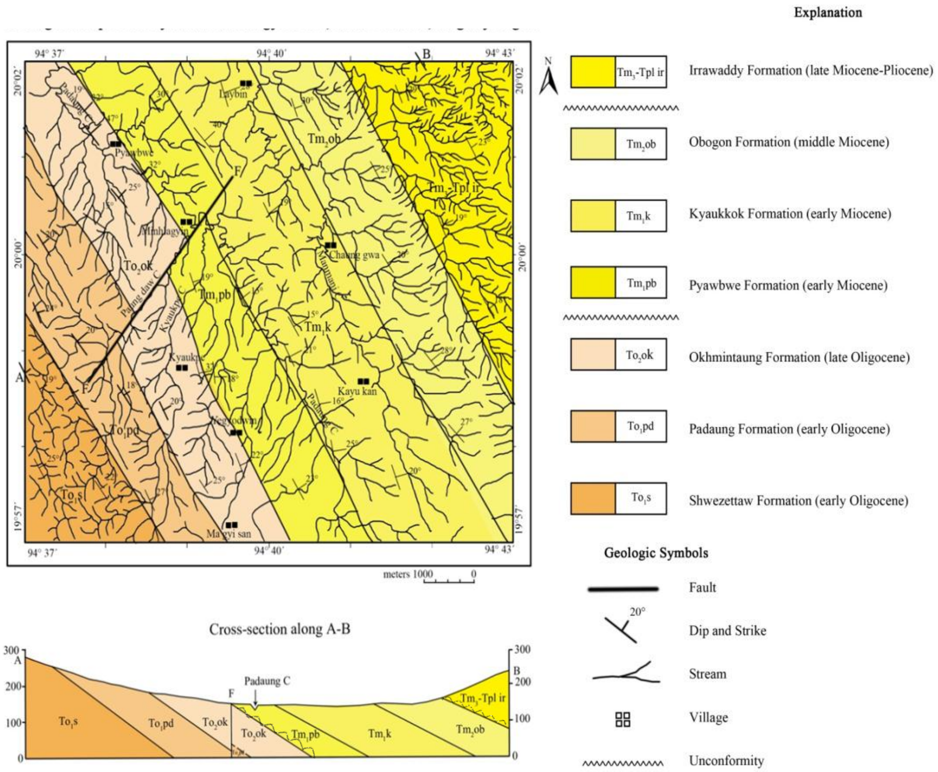


Figure 3: Geological map of the Pyawbwe-Minhlagyin area, Minbu District, Magway Region (Modified after D.G.S.E, 1982)

Lithology

Pyawbwe Formation is characterized by thin to medium bedded, pale brown to bluish grey shale and mudstone with fossiliferous sandstone interbedded (Figure 4) with buff coloured loose sand, laminated to large scaled cross-bedded, greenish grey silty clay and occasionally intercalated with hard sandstone bands. The lower part of this formation is especially thick bedded, fine to medium grained, bluish grey mudstone and shale intercalated with hard sandstone bands. Laminated to thin gypsum layers are numerously occurred on mudstone surface and sometimes shell beds are conspicuous. Lenticular, flaser, burrow and cross bedded structures are well seen along the railway road near the Pyawbwe village. Fossils are widely numerous and locally present. In the middle part of this formation, the lenticular bedding in alternated sequence of sands and shales are also occurred (figure 5). Dark grey coloured, fine to medium grained indurated sandstone with conglomerate bands are also observed in this part. Iron concretions are occasionally found in this part. The upper part of Pyawbwe Formation comprises thin to medium bedded, fine-grained, light grey to bluish grey shale, and buff coloured silty clays interbedded with pale brown loose sand. The structures show flaser and planar cross beddings. Sometimes the shales in the upper part of Pyawbwe Formation describe fissile nature and hard and compact mudstone concretions are also observed.

Figure 4: Grey coloured, medium bedded, fine grained, hard and fossiliferous sandstone band of the Pyawbwe Formation(Lat. 20˚ 01′ 10′′ N & Long. 94˚ 37′ 20′′ E)

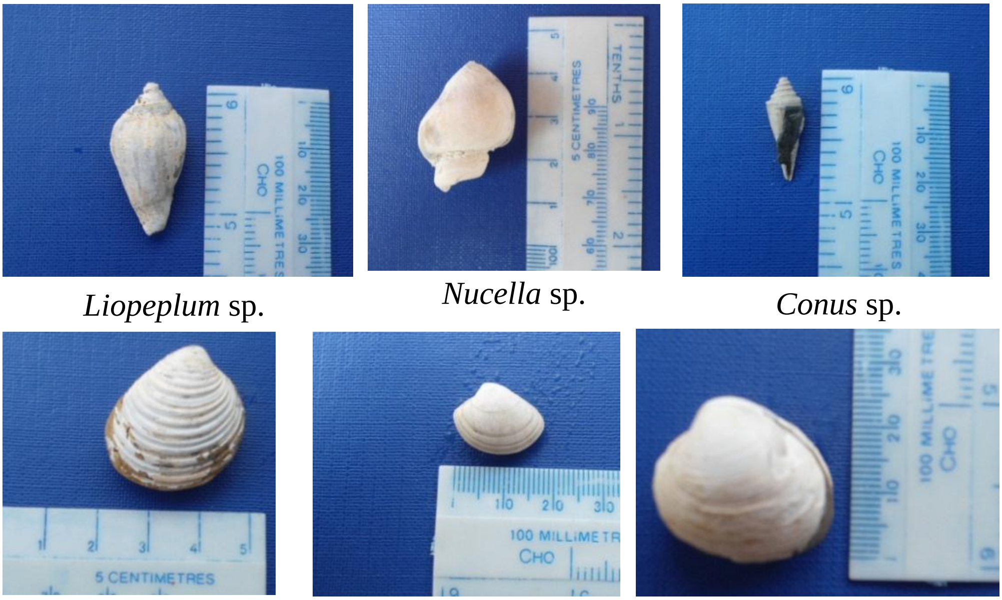
Figure 5: Lenticular bedding in alternated sequence of bluish grey shales and buff colour unconsolidated sandstone of Pyawbwe Formation (Lat. 19˚ 54′ 51′′ N & Long. 94˚ 42′ 57′′ E)

Nature of contact

The Pyawbwe Formation unconformably overlies upon the Okhmintaung Formation and was conformably overlied by Kyaukkok Formation. The thickness of sand beds increase upward.

Fauna, age and correlation

The Pyawbwe Formation is fossiliferous in the present study area. Gastropods, Pelecypods and foram are the most common fauna in this formation. *Chione*, *Nucula*, *Corbula idonea*, *Conus*, *Liopeplum*, and *Nucella* indicate an Early Miocene age for the Pyawbwe Formation (Figure 6). It can be correlated with the Letkhat Formation of the Chindwin Basin (Maung Thein, 2014) and Shwetaung Clay in the Taungtalon Area (Myint Thein, 1966).



Liopeplum sp. *Nucella* sp. *Conus* sp.

Corbula idonea sp. *Chione* sp. *Nucula* sp.

Figure 6: Index fossils in the clay of the Pyawbwe Formation

Facies Analysis of Pyawbwe Formation

General statement

Facies is a body of rock and is defined on the basis of its distinctive lithologic features including colour, bedding, composition, texture, fossils and sedimentary structures (Reading, 1981). Facies associations are more general in nature less influenced by local factors. Thus, a facies association can be used to interpret the regionalized depositional environment. The lithofacies were classified according to the facies code modified from (Miall, 1978 in Walker, 1992) on the basic of grain size, bedding nature, primary sedimentary structure and lithologic signature. They are described in order of decreasing grain size and bedding thickness. The present study area is mainly emphasized on the facies analysis of the Pyawbwe Formation due to lack of enough time.

Lithofacies of Pyawbwe Formation

In the research area, Pyawbwe Formation is exposed near the Pyawbwe village. This formation is mainly composed of shale/clay, sandstone, siltstone and mudstone with a combined thickness of 274.01 m. The stratigraphic measurement of Pyawbwe Formation was carried out along the railway road near the Pyawbwe village. It can be classified into 11 lithofacies according to the lithological and the structural characteristics of Pyawbwe Formation. The facies classification and their environmental interpretation are shown in Table (2). Columnar section of Pyawbwe sequence is shown in (Fig. a, b, c, d, e, f, g & h).

Facies (A) Pebbly Conglomerates

This facies contains pebbles and gravels bearing conglomerates. Grain sizes range from 0.3 cm to 5 cm in this facies. This facies mainly consists of quartz, chert, mud clasts and clay pebbles which are loosely consolidated in a silty clay matrix (Figure 7). Most of them are subangular to round. This conglomerate facies are yellowish brown to buff coloured. This facies is characterized by rhythmically coarsening upward nature.

Interpretation

This facies is interpreted as high energy debris flows by the rapid currents. The conglomerate faecies is thought to be deposited in the fan delta environment.

Facies (B) Planar Cross bedded Sandstone

The facies is characterized by medium to large scale cross bedded (Figure 8), buff coloured, thin to medium bedded, medium grained sandstone. In this facies, fossil fragment and burrow structure also occurred.

Interpretation

Planar cross bedding is commonly found in migrating straight crested subaqueous dunes (Miall, 1978) of the active fluvial river channel. This facies is interpreted as distributary channel deposits (delta front).

Figure 7: Subangular to rounded pebble in pebbly conglomerate of Facies (A) (Lat. 20˚ 1′ 17′′ N & Long. 94˚ 37′ 51′′ E)

Figure 8: Planar cross bedded sandstone of Facies (B) (Lat. 20˚ 1′ 17′′ N & Long. 94˚ 37′ 51′′ E)

Table (2) Lithofacies Analysis of Pyawbwe Formation exposed at Pyawbwe-Minhlagyin Area

Sedimentary Facies		Lithologic Description	Interpretation	Facies Association
Code	Name			
A	Pebbly Conglomerate	Yellowish brown to buff coloured intraformational conglomerate, pebble and gravel, consists of quartz, chert, mud clasts and clay pebble, rhythmically coarsening upward	High energy and rapid current	Fan delta
B	Planar cross bedded Sandstone	Buff coloured, thin to medium bedded, medium grained, large scale cross bedded sandstone, mud concretion, 7 m thick, occasional small scale flaser bedded, fossil fragments, burrow structure	Active distributary channel with tidal current activities	Delta front
C	Medium to thick bedded sandstone	Yellowish brown to buff coloured, medium to thick bedded, medium grained sandstone, thickening upward of sandstone bed	Distributary channel	
D	Thin to medium bedded sandstone intercalated with shale	Yellowish brown to buff coloured, thin to medium bedded, medium grained sandstone intercalated with greenish grey coloured shale, parallel lamination occur gypsum layer, fossil fragment, occasionally lenticular bedding, 0.5-2 m thick gypsum	Swampy and marsh	Delta plain
E	Interbed of Sandstone and shale with lenticular bedding	Yellowish brown to buff coloured, thin to medium bedded, medium grained sandstone, interbedded with greenish grey coloured shale, parallel lamination, lenticular bedding alternated sequence of sand and shale, thickening and coarsening upward nature of sandstone bedded	Distributary distal bar	Delta front

Table 2: Lithofacies Analysis of Pyawbwe Formation exposed at Pyawbwe-Minhlagyin Area (Continued)

Sedimentary Facies		Lithologic Description	Interpretation	Facies Association
Code	Name			
F	Thick bedded, fine grained sandstone	Yellowish brown to buff coloured, thick bedded to massive, fine grained sandstone, friable, 6 m thick, wavy lamination, upper part of Pyawbwe Formation	Levee and crevasse splay deposits bordering the distributary channel	Delta front
G	Interbed of siltstone and shale	Bluish grey coloured, thin to medium bedded siltstone and shale, nodular shale, thinning upward of silt, parallel lamination, little amount of parallel bedded sandstone, upper part of Pyawbwe Formation	River mouth bar	Prodelta
H	Clay intercalated with hard sandstone	Greenish grey to bluish grey clay intercalated with grey to yellowish brown, thin to medium bedded, coarse - grained hard sandstone, iron concretion	Prodelta	
I	Shale intercalated with fossiliferous sandstone	Light grey to greenish grey coloured shale intercalated with yellowish brown to buff coloured, thin to medium bedded, coarse grained fossiliferous sandstone, generally fissile nature shale	Delta front slope	
J	Laminated shale with sandstone intercalation	Light grey to greenish grey coloured, thin to medium bedded shale, show fissile nature, fine grained sandstone intercalation	Swampy and marsh	Delta plain
K	Massive clay with burrow structure	Greenish grey coloured, massive clay, burrow structure, fossil fragments, middle part of Pyawbwe Formation	Delta front slope	Prodelta

Facies (C) Medium to Thick bedded Sandstone

This facies mainly consists of yellowish brown to buff coloured, medium to thick bedded, medium grained sandstone. This facies is characterized by thickening upward nature of sandstone and directly overlies of shale unit (Figure 9).

Interpretation

Sandstone was deposited from traction by a low energy, unidirectional current. This facies is interpreted in distributary channel deposit of delta front by the occurrence of thickening and coarsening upward nature.

Facies (D) Medium grained Sandstone with Shale intercalation

This facies mainly comprise yellowish brown to buff coloured, thin to medium bedded, medium grained sandstone intercalated with greenish grey coloured shale. In this facies, gypsum layers are parallel to the sand and shale bedding planes (Figure 10). These gypsum layers are 0.5 cm to 2 cm in thickness.

Interpretation

This facies is thought to be a delta plain of swampy or marsh environment. The occurrence of gypsum is confined to coastal intertidal setting and to sites where marine water seep into low lying pools and basin.

Figure 9: Thick bedded sandstone directly overlies of shale unit of Facies (C) (Lat. 20° 01′ 45′′ N to Long. 94° 37′ 32′′ E)

Figure 10: Yellowish brown coloured, thin bedded sandstone interbedded with shale bearing gypsum layer of Facies (D) (Lat. 19° 57′ 00′′ N to Long. 94° 40′ 44′′ E)

Facies (E) Interbeds of Sandstone and Shale with lenticular bedding

It mainly constitutes yellowish brown to buff coloured, thin to medium bedded, medium grained sandstone interbedded with greenish grey coloured shale. This facies show lenticular bedding in alternated sequence of sand and shale (Figure 11). The sand and shale beds also show parallel lamination in this facies.

Interpretation

This facies shows lenticular bedding of sands and shale and parallel lamination in nature. The above character indicates that this facies is interpreted as distributary distal bar of delta front (Reading, 1996).

Facies (F) Thick bedded, fine grained Sandstone

This facies mainly consists of yellowish brown to buff coloured, thick bedded to massive, fine - grained sandstone (Figure 12). This facies is found in the upper part of Pyawbwe Formation near the Kayu Kan village.

Interpretation

This facies is interpreted as levee and crevasse splay deposits bordering the distributary channel, formed in response to broadening and shoaling of the channel in delta front.

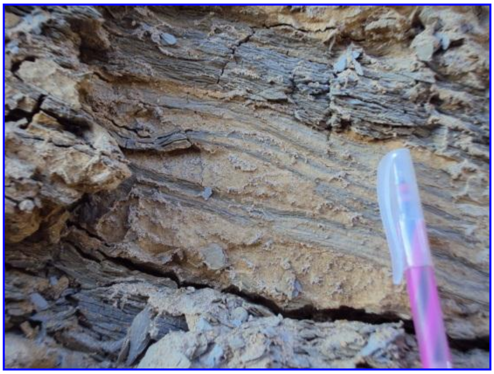


Figure 11: Lenticular bedding alternated sequence of sand and shale of Facies (E) (Lat.19˚54′ 51′′ N to Long. 94˚42′57′′E)

Figure 11: Yellowish brown to buff coloured thick bedded and fine grained friable sandstone of Facies (F) (Lat.19˚ 45′ 50′′ N & Long. 94˚ 37′ 15′′ E)

Facies (G) Interbed of Silistone and shale

This facies mainly constitutes bluish grey coloured, thin to medium bedded siltstone and shale (Figure 13). Shale in this facies appears as concretionary and nodular shape. This facies shows thinning upward nature of siltstone and show parallel lamination of shale and siltstone bedding.

Interpretation

It is bedding characters imply that the current were episodic, discrete events of small magnitude. This facies is interpreted as a deposit at some distance beyond the river mouth in the prodelta area.

Facies (H) Clay intercalated with Hard Sandstone

This facies mainly comprises greenish grey to bluish grey, medium bedded clay intercalated with grey to yellowish brown coloured, thin to medium bedded, coarse grained hard sandstone (Figure 14). This hard sandstone shows concretionary shape and varies from 30 cm to 50 cm thick in this facies.

Interpretation

This facies is variety of the lowest energy condition and represent the sediments deposited in prodelta environment.

Figure 13: Parallel laminated siltstone and concretionary nodular shale interbeds of Facies (G) (Lat. 19˚ 54′ 51′′N & Long. 94˚ 42′ 57′′ E)

Figure 14: Bluish grey coloured medium bedded clay intercalated with grey coloured concretionary shape hard standstone of Facies (H) (Lat. 20˚ 01′ 05′′ N to Long. 94˚ 37′ 07′′ E)

Facies (I) Shale intercalated with fossiliferous Sandstone

This facies contains light grey to greenish grey coloured shale intercalated with yellowish brown to buff coloured, thin to medium bedded, coarse grained fossiliferous sandstone (Figure 15). Lenticular shape of fossiliferous hard sandstone is occurred in this facies. Shale shows generally fissile nature in this part.

Interpretation

This facies is interpreted onto the delta slope (prodelta) by the occurrance of fossiliferous sandstone.

Facies (J) Laminated Shale with Sandstone intercalation

This facies is mainly composed of light grey to greenish grey coloured, thin to medium bedded shale (Figure 16). These shales show parallel lamination and fissile nature and plant rootlets are richly occurred in this facies. Occasionally, fine grained sandstone is intercalated within these shales.

Interpretation

This facies is interpreted that the depositional environment is a delta plain of swampy or marsh environment. This facies is characterized by laminated shale bearing plant rootlet.

Figure 15: Greenish grey coloured shale intercalated with lenticular shape of fossiliferous hard sandstone of Facies (I) (Lat. 20˚ 01′ 10′′ N to Long. 94˚ 37′ 20′′ E)

Figure 16: Greenish grey coloured, medium bedded shale showing fissile nature with plant rootlet of Facies (J) (Lat.21˚1′31′′N& Long. 94˚37′43′′ E)

Facies (K) Massive Clay with burrow Structure

This facies especially consists of greenish grey coloured, thick bedded to massive clay. Burrow structures and fossil fragments are usually observed in this facies (Figure 17).

Interpretation

This massive nature may be a result of the depositional mechanism on the delta front slope. The deposition of fine-grained sediments indicates the slack water condition formed by low energy depositional process (Reinck and Singh, 1980). Homogeneous bedding might be the result of strong bioturbation activity. So, this facies is found burrow structure and fossil fragments.

Figure 17: Burrow structure in the massive clay of Facies (K) (Lat. 20˚ 0′ 30′′ N & Long. 94˚ 38′ 42′′ E)

Lithofacies Association of Pyawbwe Formation

The facies of Pyawbwe Formation exposed in Pyawbwe village can be grouped into four lithofacies associations. Columnar section of Pyawbwe sequence is shown in (Figure 18. a, b, c, d, e, f, g & h).

1. Fan delta facies association

Fan Delta association comprises matrix supported conglomerate, pebbly conglomerate (Facies A) and gritty sandstone. These fan delta conglomerate and medium sandstones are deposited in alluvial fan association. Fan delta association is usually coarse grained resulting in higher sedimentation rate (Miall, 1990).

2. Delta plain facies association

The delta plain association consists of laminated shale (Facies J) and medium bedded sandstone intercalated with shale (Facies D). This facies association may have occurred in swamp, marsh, lake and distributary channel area where are filled by overbank spilling of fine-grained material from the river during flood stages with quiet energy condition (Walker and James, 1992).

3. Delta front facies association

The delta front association represents the combination of facies B, C, E and F. Medium grained sandstone with planar cross-bedding of facies B can be found in distributary channel. Medium to thick bedded sandstone of facies C deposited in distributary channel. Interbeds of sandstone and shale with lenticular bedding of facies E suggest distal bar on the seaward sloping margin of the delta front environment. Thick bedded fine grained sandstone of facies F deposited in delta front. The above characters indicate that this facies association is attributed to tidal influence delta front deposits. In this association, distributaries channel, subaqueous levee, distributary mouth bar and distal bar are present. A distributary channel is a natural stream which leads a part of the sediment and water discharge of a major stream into the sea. The most common sedimentary structure in the distributary channel deposits are cross-bedding, current ripple bedding, and erosional surface. Some parts of the subaqueous levee are exposed as sand flats at low tides. Subaqueous levee deposits are made up of very fine sand slit and mud. Sedimentary structure produced by current action is dominant.

4. Prodelta association

The prodelta is mainly composed of facies G, H, I and K. Prodelta is an environment where finer particles settle out from suspension and disperse over wide area by the basinal processes (Reading, 1996). In river-dominated deltas, prodelta mudstones are typically massive, well stratify and may show graded bedding (Walker and James, 1992). Massive clay with burrowing structure (Facies K), well lamination of facies G, clay intercalated with sandstone (Facies H) and shale intercalated with fossiliferous sandstone (Facies I) suggest that they are the prodelta association.

Depositional environment of Pyawbwe Formation

The Pyawbwe Formation shows the characteristics of fan delta, delta plain, delta front and prodelta. The lower part of Pyawbwe Formation is occupied by the wave and tidal influence delta front associated facies. These include wavy laminated sandstone, laminated silistone and clay, flaser and lenticular bedding of sandstone and shale. The middle and upper parts of Pyawbwe Formation are occupied by delta plain and prodelta. These include massive clay bearing burrow structure, shale intercalated with fossiliferous sandstone, sandstone with planar cross bedding and sandstone intercalated with shale bearing gypsum.

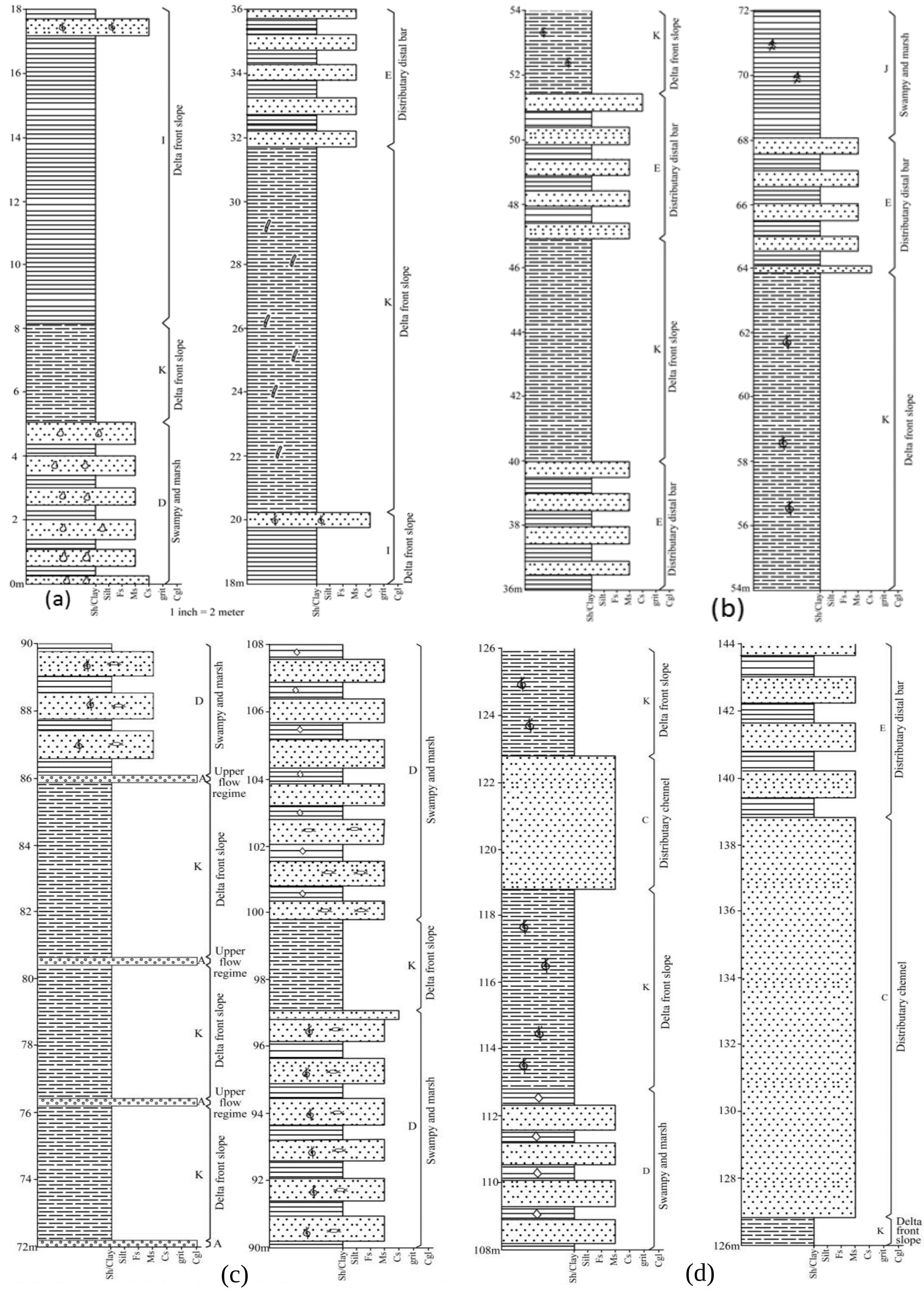


Figure 18: (a,b,c,d) Columnar Lithofacies section of Pyawbwe Formation measured along the railway near the Pyawbwe Village

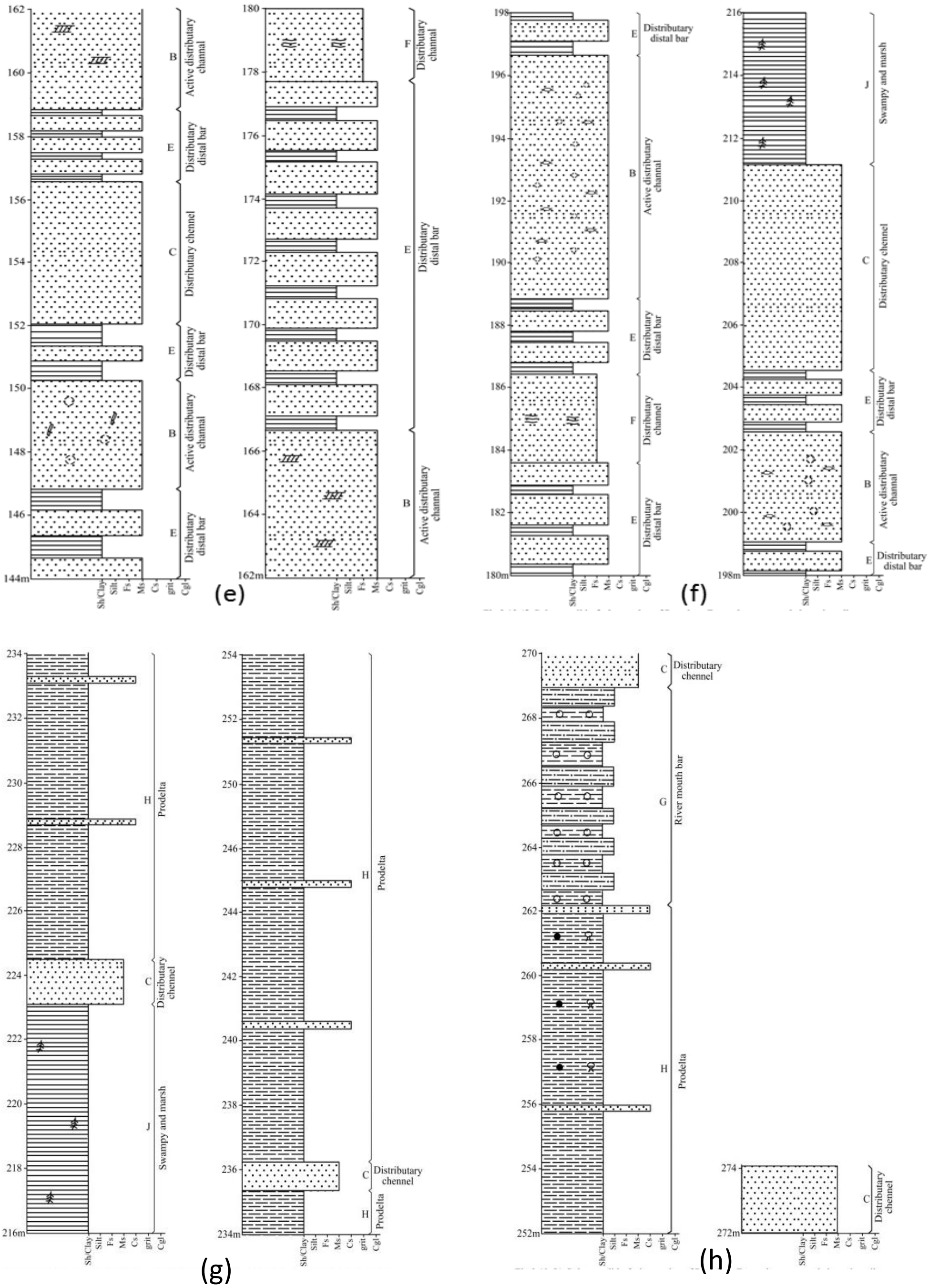
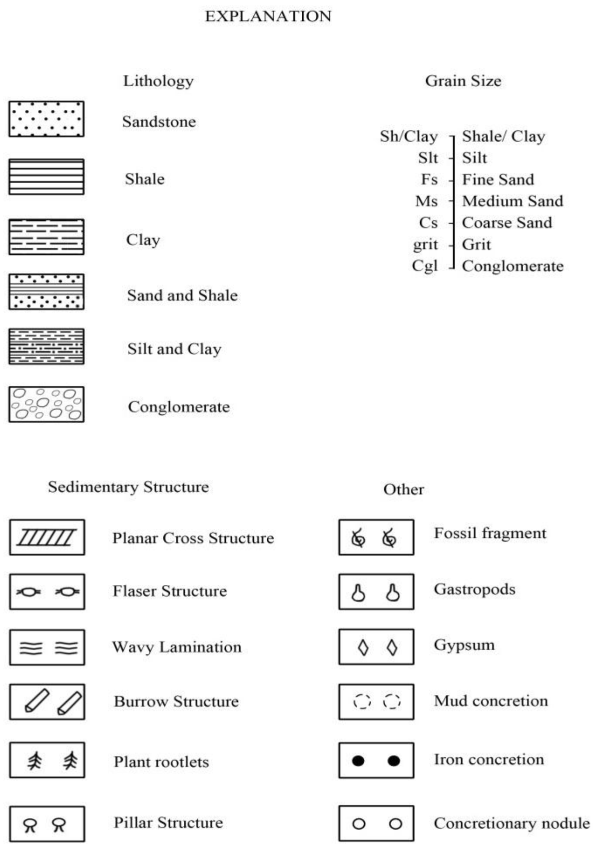


Figure 18: (e,f,g,h)) Columnar Lithofacies section of Pyawbwe Formation measured along the railway near the Pyawbwe Village



Summary and Conclusions

The research area, Pyawbwe-Minhlagyin area is situated in Minbu Township, Magway Region. It is located between North Latitude 19° 57´ and 20° 02´ and East Longitude 94° 37´ and 94° 43´. The purpose of this research is to interpret the depositional environment of the area by studying the detailed analysis of the lithofacies and lithofacies association. The research area mainly emphasizes on the facies analysis of Pyawbwe Formation for environmental interpretation. The maximum thickness is about 274.01 meter. There are at least (11) lithofacies of Pyawbwe Formation and can be grouped into (4) lithofacies association such as fan delta association, deltal plain association, delta front association and prodelta association. The lower part of Pyawbwe Formation is occupied by the wave and tidal influence delta front associated facies. The middle and upper parts of Pyawbwe Formation are occupied by delta plain and prodelta.

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MINERALOGY OF THE METASEDIMENTARY ROCKS OF PIN-LE-IN AND NYAUNG-OK AREA, MADAYA TOWNSHIP, MANDALAY REGION, MYANMAR

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Abstract

The research area is situated in Madaya Township, Mandalay Region which lies on one inch topographic map No.93-B/3. This area is bounded between latitude 22° 11′ N to 22° 14′ N and longitude 96° 33′ E to 96° 35′ E. Pin-le-in and Nyaung-ok area is located between the Shan massif in the east and Tertiary sediment in the west. The regional trends of metamorphic rocks in present area are nearly north-south in direction. Yatkanzin Taung is occupied by metamorphic units, especially marble and calc-silicate rocks. Igneous rocks and metasedimentary rocks mainly distributed in the research area and granitic rocks partly intruded into metasedimentary rocks. Metasedimentary rocks are marbles, calc-silicate rocks and gneisses. Biotite granite is highly weathered in the research area. Hornblende granite is mainly occupied at the eastern part of Bodawgyi Taung range. Marbles can be subdivided into diopside marble, phlogopite marble and white marble. Calc-silicate rocks are interbedded with white marble at Yatkanzin Taung range and it is also interbedded with biotite-hornblende gneiss at Bodawgyi Taung range. Biotite-hornblende gneiss is well exposed at Bodawgyi Taung and it is partly in contact with hornblende granite. Minerals occurred the research area consist of calcite, alkali feldspar, plagioclase, quartz, hornblende, biotite, diopside, phlogopite, sphene, spinel, garnet and scapolite. Contact and regional metamorphism can be observed in this area. According to the mineral assemblages, the regional metamorphism of the research area took place under "amphibolite facies". The limited occurrences of some gems and industrial minerals can be encountered in the research area. The rough stones of spinel, garnet are found in some marble and pegmatite.

Keywords: Metasedimentary rocks, Mogok belt, Amphibolite facies

Introduction

Pin-le-inn and Nyaung-ok area is nearly by Bodawgyi Taung and Yatkanzin Taung range. The area interests for their gem minerals, ore minerals and geological features to study about gemology, mineralogy and petrology. The

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research area is bounded by N 22° 11′ to N 22° 14′ and E 96° 33′ to E 96° 35′ which is located in the Madaya Township, Mandalay Region, (Figure 1). One inch topographic map number is 93-B/3. The total area coverage is about 10 km^2 in extent, including Nyaung-ok and Pin-le-in village. The highest landmark of the area is Bodawgyi Taung, its highest peak is 447 meters above sea level. The drainage patterns of the area are radial in the southern part (Bodawgyi Taung) and dendritic in the rest of the region. Generally dendritic pattern can be divided into coarse-dendritic pattern and fine-dendritic pattern in some area which occur in metamorphic rocks.

Purposes of Research

This research attempts to constrain the mineralogical aspects of some gem minerals with the following objectives:

- To prepare detailed geological map
- To study the mineralogy of various rock types
- To carry out the relationship among the geology, petrography and mineralogy

Methods of Research

Rock samples were collected for the different rock types to carry out the mineralogical research in the laboratory. The field investigations were made along road cuttings, foot paths and streams, and locations were made by G.P.S. The representative samples were studied by detailed examination of various metamorphic rocks for better understanding of the mineralogy of the area. Good exposures and prominent panoramic views are taken as a photographic data. The laboratory methods are megascopic observation of the collected specimen and microscopic examination of thin sections from various rocks units.

Previous Works

Pin-le-inn and Nyaung-ok area is located within the Mogok Metamorphic belt. Many authors described about this area and its environs by several point of viewing. Thein Win (1980) and Yin Yin Nwe(1986) were investigated the research area at different fields of view.

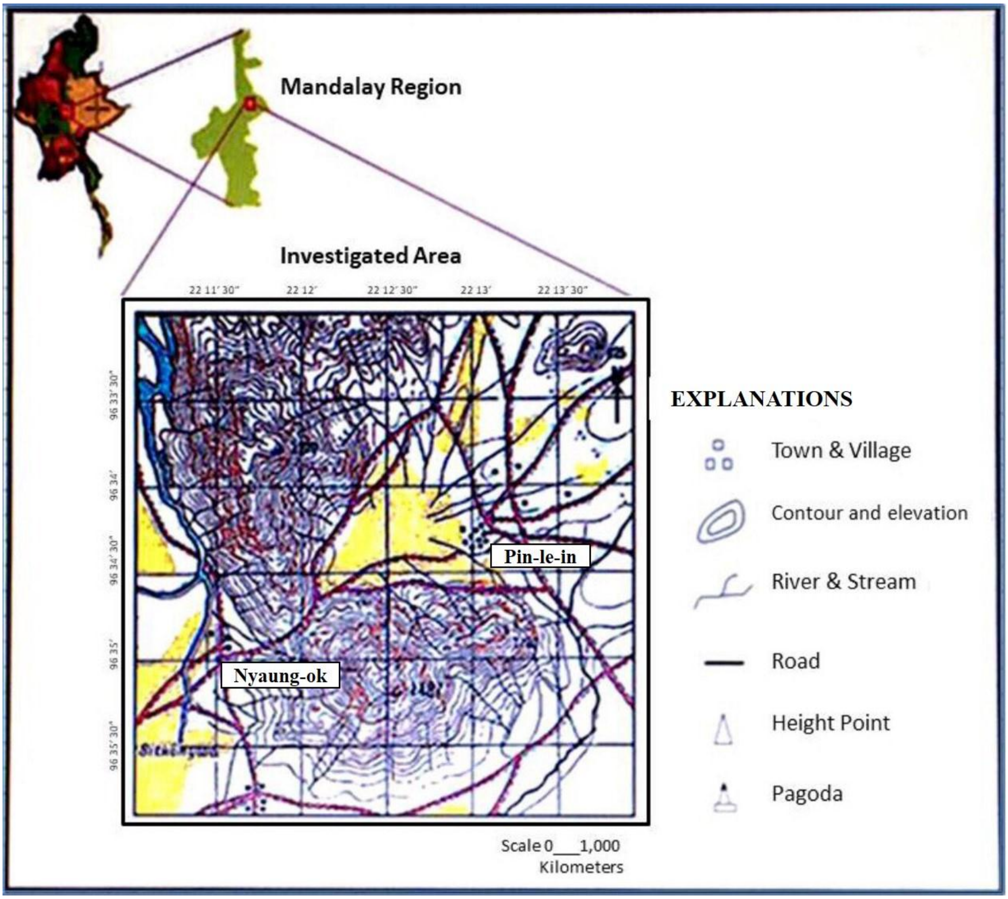

Figure 1: Location map of the research area

Regional Geologic Setting

The regional geology of the research area is situated in the complex of metasedimentary rocks and igneous intrusive lying between the Shan massif in the east and Tertiary sediments of "Central Burma Basin" in the west. The area also lies in the southern part of the "Mogok Belt" of Scarle and Haq (1964). These crystalline rocks or metasedimentary rocks are formed as a result of tectonic activity related to the Himalayan Orogeny (Figure 2). These crystalline rocks, phlogopite marble, spinel-chondrodite marble, white marble, calc-silicate rocks, garnet-biotite gneiss and biotite-hornblende gneiss are dipping generally to the east.

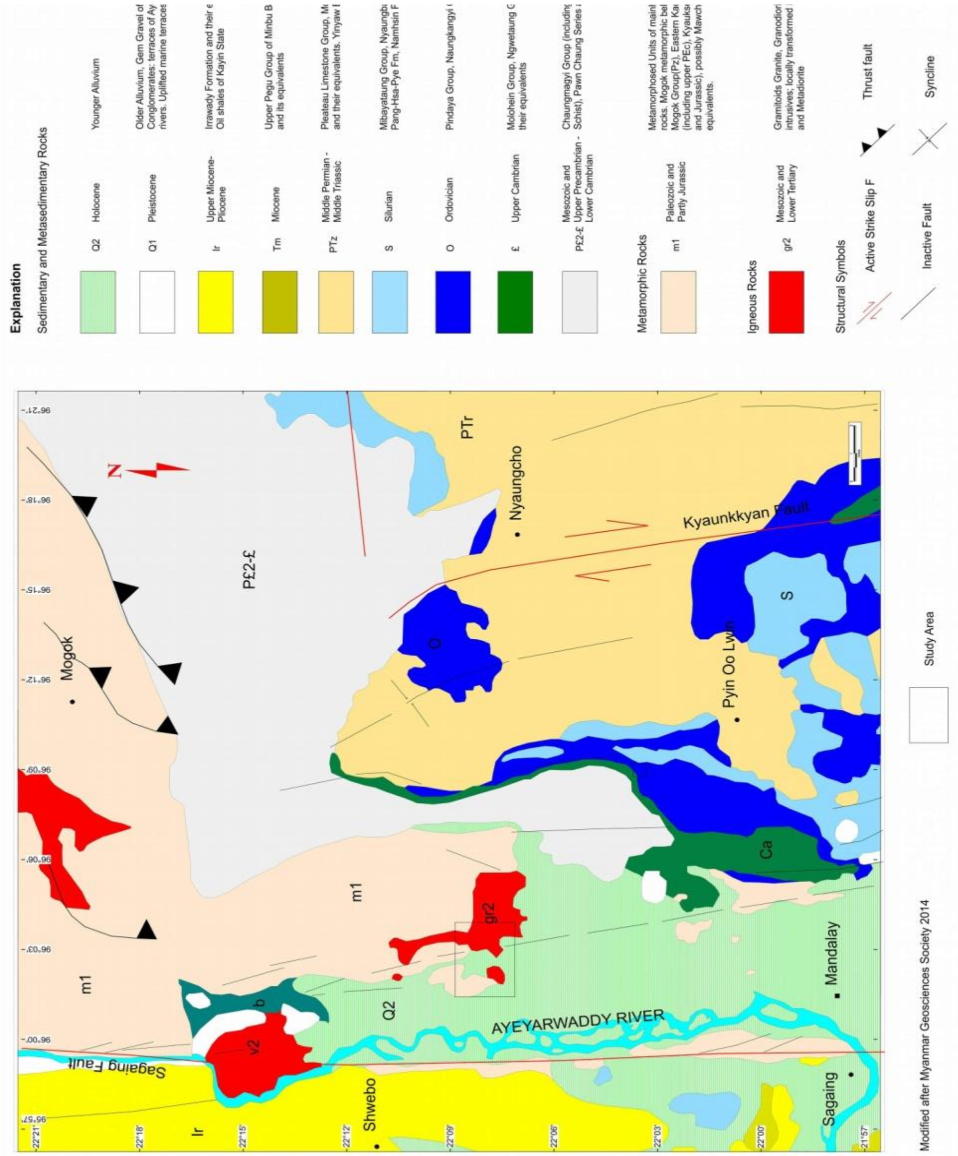

Figure 2: Regional Geologic Map of the Research Area (Modified after Myanmar Geosciences Society 2014

Sequences of the rock units

The rock units of the stratigraphic succession are described and mapped in the area. The rock succession established mainly on the basic of correlation and field relation (After Thein Win, 1980) is as follow;

Igneous rocks

Rock unit	Age
Pegmatite	
Leucogranite	Tertiary
Biotite microgranite	Tertiary
Biotite granite	Tertiary
Granodiorite	Tertiary
Hornblende granite	

Metamorphic rocks

Rock unit	Age
Biotite hornblende gneiss	Upper Paleozoic to Mesozoic
Calc-silicate rocks	Upper Paleozoic to Mesozoic
White marble fine to medium grained with some spinel	Upper Paleozoic to Mesozoic
Phlogopite and graphite	Upper Paleozoic to Mesozoic
Phlogopite marble	Upper Paleozoic to Mesozoic
Diopside marble	

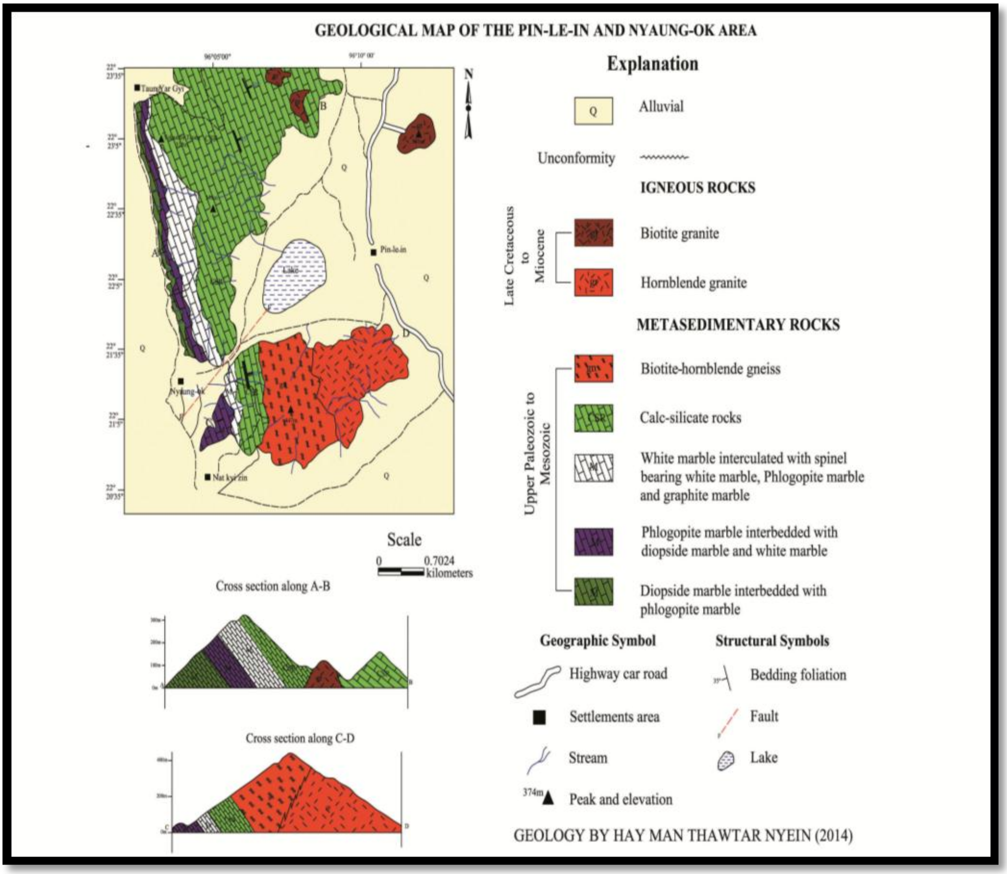

Figure 3: Geological Map of the Pin-le-in and Nyaung-ok area

Biotite hornblende gneiss

It is widely distributed throughout at Bodawgyi Taung range, (Figure 4). The rock is chiefly composed of feldspar, quartz, hornblende and biotite. Accessory minerals are sphene and opaque minerals. Hornblende presents more abundant than biotite **(**Figure 10a & b).

Calc-silicate rocks

Drag folded outcrop nature of Calc-silicate-rocks which are exposed in middle part of the Bodawgyi Taung area (Figure 5). The mineral composition is calcite, diopside, scapolite, quartz, alkali-feldspar, and sphene, (Figure 11a & b). Alkali-feldspar sphene and opaque minerals are composed as accessory minerals.

White marble

White marble is distributed mainly at Yatkanzin Taung range, (Figures 6 & 7). It also occurs at the western base of Bodawgyi Taung. Major constituent minerals of the rocks are calcite. It shows coarse-grained granoblastic texture. Accessory minerals are graphite and spinel (Figure 12a & b).

Phlogopite marble

This unit is mainly distributed at Yatkanzin Taung range, (Figure 8). It also occupies at Bodawgyi Taung. It is mainly composed of calcite, phlogopite, and diopside (Figure 14a & b).

Diopside marble

This unit is mainly distributed at the western base of Yatkanzin Taung range, (Figure 9). Diopside marble chiefly consists of calcite and diopside as main minerals. Phlogopite is occurred as accessory mineral (Figure 15a & b).

Figure 4: Outcrop nature of biotite hornblende gneiss, it is well exposed at the middle part of the Bodawgyi Taung range, Location: N - 22° 21′ 19.0″, E - 96° 05′ 50.3″, Facing: 60°

Figure 5: Calc-silicate-rocks are exposed in middle part of the Bodawgyi Taung area, Location: N - 22° 22′ 13.3″, E - 96° 4′ 56.8″, Facing: 25°

Figure 6: White marble is well exposed at Yatkanzin Taung range, Location: N - 22° 21′ 34.4″, E - 96° 5′ 1.3″, Facing: 360°

Figure 7: Biotite granite intruded into white marble at Yatkanzin Taung range Location: N - 22° 21′ 34.4″, E - 96° 5′ 1.3″, Facing: 360°

Figure 8: Phlogopite marble is well exposed at Yatkanzin Taung range, Location: N - 22° 21′ 37.0″, E - 96° 05′ 00.3″, Facing: 130°

Figure 9: Diopside marble is well exposed at Yatkanzin Taung range, Location: N - 22° 21′ 37.0″, E - 96° 05′ 01.2″, Facing: 260°

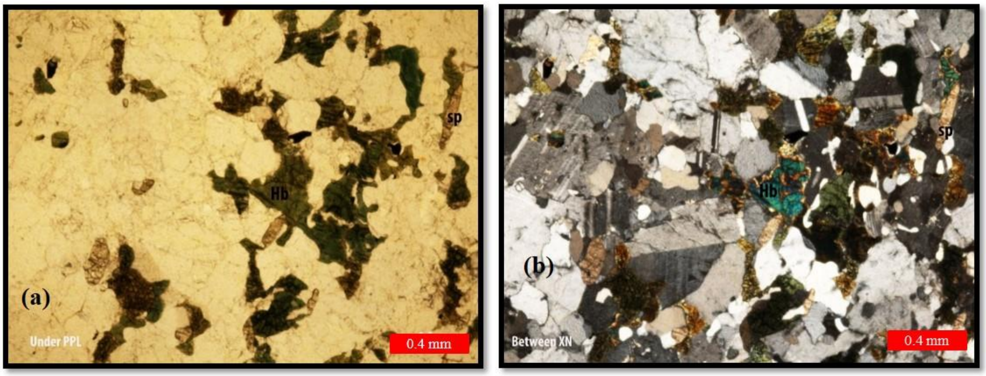

Figure 10: (a) (b) Photomicrograph of biotite hornblende gneiss: Hb=hornblende, sp=sphene

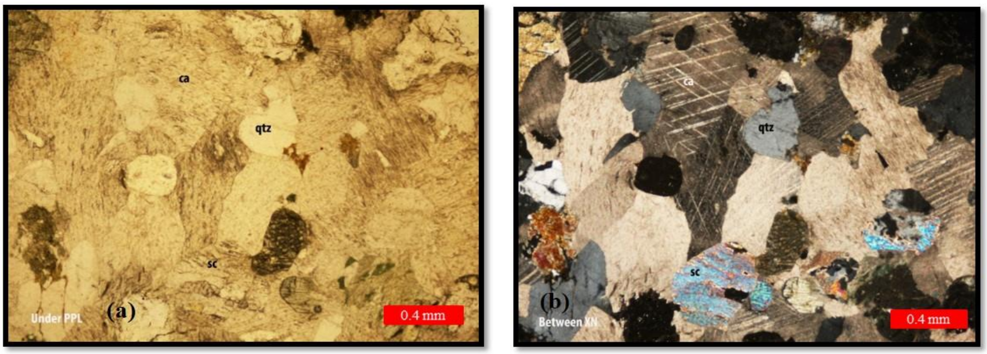

Figure11: (a) (b)Photomicrograph of calc-silicate rock: ca=calcite, qtz=quartz, sc=scapolite

Figure 12: (a) (b) Photomicrograph of white marble: ca=calcite

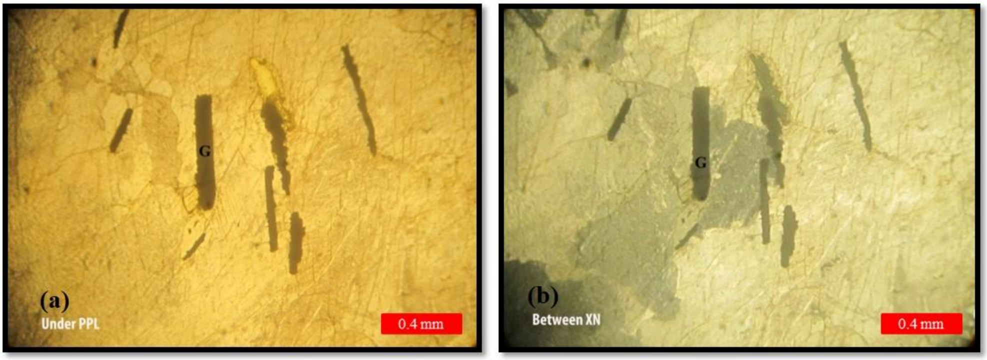

Figure 13: (a) (b) Photomicrograph of white marble: G=graphite

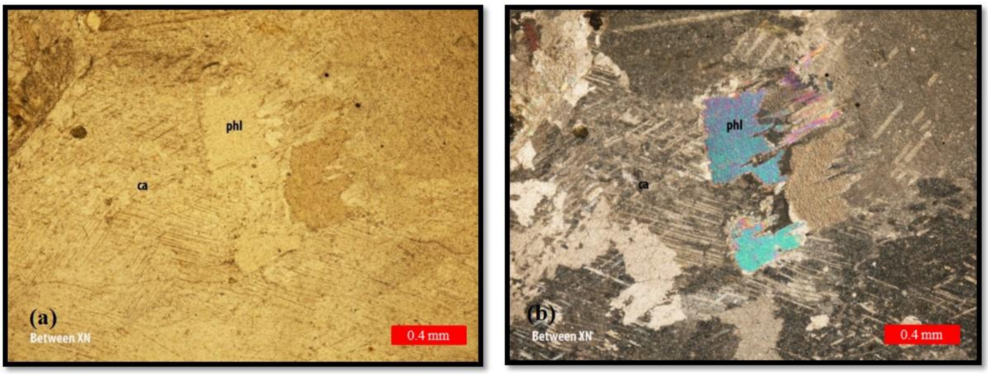

Figure 14: (a) (b) Photomicrograph of phlogopite marble: phl=phlogopite, ca=calcite

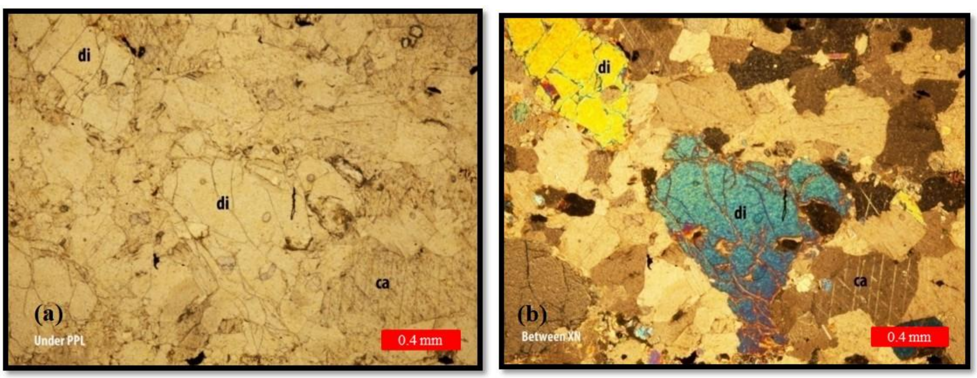

Figure 15: (a) (b) Photomicrograph of diopside marble: ca=calcite, di=diopside

Visual estimation of rocks in the research area

No	Minerals(%)	Rocks				
		Biotite hornblende gneiss	Calc-silicate rocks	White marble	Phlogopite marble	Diopside marble
1	Alkali feldspar	30	-	-	-	-
2	Plagioclase	15	-	-	-	-
3	Quartz	25	20	-	-	-
4	Hornblende	12	-	-	-	-
5	Biotite	10	-	-	-	-
6	Calcite	-	30	95	80	80
7	Phlogopite	-	-	-	11	5

Metamorphism

Types of metamorphism

Regional metamorphism can be observed in the research area. It is the most widespread and common type. It is characterized by the widespread occurrence of gneiss and calc-silicate rocks throughout the area. The occurrences of biotite hornblende gneiss and calc-silicate rocks containing the minerals diopside, scapolite, biotite, hornblende and sphene, type of metamorphism in the research area reached in amphibolite facies.

Generally, the regional strike of area is NNW-SSE and all metamorphic follow the regional trend. Therefore, it is obvious that the research area had undergone predominately one major phase of regional metamorphism.

Mineral assemblages and metamorphic facies

The nomenclature, defining mineral assemblages and metamorphic facies classification made in this area are based on Turner and Verhoogen (1960).

Mineral assemblages of the research area are described below. The mineral assemblages are used to define the metamorphic grade and facies. The mineral assemblages are graphically represented by means of ACF and AKF diagram.

According to the mineral assemblages, the regional metamorphism of the research area took place under "amphibolite facies" (Turner,1968), (Figure 16).

Regional metamorphism	**Rock Type**
Amphibolite facies	
(a)Pelitic rock	
1. Alkali-feldspar+ quartz+ plagioclase+ hornblende+ biotite+ sphene	Gn
(b)Calcareous rock	
1. Calcite+ quartz+ scapolite+ diopside+ sphene+ alkali-feldspar	CSR
2. Calcite+ Spinel	M
3. Calcite+ phlogopite+ diopside	M
4. Calcite+ diopside+ phlogopite	M

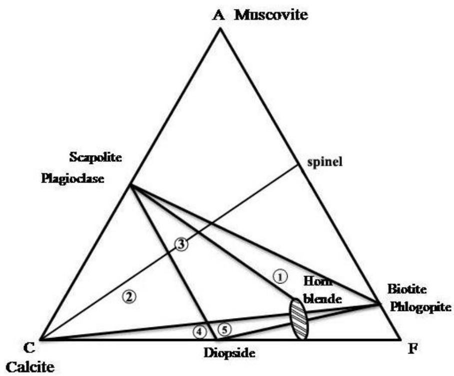

Figure 16: Mineral assemblages and metamorphic facies recognized in Pin-le-inn and Nyaung-ok area

Mineralogy

Calcite

It is major constituent of marble (Figure 17a & b). Two sets of rhombohedral cleavages may distinct. Polysynthetic twinning and twinkling effect are very common in calcite.

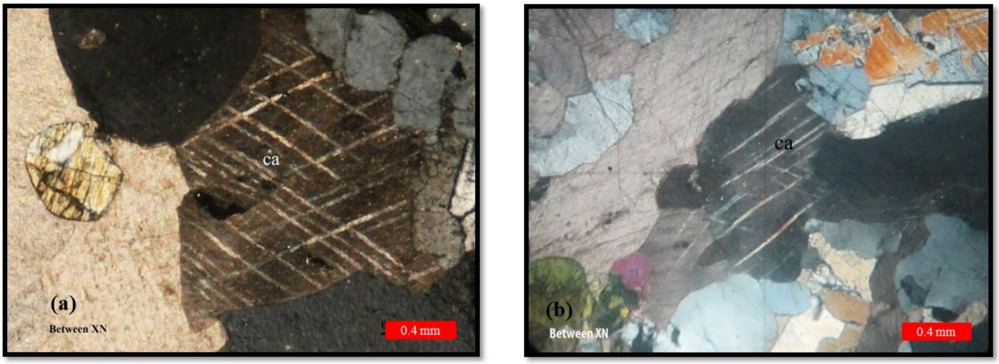

Figure 17: (a) (b) Photomicrograph of calcite in calc-silicate rock, ca=calcite

Plagioclase feldspar

Plagioclase feldspar is essential in biotite granite, hornblende granite, calc-silicate rock and biotite hornblende gneiss. Polysynthetic twinnings are well observed and twin bands are slightly bent. Most of the plagioclases are inclined extinction. Extinction angle increased with increasing calcium content. Plagioclasse are determined by using Michel-Levy method. Biotite granite is the range of plagioclase composition is "Albite to Oligoclase" from An_{10} to $An_{14.}$ Hornblende granite is the range of plagioclase composition is "Albite to Oligoclase" from An_{10} to An_{11} (Figure 18a&b).

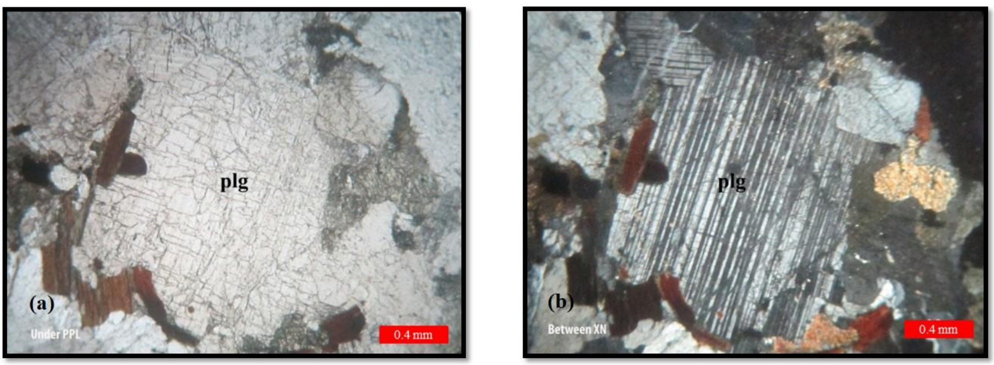

Figure 18: (a) (b) Photomicrograph of plagioclase in biotite hornblende gneiss, pgl=plagioclase

Quartz

Quartz is including in gneiss and CSR units. In quartzofeldspathic units, the grain size is ranged from less than 1 mm to more than 5mm (Figure 19a & b).

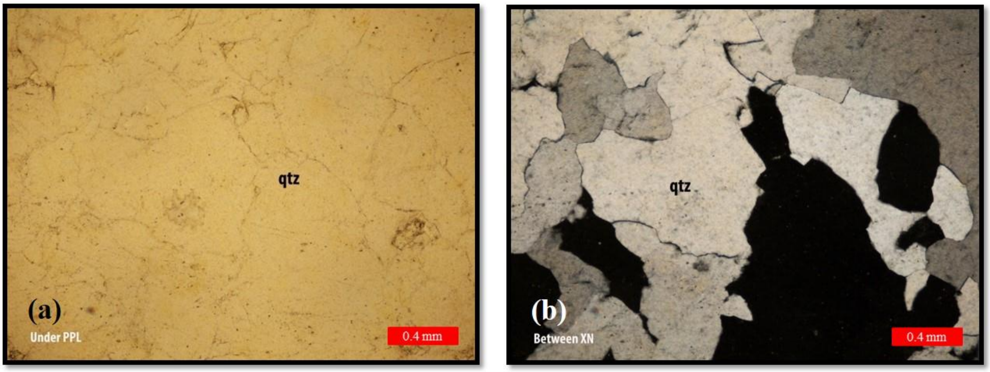

Figure 19: (a) (b) Photomicrograph of quartz in quartz vein, qtz=quartz

Hornblende

Hornblende is dominant in biotite hornblende gneiss (Figure 20a & b).

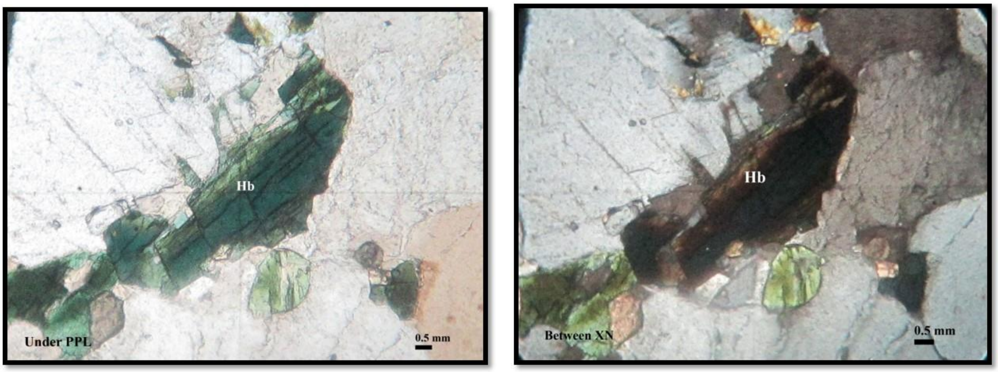

Figure 20: (a) (b) Photomicrograph of hornblende in biotite hornblende gneiss, Hb=hornblende

Diopside

Diopside is mainly found in marble and calc-silicate rock (Figure 21a & b).

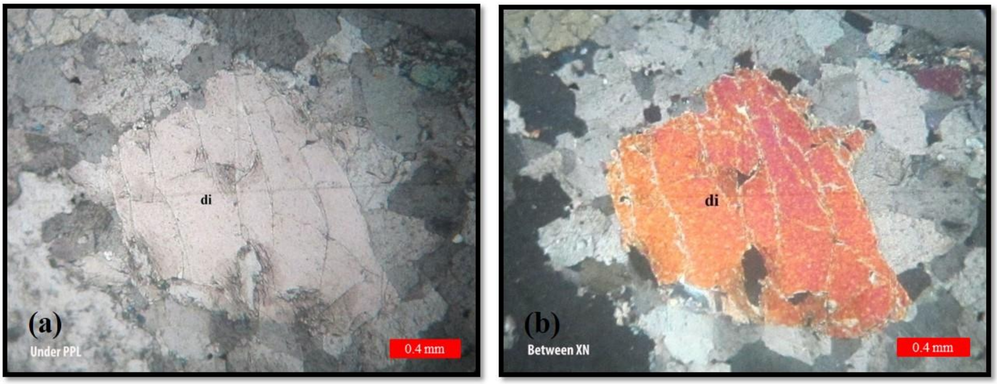

Figure 21: (a) (b) Photomicrograph of diopside in diopside marble, di=diopside

Phlogopite

Phlogopite in this area is associated with diopside marble and white marble. (Figure 22a & b)

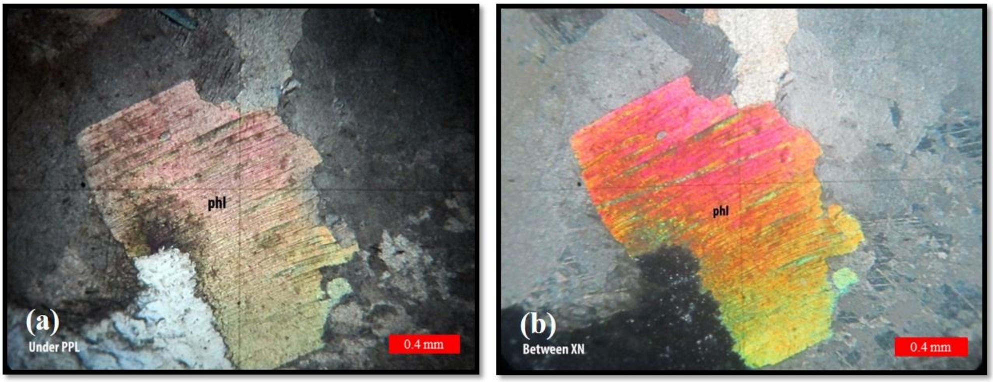

Figure 22: (a) (b) Photomicrograph of phlogopite in phlogopite marble, phl=phlogopite

Sphene

Sphene is widely distributed in this area as a minor constituent. Sphene is common in biotite-hornblende gneiss and calc-silicate rocks. (Figure 23a & b)

Figure 23: (a) (b) Photomicrograph of sphene in calc-silicate rocks, sp=sphene

Garnet

It is found in marble unit, gneiss unit, pegmatite veins and quartzofeldspathic veins. (Figure24a & b)

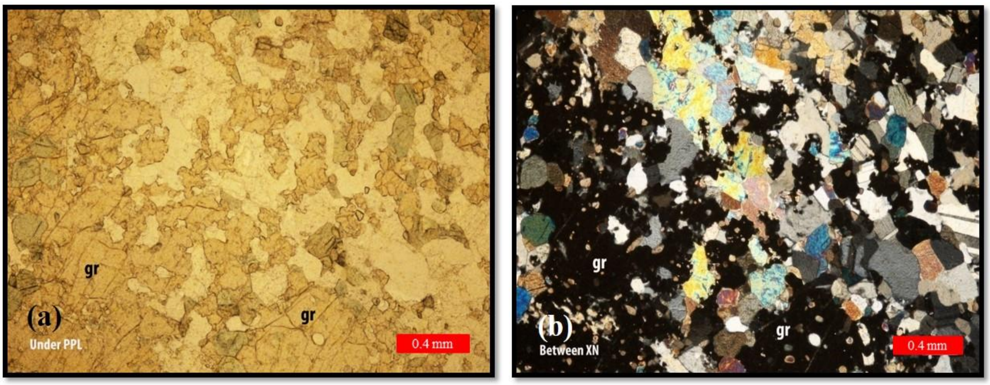

Figure 24: (a) (b) Photomicrograph of garnet aggregates in pegmatite dykes, gr=garnet

Scapolite

It is very common in calc-silicate rocks. Scapolite shows strong birefringence. (Figure 25a & b)

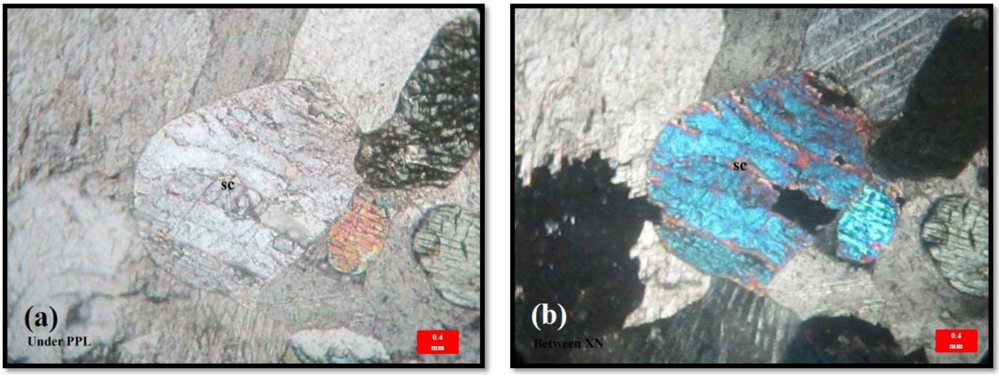

Figure 25: (a) (b) Photomicrograph of scapolite in calc-silicate rocks, sc=scapolite

Spinel

It can only occur in marble unit. (Figure 26a & b)

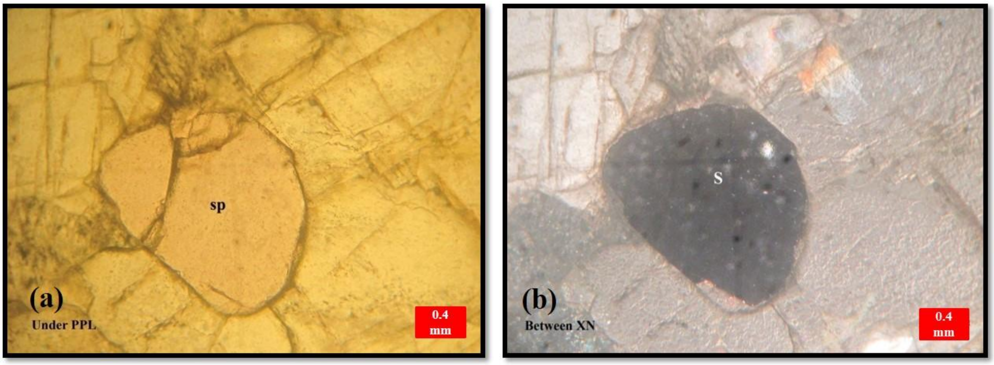

Figure 26: (a) (b) Photomicrograph of spinel in white marble: S= spinel

Opaque minerals

They cannot be identified by under thin section, according to their shape. Possible opaque minerals are pyrite, magnetite and illuminate.

Economic minerals

The limited occurrences of some gems and industrial minerals can be encountered in the research area. This area can be operated the systematic production of gem minerals as the research area is a part of Mogok stone tract. Well-known decorative materials of pure white marble productions were operated since last some years ago in this area (Figure 27a & b). Gem minerals found in the research area are spinel, garnet, tourmaline, diopside and sphene, and they need to produce systematic mining method under safety site. The main products from white marble are beautiful red spinel and crystals reach up to 1.5cm in size. Numerous rough stones of spinel are abundantly found in marble at Yatkanzin Taung. But clear red-rose spinels are not found in sufficient quantity to warrant extraction (Figure 28a, b & c).Lots of garnet crystals noticeably found in pegmatite dykes at Bodawgyi Taung and they are almandine garnet (Figure 29).Tourmaline and sphene occur in the veins of pegmatite dykes in some places of Bodawgyi Taung range. (Figure30).

Figure 27: (a) Old white marble quarry at the base of Yatkanzin Taung (b) Pure white marble plates excavated from the research area were used as a construction material

Figure28: (a) Spinel found in white marble outcrop at Yatkanzin Taung, Location: N-22° 22′ 41.4″, E-96° 4′ 57.2″,Facing: 120°, (b)Spinel segregation found in white marble exposure at Yatkanzin Taung,Location: N-22° 21′ 34.4″, E-96° 05′ 01.3″,Facing: 145°, (c)A super rare large red spinel notably found in white marble at Yatkanzin Taung

Figure 29: Some garnets are thrown by weathering found in the vein of pegmatite dykes at Bodawgyi Taung,Location: N-22° 21′ 25.8″, E-96° 05′ 17.3″,Facing: 90°

Figure 30: Tourmaline found in pegmatite dykes at Bodawgyi Taung,Location: N-22° 21′ 25.4″, E-96° 05′ 28.3″

Summary and Conclusions

The research area is situated in Madaya Township. Metasedimentary rocks are marbles, calc-silicate rocks and gneisses. Minerals occur in this area consists of calcite, alkali feldspar, plagioclase feldspar, quartz, hornblende, biotite, diopside, phlogopite, sphene, spinel, garnet and scapolite. According to the mineral assemblages, the regional metamorphism of the research area took place under "amphibolite facies". The limited occurrences of some gems and industrial minerals can be encountered in this area.

Acknowledgements

Firstly, we would like to thankful to Dr Aye Aye Tun (Rector) and Dr Yin Yin Than (Pro-Rector), University of Bago for giving us their kind permission to do this research project. We wish to express our special gratitude to Dr Khin Maung Hla (Professor and Head, Department of Geology, University of Bago) and Dr Aye Aye Han (Professor Department of Geology, University of Bago) for their valuable advices and discussions.

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PETROGRAPHIC DESCRIPTIONS OF MESOZOIC IGNEOUS ROCKS IN ZINGYAIK AREA, PAUNG TOWNSHIP, MON STATE

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Abstract

The study area is located at the northwestern part of Mawlamyine, Paung Township, Mon State. It lies between latitudes 16° 39' 00" to 16° 43' 00" N and longitudes 97° 26' 00" to 97°28' 00" E. One-inch topographic map sheet no. is 94 $H/_5$ of Myanmar Survey Department. The study area lies within a part of the Mogok belt which is extending from Putao in the north through Mogok to Mottama in the south. The research area also lies within a part of the Karen- Tenasserim unit. Igneous rocks of the research area are foliated biotite granite, porphyritic biotite granite, gneissose granite, biotite microgranite, tourmaline granite, schorl rock. Microgranite sill, leucogranite dyke, pegmatite dykes, aplite veins, quartz and quartzofeldspathic veins occur as minor igneous rocks. According to the diagrams, all igneous rocks are plotting in the "Granite" field. Due to field observations and geochemical characteristics, igneous rocks of the study area confirm in "S" type".

Keywords: *Granite, S-type*

Introduction

Location and Size

The study area is situated in the northwestern part of Mawlamyine, Paung Township, Mon State. One inch topographic map sheet no. is94 $H/_5$ of Myanmar Survey Department (Figure 1). It is commonly a mountainous rugged terrain. There are many streams in this area. The prominent drainage density of the study area is moderate to coarse-texture.

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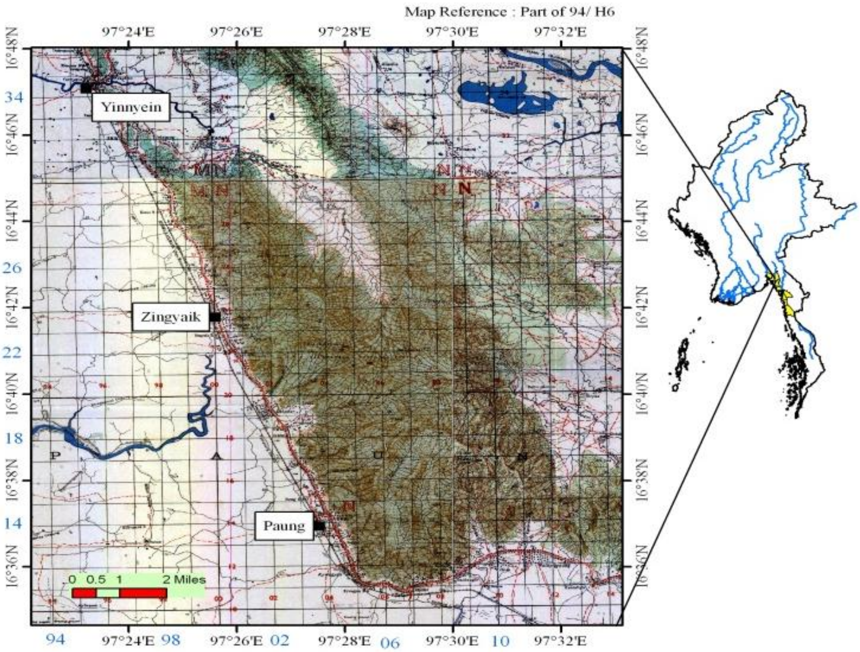

Figure 1: Location map of the study area

Regional Geologic Setting

Regional geological map of the study area and its environs can be seen in Figure (2). The study area lies within a part of the Mogok Belt (Searle and Haq, 1964) which is extending from Putao in the north through Mogok to Mottama in the south. Mg Thein regarded the Central Granitoid Belt of Burma as being developed in the tectonic setting of subduction related magmatic arc.The study area is situated in the northern part of Martaban Range which is a part of the western tin bearing batholith well known to be Western Tin Belt of South East Asia Tin Province (Mitchell, 1977, Nyan Thin 1984). The study area is covered by low to medium grade metamorphic rocks of Taungnyo Group (Lower Carboniferous), the igneous intrusions (Late Cretaceous to Early Eocene) and alluvial units (Quaternary).The general structural trend of the study area is NNW-SSE in direction.

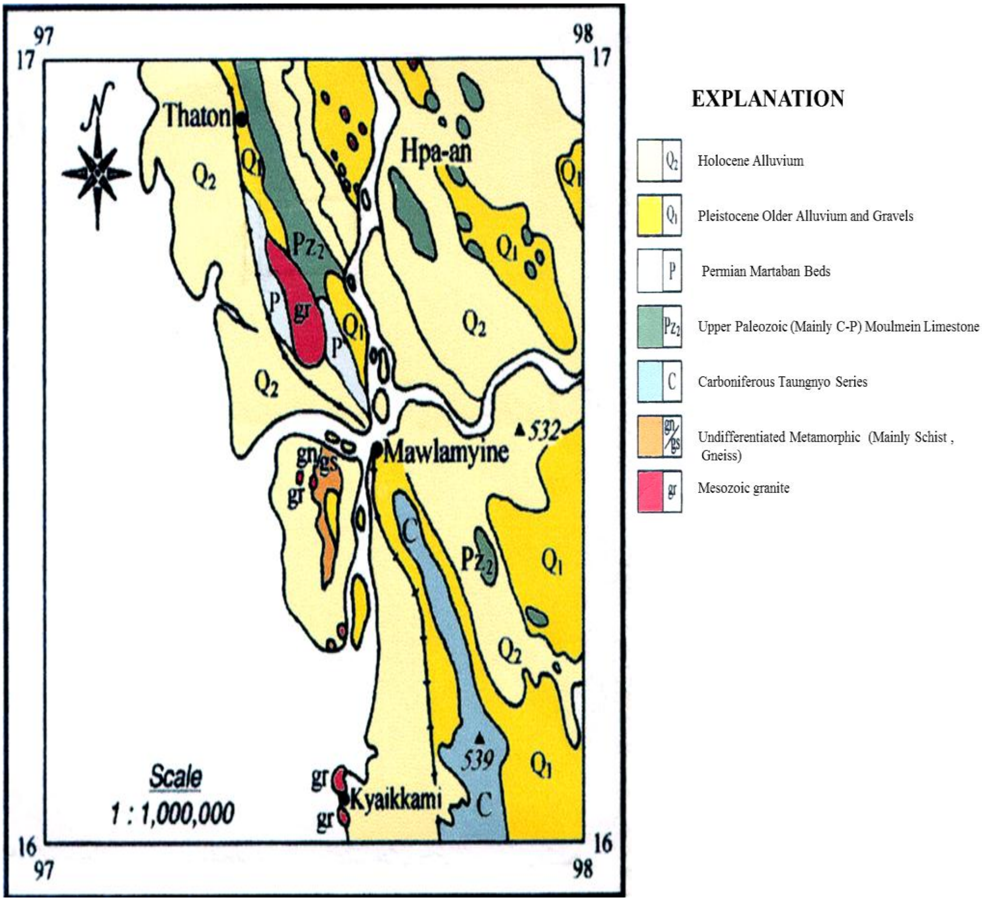

Figure 2: Regional geological map of the study area (From Geological Map of Myanmar Survey Department, 1977)

Rock Sequence of the Study Area

The rock sequence of the study area is shown in Table (1)**.**

Table (1) Rock Sequence of the Study Area

IGNEOUS ROCKS

Rock	Age
-Quartz and quartzofeldspathic veins	Late Cretaceous
-Pegmatite dykes and aplite veins	
-Leucogranite dyke	
-Microgranite sill	
-Schorl rock	
-Tourmaline granite	
-Biotite microgranite	
-Porphyritic Biotite granite	
- Foliated biotite granite	

Distribution of Major Rock Units

The study area is mainly composed of igneous rocks. Igneous rock units are the most widespread unit in the study area. Foliated biotite granite, porphyritic biotite granite, gneissose granite, biotite microgranite, granite, schorl rock are the most significant igneous rock units of the study area. In addition, microgranite sill, leucogranite dyke, pegmatite dyke and aplite veins quartz and quartzofeldspathic veins are also seen. They are noticeably elongated (linear) bodies. Their axes are nearly parallel to NNW-SSE trending with the country rocks.

Foliated Biotite Granite

Field and megascopic Study

This unit occurs at the southwestern part of the study area. Best exposure cropped out at the top hill of KyaukPone Taung and Pahtan Taung (Figure 3). It is medium to coarse-grained. At the peak of Kyauk Pone taung, this foliated biotite granite rocks are very scattered. On the visible surface, there is foliated nature with parallel arrangement of biotite mica flakes. Mosaic shaped cracks in foliated biotite granitecan be seen.

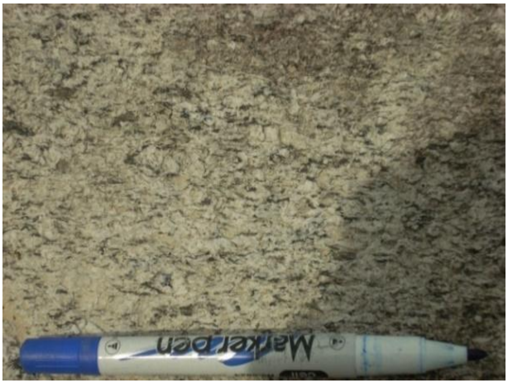

Figure 3: Best exposure of Foliated biotite granite at the top hill of Kyauk Pone Taung

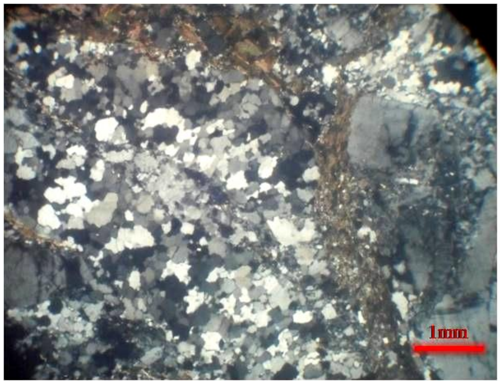

Figure 4: Foliated nature of mineral grains in foliated biotite granite, Between X.N

Microscopic study

It is medium to coarse-grained. It shows foliated nature with quartz, alkali feldspars, plagioclase (Figure 4). Quartz occurs as large to small grains with suture boundaries. It gives wavy extinction**).** Some quartz occurs as recrystallized minute anhedral aggregates forming around large feldspars. Orthoclase occurs as subhedral forms, show marginal granulation. It shows simple twinning. In foliated biotite granite, many orthoclase are observed. Some are sericitization. Plagioclase occurs as subhedral form with polysynthetic twinning Biotite occurs as subhedral forms. Some are bent due to deformation. Some biotite flakes are partially altered to chlorite. Sericite mica flakes are found among the foliated nature.

Porphyritic Biotite Granite

Field and megascopic study

This unit is the most widespread unit in the study area. This unit is well exposed at the peaks of Ka La Ma taung ,Yedagun taung and Min Tayatapar taung. Biotite granite is coarse-grained, porphyritic texture, with phenocrysts (megacrysts) of quartz, feldspars. It is mainly composed of quartz, feldspar and biotite. Tourmaline occurs as minor amount. It is light grey colour in fresh surface and pale yellowish colour is weathered surface. At Ka La Ma taung, this rock unit is well exposed. Most of this unit is highly weathered, brownish yellow is weathered and grayish white is fresh. Biotite granite is gradationally contact with microgranite,. Preferred orientation of coarse-grained minerals is found in biotite granite unit at Barr Mae cave (Figure 5). At the pagoda near Defense Service, many milky quartz grains are scattering. At the peak of Yedagun taung waterfall, (Local name-Ma Min Sein Waterfall), this unit is well exposed and highly weathered. Zoned feldspars are also observed on the visible surface**.** Tourmaline contains as minor amount. White and yellowish white colour megacryst quartz is found, scattered. Size of some quartz is 3 inch × 1.5 inch in length**.**Its length is 2 to 3 inch and width is about 5 inch. In addition, aggregates of biotite flakes are also observed in Yedagun taung .Some zoned feldspar porphyry is also observed. At the peak of Min Tayatapar taung, the northeastern part of the study area, spheroidal weathering nature can be seen at the Ko Yin Lay (Local name) monastery, large boulders are also found at this place (Figure 6).

Figure 5: Preferred orientation of coarse-grained minerals in biotite granite unit at Barr Mae cave, at the peak of Kalama Taung

Figure 6: Large boulders in Ko Yin Lay Monastery at the northern part of the study area

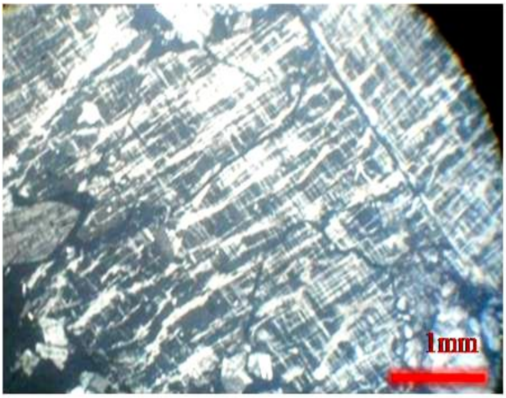

Figure 7: Perthite in biotite granite, Between X.N

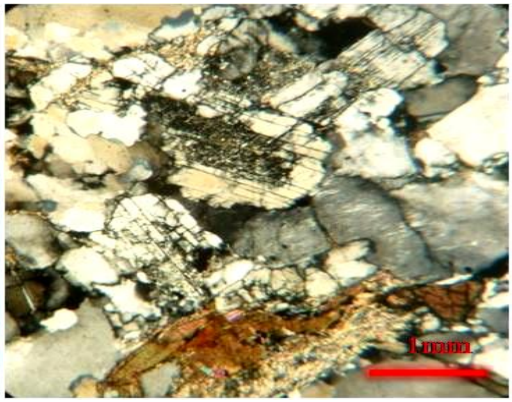

Figure 8: Saussuritization of plagioclase inbiotite granite, between X.N

Microscopic study

Biotite granite is coarse-grained, hypidimorphic, granular texture. It is essentially composed of alkalifeldspar, quartz, plagioclase, biotite. Apatite, zircon and opaque minerals occur as accessory minerals. These samples fall in the monzogranite and syenogranite field. Main alkalifeldspar occurs as perthite, orthoclase and microcline. Perthites are observed as vein perthite, string perthite, patch perthite, flame perthite and microcline microperthite (Figure 7). Seive texture and myrmekitic texture are also seen. Orthoclase shows simple contact twinning, it occurs as twinned and untwined. Sizes range from 2 to 5 mm. Perthite indicates that the temperature of formation will be less than 660° C. Perthites were developed at lower temperature and subsequently cooled slowly. Quartz occurs as two different forms. Some are large and some are found as interstitial anhedral grains. They show wavy extinction due to the strain effects. Some grains are embedded on the surface of some feldspars grains. Some quartz occurs as inclusions in perthite. Sericitization can be observed at the margin of orthoclase. In some orthoclase, there are inclusions**)**. In addition; some orthoclase are distorted. Plagioclase occurs as subhedral form with polysynthetic twinning. Saussuritization occurs in the centre of zoned plagioclases in Figure (8). Some plagioclases are normal zoning in and distorted zoned plagioclase can be seen**.** Biotite shows strong paleochroism. Some are bent and contorted. Microcline mineral is also observed**.** Some biotites alter to chlorite. Muscovite mineral is also seen. Zircon occurs as inclusion in biotite. Bent biotite mineral is also found .Zircon, apatite, tourmaline minerals occur as accessory minerals.

Biotite Microgranite

Field and Megascopic Study

Biotite microgranite unit is found at the southern part of the study area. It is well exposed at Thingan Hlyan Taung and Kyauk Chaw chaung (Figure 9 and Figure 10). It has medium-grained, light grey colour on fresh surface and buff to brownish grey colour on weathered colour. The alignment of metasedimentary xenoliths also can be seen. Some xenolith has reaction rim. Various sizes of xenoliths are shown in Figure (11). Striations on the surface of xenoliths can be observed**.** Some xenoliths are round. Alignment of feldspars is obvious at Loc.N 040192 along Myaukso Chaung.

Figure 9: Biotite microgranite unit at the peak of Thingan Hlyan Taung

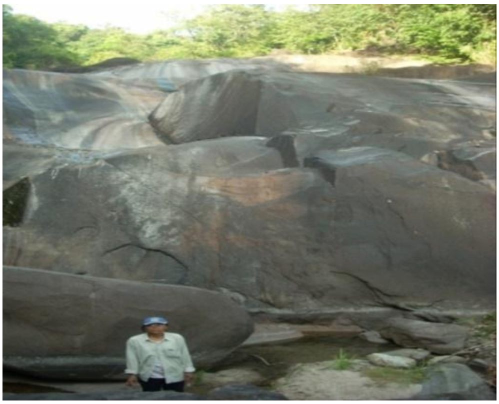

Figure 10: Well exposed nature of Biotite microgranite unit in Kyauk Chaw chaung, Loc.039190

Figure 11: Various sizes of xenoliths in Biotite microgranite in Kyauk Chaw chaung, Loc.039191

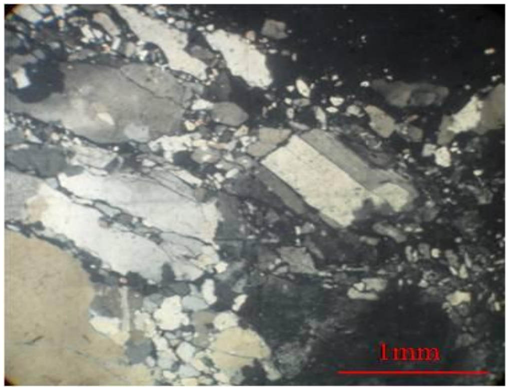

Figure 12: Simple twinning with orthoclase inBiotite microgranite

Microscopic Study

It is medium-grained, hypidiomorphic granular texture**.** It is mainly composed of quartz, orthoclase, plagioclase, biotite and muscovite. Orthoclase has euhedral to subhedral forms. It shows simple twinning (Figure 12). Some are distorted. At the centre of some orthoclase, many inclusions are also observed. Some alkali feldspars alter to sericite**.** Quartz shows wavy extinction. Some quartz occurs as anhedral grains**.** Plagioclase occurs as subhedral forms with polysynthetic twinning**.** Chlorite is also found as alteration product of biotite.

Tourmaline Granite

Field and Megascopic Study

This unit occurs at the northern part of the study area. Best exposure cropped out at the foot hill of Min Tayartapar Taung (Figure 13). It is coarse-grained (Figure 14). On the visible surface, there is mineralization with parallel arrangement of biotite mica flakes and tourmaline (Figure 15).

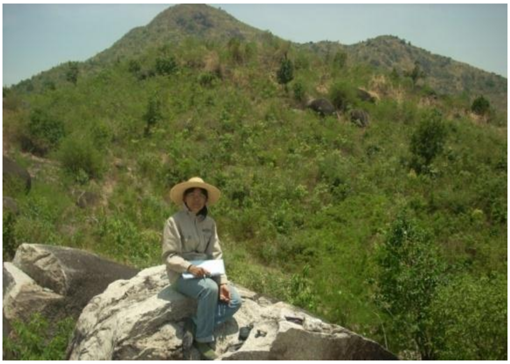

Figure 13: Best exposure nature of Tourmaline granite at the foot foot hill of Min Tayartapar Taung

Figure 14: Closure view of medium-grained Tourmaline granite at the foot foot hill of Min Tayartapar Taung

Figure 15: Mineralization with parallel arrangement of biotite mica flakes and tourmaline in Tourmaline granite at the foot foot hill of Min Tayartapar Taung

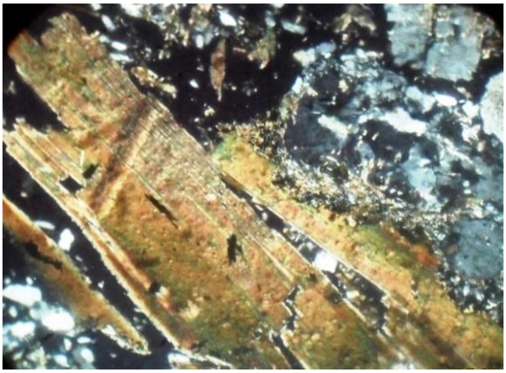

Figure 16: Subhedral form tourmaline mineral in Tourmaline granite, Between X.N.

Microscopic study

It is coarse-grained, hypidiomorphic granular texture**.** It is mainly composed of quartz, orthoclase, feldspar, biotite and tourmaline. Tourmaline mineral occurs as subhedral form (Figure 16).

Leucogranite Dyke

Field and Megascopic study

Leucomicrogranite dyke intruded into porphyritic biotite granite at Loc. N 019272. It is located at the left side of the car road from Zingyaik to Min Tayatapar taung (Figure 17). Its weathered colour is yellowish white and fresh colour is white. Its trend is 110˚-290˚.It is medium-grained.

Microscopic study

It is coarse-grained. It contains feldspar quartz, biotite and muscovite. Quartz shows anhedral forms. It is made up of unequal quartz grains (Figure 18). It shows wavy extinction. Some feldspars have many cracks**.**

Figure 17: Intrusion of Leucogranite dyke in Biotite granite at Loc. N019272 (N 16˚43' 34.3"-E 97˚26'32.6"), Facing-Due West

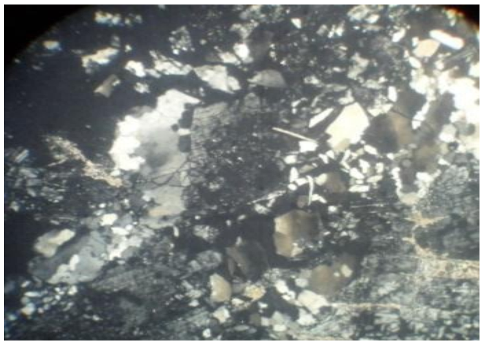

Figure 18: Quartz and feldspar minerals in Leucogranite, between X.N

Microgranite Sill

Field and Megascopic study

At Loc. N 011226, microgranite sill intruded into biotite gneiss at the midst of Zingyaik Waterfall (Local name- Kyauk Thin Baw Waterfall) well observed. It is also found at elevation 122' of Zingyaik waterfall (Figure 19). Its trend is 170˚-350˚ and length is about 250 feet. At the left side of this waterfall, a normal fault is also found near the microgranite sill. Fault trend is 60˚-240˚.

Pegmatite Dykes

Field and Megascopic study

Pegmatite dykes are found at Loc. N 014279 in Min Tayatapar taung (elevation 2069′) intruding biotite granite (Figure 20). Quartz, feldspar and tourmaline are found as main constituents. Minerals'' alignment is 110˚-290˚. At U Pann Shwe's garden (Loc .N 030264), pegmatite vein is also observed in (Figure 21). Its vein trend is 285° -105°. It shows yellowish white colour in weathered surface and fresh colour is grayish white.

Figure 19: Microgranite sill intruded into biotite gneiss at Kyauk Thin Baw Waterfall (Local name- Zingyaik Waterfall), Loc.N 16˚41'18.4"- E97º26'12.8", Facing - Due East.

Figure 20: Pegmatite vein with tourmaline minerals in biotite granite at Min Tayatapar taung, Loc.N012280, Facing - Due south

Figure 21: Small pegmatite vein in Biotite granite near Min TayataparTaung, Loc. N012280, Facing - Due south

Figure 22: Quartzofeldspathic vein in biotite gneiss at Zingyaik Waterfall quarry, Loc. **N**008235, N 16˚41'44.5"- E 97 26'02.6", Facing 85˚

Quartzofeldspathic and quartz veins

Field and Megascopic study

Quartzofeldspathic vein is found in biotite gneiss at Zingyaik waterfall quarry, trending with 105˚-285˚and width is about 1.8 feet at elevation 55 feet (Figure 22). Quartz veins are found at Loc.N050291, near Se Daw Oo pagoda at the eastern part of the Kadaik Dam (Figure 23). Vein's trend is 30˚-210˚.Aplite vein is also found intruded into biotite microgranite at Myaukso chaung, Kyauk Chaw of Otada village (Figure 24).

Figure 23: Quartz vein near Se Daw Oo Pagoda at the eastern part of Kadaik Dam, Loc. N 050291, Facing-295°

Figure 24: Aplite vein in Biotite microgranite at Myauksochaung, Loc.N039191

Analytical data

Nine representative samples were selected for petrochemical analysis. The granitoid rocks such as porphyritic biotite granite, foliated biotite granite and biotite microgranite of the research area were sent to the geochemical laboratory of Department of Earth Resources Engineering, Faculty of Eng., University of Kyushu, 744 Motooka, Nishi-ku, Fukuoka, 19-0395, Japan. X-ray fluorescence spectrometry was used for major oxides and trace elements determination. According to these analytical data, igneous rocks of the research area fall in “Granite” Field (Figures 25 and 26). In addition, field observations and geochemical characteristics, igneous rocks of the study area confirm in "S" type" (Figure 27).

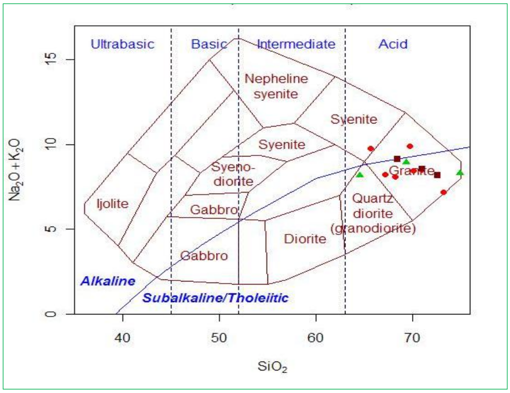

Figure 25: TAS diagram of Cox et.al (1979) showing the igneous rocks of the research area

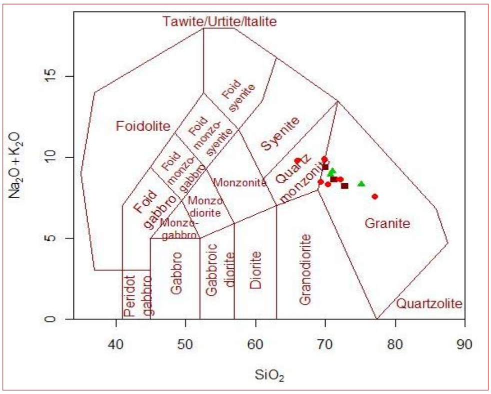

Figure 26: TAS diagram of Middlemost (1985) showing the Granite field of the research area

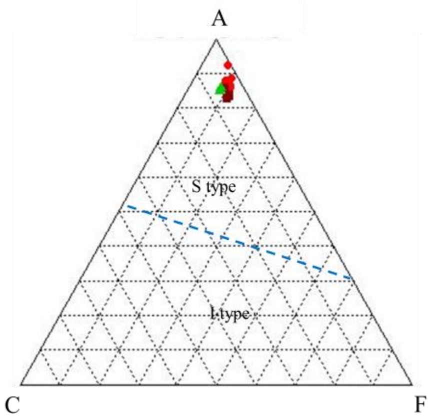

Figure 27: ACF diagram for the igneous rocks of the study area (after Hine et al.,1978) Molar ratio: A=Al_2O_3-Na_2O-K_2O,C=CaO, F=Fe_2O_3 + MgO

Summary and Conclusions

The study area is situated at the north northwestern part of Mawlamyine, Paung Township. The study area lies within a part of the Mogok belt. It also lies within a part of the Karen- Tenasserim unit. Major igneous rocks are foliated biotite granite, porphyritic biotite granite, biotite microgranite, tourmaline granite, schorl rock. Minor igneous rocks are microgranite sill, leucogranite dyke, pegmatite dykes, aplite veins, quartz and quartzofeldspathic veins occur. According to field observations and petrographic datas, all igneous rocks are plotting in the "Granite" Field. Due to field interpretations and geochemical characteristics, igneous rocks of the study area confirm in "S" type".

Acknowledgements

I would like to express my thanks to supervisor, Part time Professor U Hla Kyi, Applied Geology Department, University of Yangon and U Thein Win, Pro-Rector (Retd.), West Yangon University for guided my research work and discussion. My grateful thank want to Sayar U Ngwe Soe and wife, U Min Han Nyein, villagers and many people for their valuable suggestions and help during this research work.

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PRELIMINARY STUDIES ON SUBSIDENCE IN BAGAN - NYAUNG OO AREA, MANDALAY REGION

Tun Naing Zaw[1], Swun Wunna Htet[2], Min Thura Mon[3]

Abstract

Bagan - Nyaung Oo area is the most important architectural complex in Myanmar and is situated between 94°45’ 00” E to 95°00’ 00” E and 21°00’ 00” to 21°15’ 00” N. The research aim is to assess whether any subsidence is currently occurring in Bagan- Nyaung Oo area and to identify whether groundwater extraction is the main case. Subsidence is a typical geohazard for low elevated coastal areas and river basin especially when densely populated. It was only recently that the potential for hazard in Bagan – Nyaung Oo area was acknowledged, but the rates and extent of such hazard remain unknown. Bagan – Nyaunng Oo has a large urban extent and is expanding rapidly. Inhabitants and ecosystems in delta and river basin areas are becoming increasingly vulnerable to the effects of subsidence, triggered both by natural causes and anthropogenic causes. The study area covers mostly the alluvial plain beside the Ayeyarwady River and partly the debris and small fan materials derived from Tuywin Taung and Tantkyi Taung hills which are exposed with rocks of Miocene to Oligocene. Bed rocks are mainly represented by rocks of Irrawaddy Formation (Late Miocene to Pliocene), Okhmintaung Formation (Upper Oligocene) and Padaung Formation and Shwezettaw Formation (Lower Oligocene). Mainly the alluvial soils of Quaternary-Recent are deposited on the plain and along the river banks by fluvial action. The areas susceptible to landslides, rock falls, mass movements, and debris flows hazards are demarcated in the Tuywin Taung and Tant kyi Taung that have been encountered with a number of small tension cracks, active and old landslides. Side cutting in both sides of Ayeyarwady River is caused by river bank scouring and rain water resulting into steep slopes. In the rainy season, low lands adjacent to the Ayeyarwady River and the main streams in the area are affected by flood. Bagan – Nyaung Oo area is situated on the bank of Ayeyarwady River. So water-based transformation and rich agricultural soils create an environment that is suitable for rapid economic growth and urbanization along river basin area. The level of human influence throughout this rapid urbanization and excessive groundwater extraction requires detailed examination in order to prevent man-made disasters and irreparable damage being caused to the environment. Subsidence is a key contributing factor to flood risk and extreme weather events and soit needs to be better evaluated, especially in

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area with large exposed populations. Human-induced land subsidence is mainly caused by excessive groundwater extraction as a result of rapid urbanization or extraction of other resources. The results of land subsidence are an increased vulnerability to flooding, infrastructural failures, aquifer salinization and permanent geological deformation.

Keywords–*Subsidence, Inhabitants, ecosystems, anthropogenic causes, groundwater extraction, irreparable damage, flood risk, infrastructural failures, and aquifer salinization*

Introduction

Inhabitants and ecosystems in delta, low elevated coastal area and river basin areas are becoming increasingly vulnerable to the effects of subsidence, triggered both by natural causes and anthropogenic causes. Ground surface in delta regions, low elevated coastal area, and river basin areas are susceptible to subsidence as a result of both natural and human-reduced causes. Bagan-Nyaung Oo area is the most picturesque architectural complex in Myanmar and is a global pilgrimage center. The area contains ancient Buddhist shrines that have been restored and repaired to retain the original architecture. The study area has a large urban extent and is expanding rapidly and resulting this geo-hazard. Human-induced land subsidence is mainly caused by excessive groundwater extraction as a result of rapid urbanization. In Bagan-Nyaung Oo area, the problem that can rise as a result of land subsidence which are an interested vulnerability to flooding and storm surges, infrastructural failures, aquifer salinization and permanent geological deformation. Subsidence in the study area is a key contributing factor to flood risk from sea-level rise and extreme weather events and so it is needed to evaluate the hazard of subsidence.

Location

Bagan-Nyaung Oo area is situated between 94° 45’ 00”E to 95° 00’ 00” E and 21° 00’ 00” N to 21° 15’ 00” N. It is located on both sides of the Ayeyarwaddy River and approximately 145 km southwest of Mandalay and 187 km from Yangon. Bagan stands on the east bank of the Ayeyarwaddy (Figure 1).

Bagan-Nyaung Oo area is the most important architectural complex in Myanmar-Bagan, in which the Buddhist religion took deep root, strengthening and broadening the outlook of the whole society. The World Heritage Site of Bagan is the Golden Land of wonders. Over 3,000 extant monuments are scattered across a vast arid plain that proclaim the piety and power of Myanmar's first empire. As a manifestation of a dynamic and original form of architecture, Bagan stands the other great Buddhist center of South-East Asia, such as Angkor in Cambodia or Borobudur in Java.

Bagan is a pilgrimage center and contains ancient Buddhist shrines that have been restored, redecorated and are in current use. The study area is dominated by the ancient temples and pagodas and the area also occupies both of urban and rural environments.

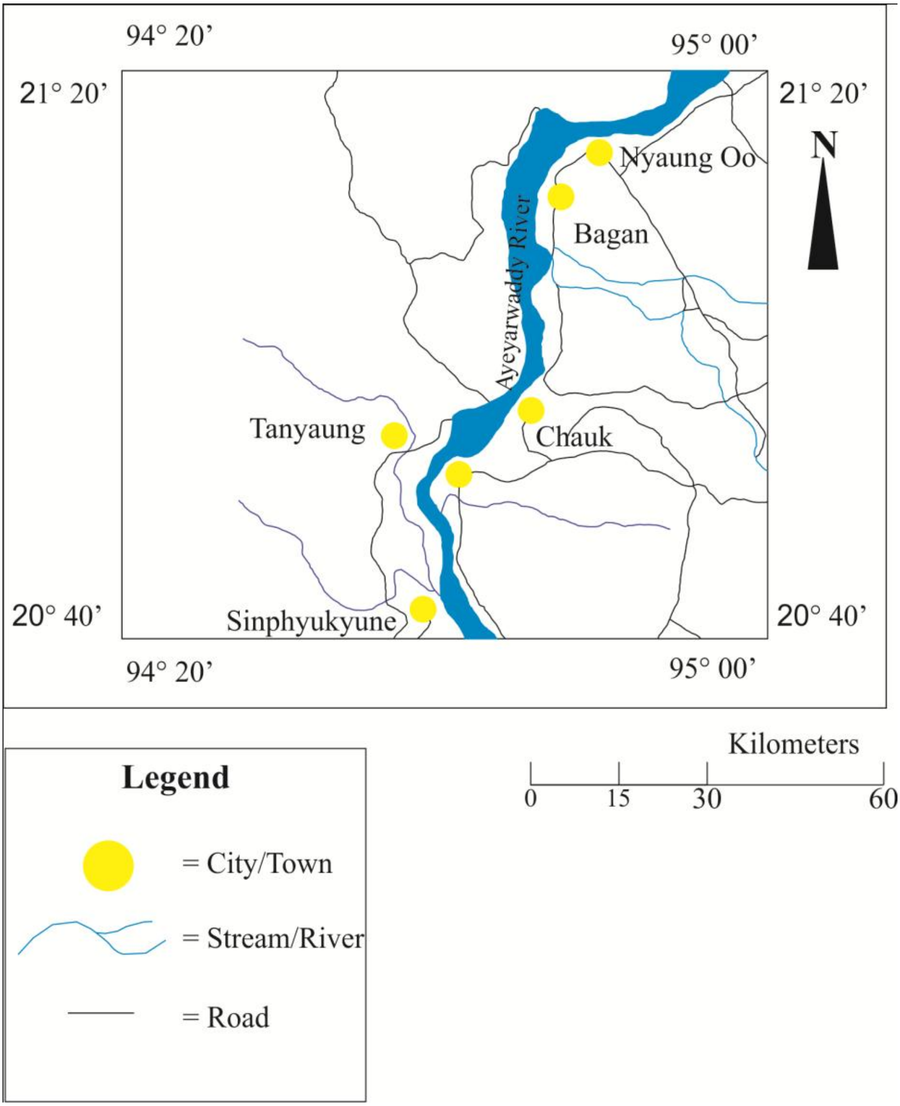

Figure 1: Location Map of the Research Area

Topography and Drainage

Generally, the study area is mainly within the low level plain situated beside the Ayeyarwaddy River (Figure 2).The attitude of the study area ranges from 5.2 m to 408m above sea level. Bagan-Nyaung Oo area lies on either side of Ayeyarwaddy River, as a vast plain on the eastern bank. There are mountain ranges namely, Taywin Taung in the southeast and Tantkyee Taung in the west (Figure 3).

The drainage pattern in the study area is dominant by dendritic drainage pattern (Figure 4). Most of the drainage are very poorly dense that means the dry streams in the dry season. Ayeyarwaddy River is the main drainage channel of the research area and it is running into the nearly N-S direction. Ayeyarwaddy River morphology is controlled by underlying structures and active tectonism.

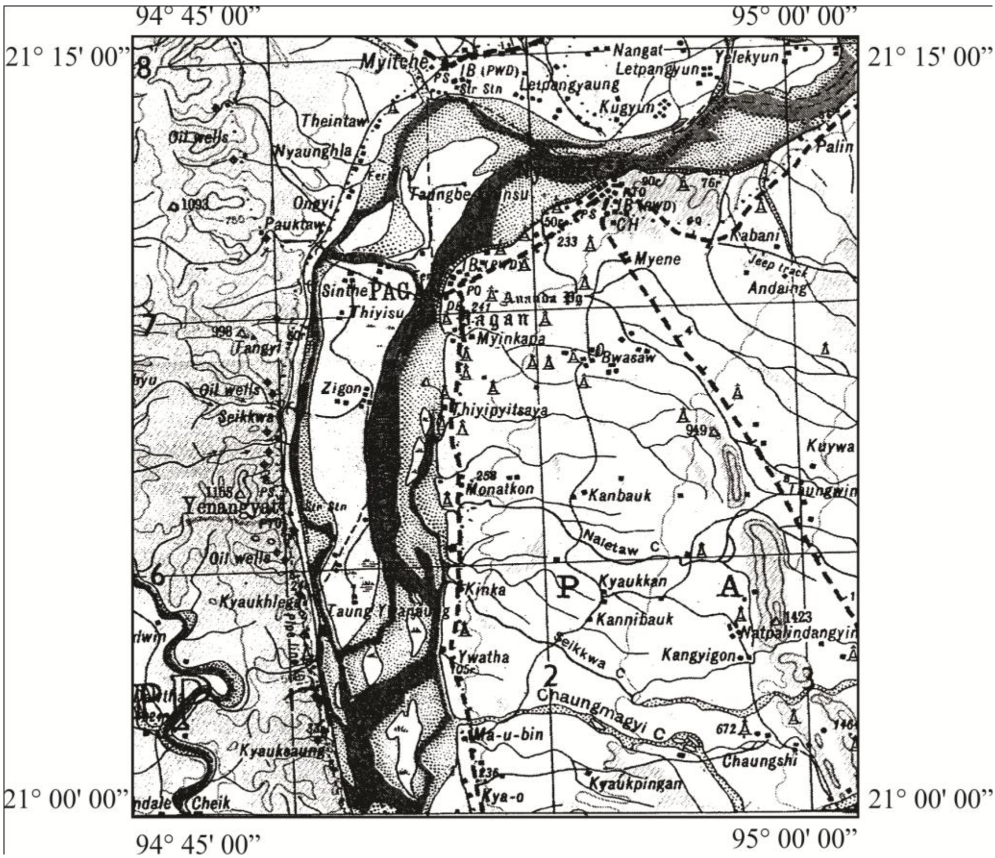

Figure 2: Topographic Map of the Research Area

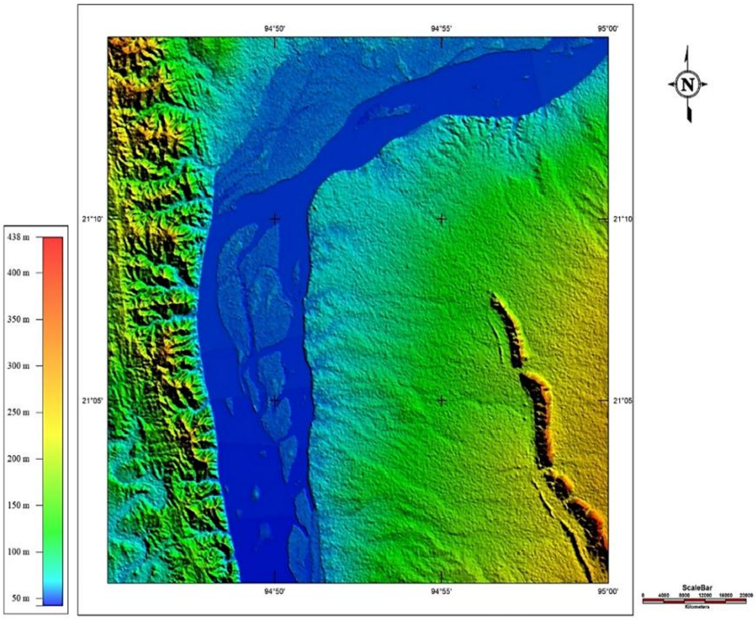

Figure 3: Physiographic Map of the Research Area

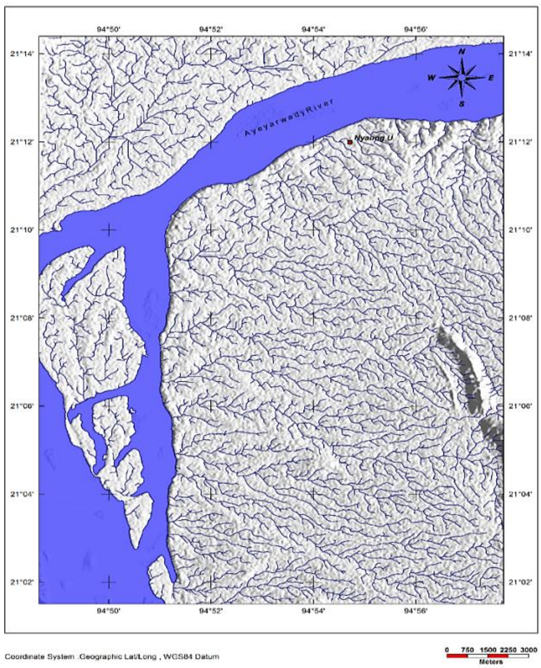

Figure 4: Drainage Map of the Research Area

Climate

The climate of the research area is tropical but the seasons can vary drastically. In summer (from March to May), the temperature rises to 43°C during the day and falls to 24°C in the night, with no rainfall. In the winter (from November to February), the temperature is about 30°C in the day and night temperature is about 30°C. Monsoon starts in June and ends in October (Figure 5).

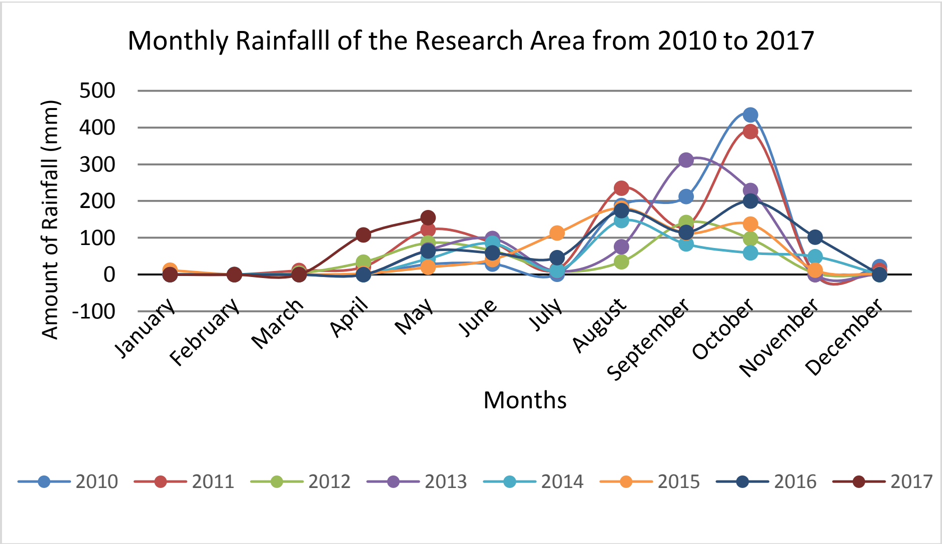

Figure 5: Monthly Rainfall of the Research Area from 2010 to 2017

Methods and Materials

The study aims to demonstrate the application of remotely sensed digital image processing and visual interpretation for engineering geology approach to environmental studies in a specific area. To carry out the ground survey for land interpretation is necessary to check and link the information received from satellite images. The methodology of the study can be divided into interpretation of image, spatial analysis and field survey. Materials used in the study are maps, information, software facilities and other.

(1) Satellite Images

The following satellite images were collected:

Landsat 7/ TM year of acquisition. (2010, 2015)/ path and row 133/045/7 bands/ CCT, BSQ, 8 bits.

Landsat 8 OLI/TIRS Level 1 Data Product, Date: 2/5/2018, row/path = 134/45, mainly OLI bands.

(2) Spatial Data

Topographic map, the scale of one-inch map sheet no. 84K/16 is used as base map for geographic database of the research area. UTM (quarter-inch) and topographic map (quarter-inch) scale are used to identify the significant topographic criteria.

(3) Non-Spatial Data

Statistics data (monthly rainfall, monthly mean water level, and earthquake data from Department of Meteorology and Hydrology (DMH).

(4) Software

Microsoft Excel 2013 for plotting the graph

Global Mapper v.15.2

ArcGIS 10.1

CorelDRAW X8

ENVI 4.2.

MapInfo 2011

(5) Technical Methods

Basically, technical methodology consists of three parts, the first one is visual analysis, the second is digital image analysis and the third is integration of field data and remote sensing analysis.

Satellite Image Analysis

Satellite data of Landsat 7 Thematic Mapper TM were selected from the research. These data are recorded on seven bands with Landsat 7 satellite, the study area fells within path/row 133/045 with 30 meters ground resolution (Figure 6). Visual image interpretation and digital image processing were applied for classifying images in a base of land cover/land use and to enhance image quality. In this research, ground control points were selected by following permanent features evenly distributed throughout the area and identified easily both in image and topographic maps. The Universal Transverse Mercator (UTM) projection method is employed in the research. The scale of Topographic maps used this research area was quarter-inch.

Image enhancement and band combination in the manipulation of image density can see more easily certain features of the image. In this research, the false colour composite (R: G: B=4:5:3) was made for land use/land cover interpretation. TM images were analyzed to identify the major structural patterns and lithology, and LULC by using ENVI 4.2.

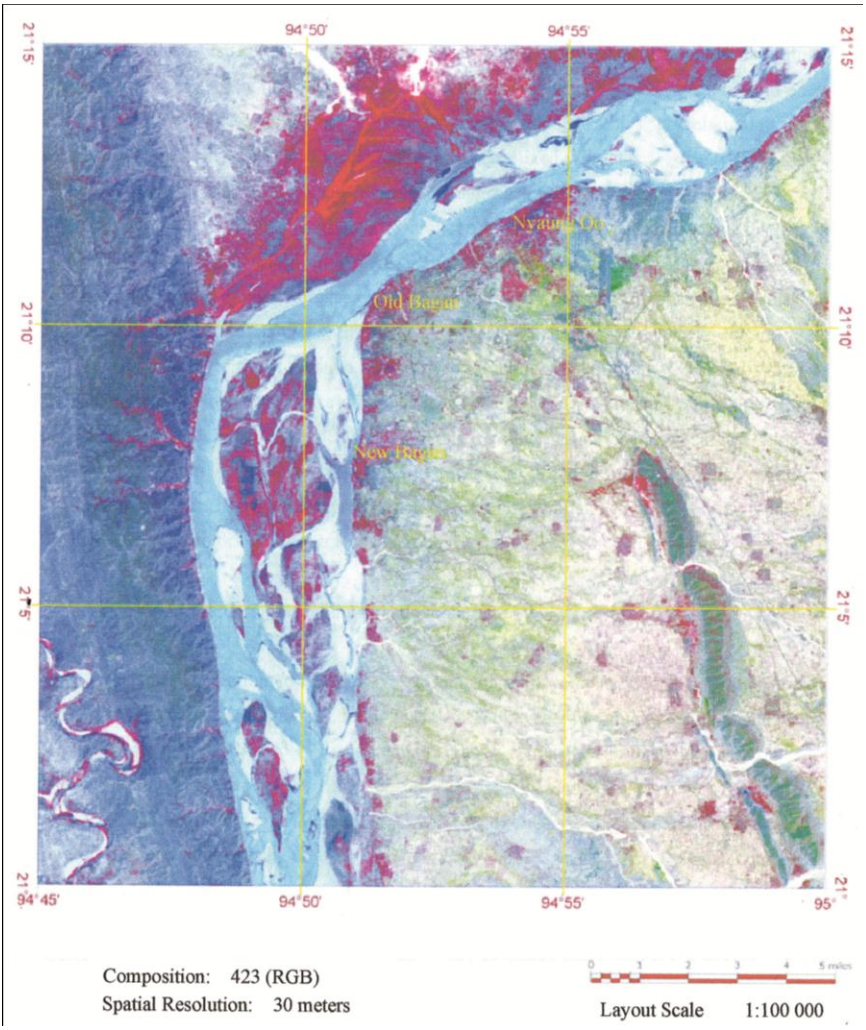

Figure 6: Satellite Image of the Research Area (Image Rectification)

Geological and Geomorphologic Setting

Bagan-Nyaung Oo plain is part of a system of sedimentary basin developed during Miocene-Pleistocene in the Central Myanmar Basin. The basin is filled by a thick succession of Miocene-Pliocene marine sediments (mainly clay and silty clay) and Pleistocene fluvial sediments (mainly gritty sandstone, coarse sandstone and gravel bed) (Figure 7).

The study area covers mostly alluvial plain, the debris and small fan materials derived from Tuywin Taung and Tankyee Taung hills which are composed of rocks of Miocene to Oligocene.

In the research area, the exposed rocks units are Irrawaddy Formation (Late Miocene to Pliocene), Okhmintaung Formation (Late Oligocene), Padaung Formation and Shwezettaw Formation (Early Oligocene). The Shwezettaw Formation is well-exposed at the Tuywin Taung Range. The Pyawbwe Formation well-exposed at the Tankyee Taung Range.

The vast plain in the area consists of flood sediments derived by the Irrawaddy River. The alluvial soils (Quaternary-Recent) are deposited on the plain and along the Irrawaddy river bands. There are five types of soils such as: (1) active alluvial fan, (2) river bed deposits, (3) gravel deposits, (4) colluvial soil and (5) residual soil.

Active alluvial fan is derived from landslides and brought down by tributaries to the main stream. River bed deposit occurs along the riversides and on the flood plain itself. Gravel deposit is locally developed on the both sides of the rivers and streams. Gravel deposit consists of sub-angular to pebbly and gravelly rounded quartzite, gneiss and phyllite with fine sand, silt and clay matrix. Colluvial soil occurred at the base of slopes and consists of clay, silt and sand with angular gravel to cobble size fragments of shale, phyllite and quartzite/ meta-sandstone). These colluvial deposits are derived from old landslides. Residual soil is developed in place on flat to gentle hill slopes. Residual soil mainly consists of clay, silt, and gravel size rock fragments.

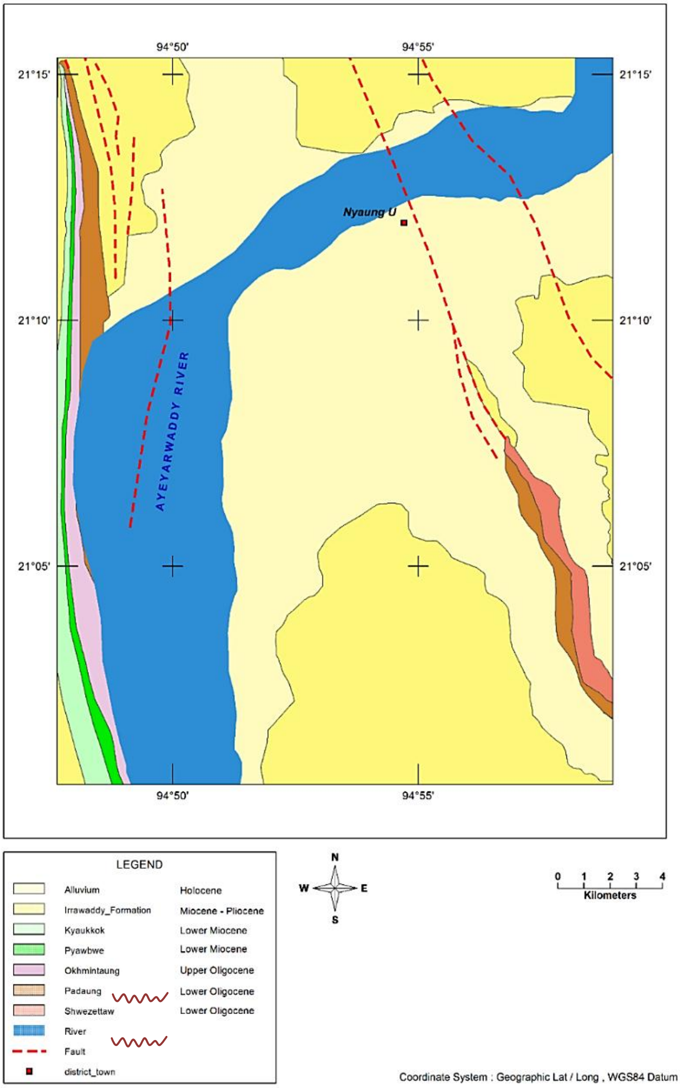

Figure 7: Geological Map of the Research Area (Tun Naing Zaw, Min Thura Mon and Swun Wunna Htet, 2017)

Groundwater Extraction and Subsidence

Despite the presence of urban and industrial areas, the plain is characterized by the presence of a diverse range of industries, with large sectors characterized primarily by agriculture. Indeed, the Bagan-Nyaung Oo plain is one of the largest agricultural basins in Bagan-Nyaung Oo area, due to the extensive use of intensive cultivation practices.

Each one of the hundreds of small farms and estates is self-sufficient in term of water supply, and despite the public water supply network, several independent and usually uncontrolled water wells have been drilled.

Groundwater has been considered a secure and unlimited resource and has been withdrawn for the main economic activities, particularly providing water supply for industrial, agricultural, household and hotels purposes. Water demand has continuously increased, due to both the development of several new economic activities and the sight rise of the population of the plain, particularly in the main hotel zones, and in the main industrialized centers. Increased groundwater pumping, without sufficient surface recharge, has forced the groundwater in the basin to drip with related acceleration of sediment compaction.

The gradual lowering of the water table has led to a reduction of pore water pressures in the saturated soil. Water withdrawal, without replacement of water by air, causes increased consolidation. The ultimate effect is the non-reversible lowering of the land surface. Thus, total volume of unconsolidated fine-grained deposits and weekly cemented sediments of the exploited aquifer is reduced, with a consequent reduction of aquifer storage capacity.

Land subsidence is more and more often related to land and water use practices. The natural compaction of unconsolidated and normal-consolidated fine-grained deposits is exacerbated by human activities, such as excessive ground water pumping from aquifer with related water table decline, rapid and progressive urbanization, and huge load imposition.

With many urbanized and industrialized areas in Bagan-Nyaung Oo and its conurbation have been developed over fine-grained deposits; alluvial materials deposited in tectonically subsiding basin represents the most productive type of aquifers.

Subsidence can have a strong impact on landscape in terms of both loss of land elevation and changes of topographic gradient where land drop is not uniformly distributed.

Flood and Subsidences

Side cutting in both sides of Ayeyarwaddy River is caused by riverbank scouring and rain water resulting into steep slopes. Slope failures causing landslides are common along eastern bank of the river in central portion of the area. There is a number of river bank failures within 5 to 10 meters.

A buffer zone of 30m is desirable not to have any settlements and construction works to allow natural stabilization.

River bank cutting between Nyaung Oo and New Bagan is another threat to cutting failure that needs to be taken care of soil failure. Low land area gets flooded and covered with sediment deposited during the rainy season by flood.

In the rainy season, lowlands adjacent to the river and the river and the main streams in the area are likely to be affected by flood as they are prone to flood hazards. Hence, these areas are not suitable for human settlements but can be utilized for agricultural field. A risk of flash flood can always be a threat in these areas in future in the rainy season.

Ayeyarwaddy River is general bed load channel type. River flowing between the banks on the beds composed of sediments is transported by the river are sensitive to changes of sediments load, water discharge and variation of valley floor slope. In the research area, western bank of Ayeyarwaddy River, three steps of river terraces are observed in bagan-Nyaung Oo area (Chhibber, 1934) and alluvial terraces and colluvial deposits are widely distributed in the research area.

In 2010, the rate of western river bank erosion and deposition are obviously increased, therefore the west bank of Ayeyarwaddy River is more vulnerable to river bank erosion and flooding (Figure 8a and 8b). The same phenomenon happened in 2015 (Figure 9a and 9b).

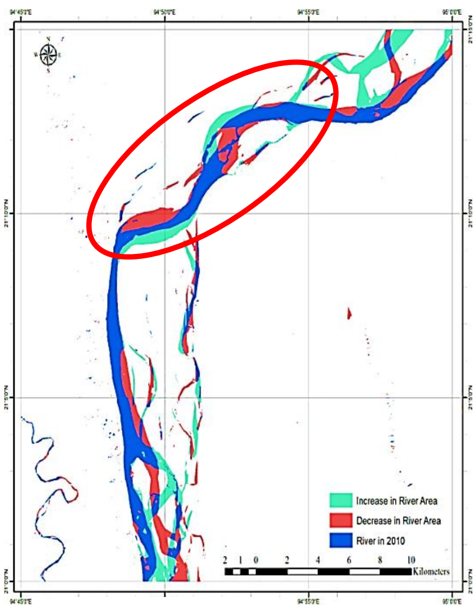

Figure (8a)

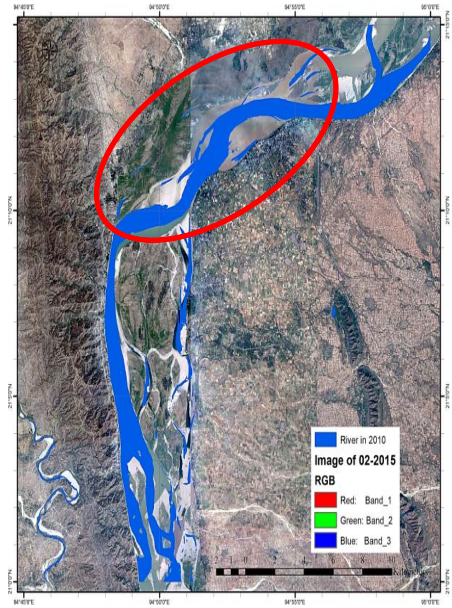

Figure (8b)

Figure 8 (a and b): 2010 Ayeyarwaddy River Line with Increase and Decrease in Water Bodv

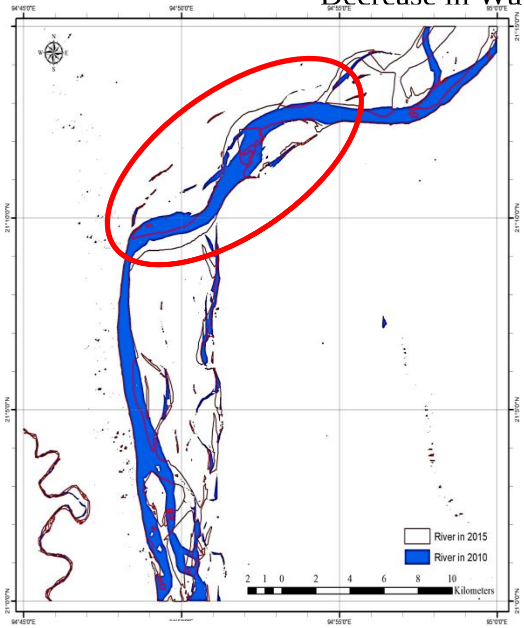

Figure (9a)

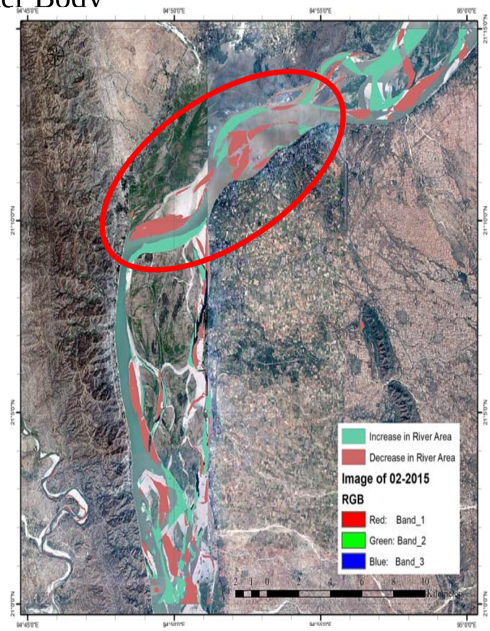

Figure (9b)

Figure 9 (a and b): 2015 Ayeyarwaddy River Line with Increase and Decrease in Water Body

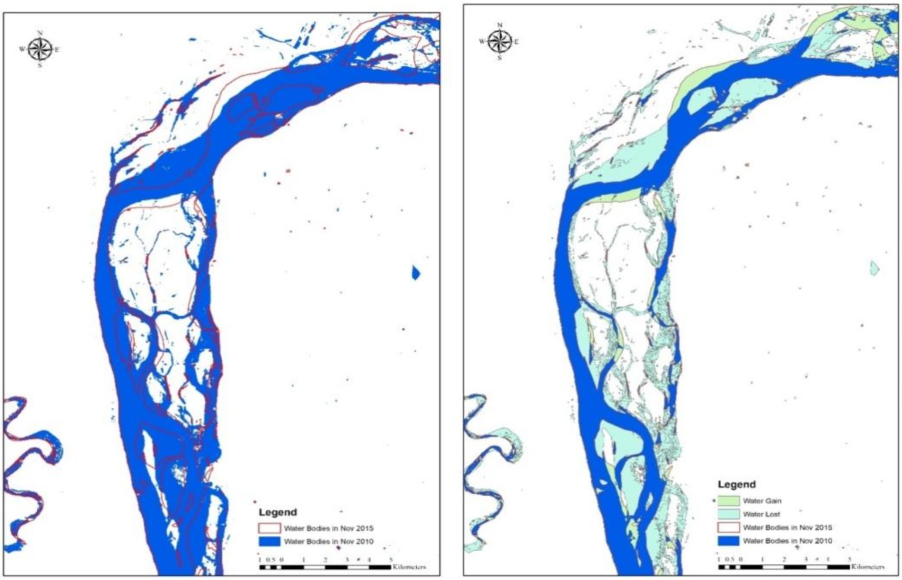

Figure 10: Comparison of Water Bodies and Water Gain/Lost in 2010 and 2015 (Drawing Based on Satellite Images)

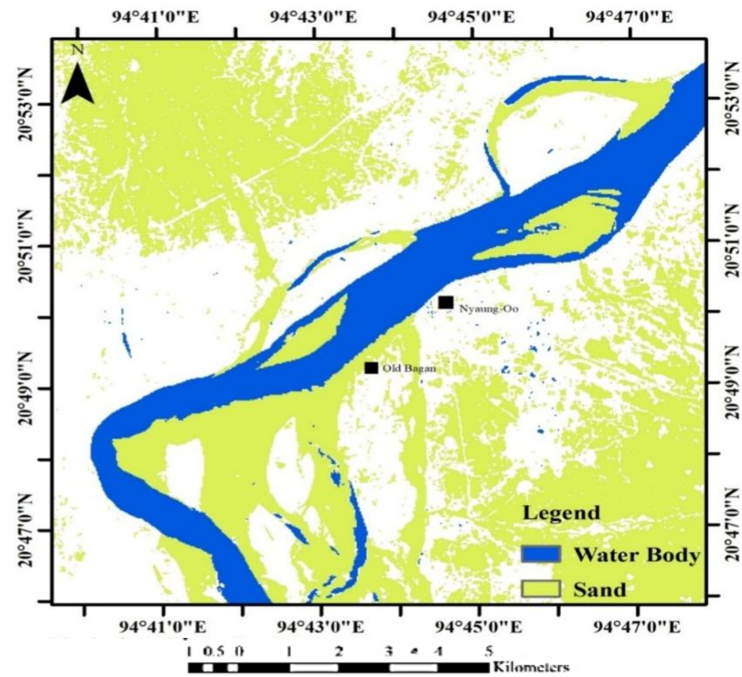

Figure 11: Delineated body of river water and sand of the research area (from Landsat 8 image) (Map by Tun Naing Zaw, Swun Wunna Htet and Min Thura Mon, 2018)

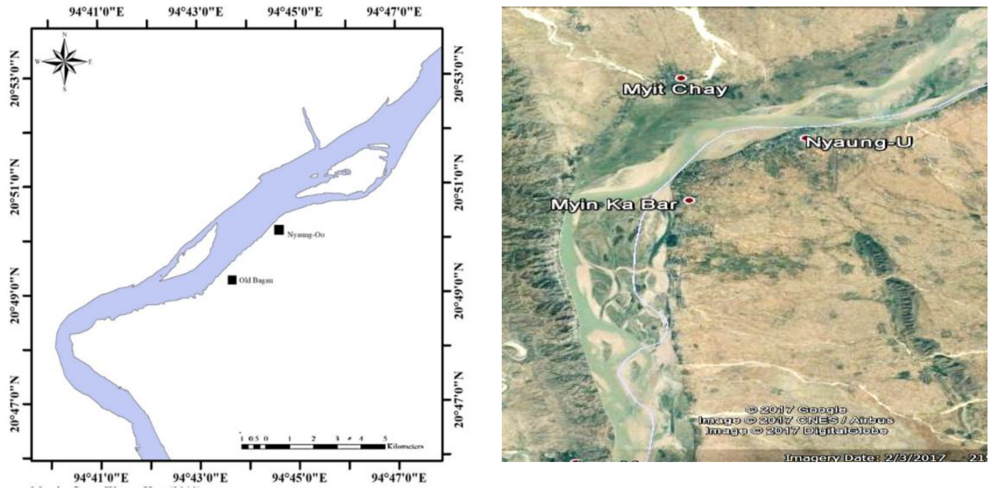

Figure (12) Comparison of water body of Ayeyarwaddy River in 2017 (right) and 2018 (left)

Differential Erosion and Relief of River Banks along the Ayeyarwaddy River

Rate of the Ayeyarwaddy River in the base level for adjacent hill slope of river banks because of flooding which can cause creep and wash landslides near the river banks. River erosion and deposition contribute to arise the base level of Ayeyarwaddy River.

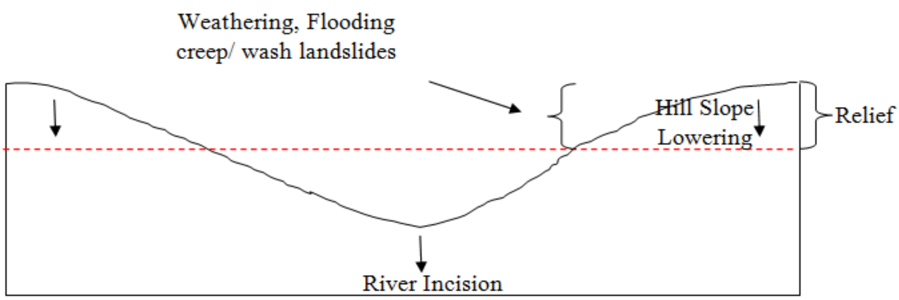

Figure 13: Sediment Fluxes in Ayeyarwaddy River

The sediment load of Ayeyarwaddy River can be partitioned into the bed load, suspended load and dissolved load. Whereas the highest bed load fluxes typically occur during high water discharge, the highest solute concentration typically occur during low flows. Suspended-load fluxes typically occur during flood. Input of sediment from adjacent river banks can vary in predictable ways in different climatic regimes. River bank landslides and subsidence occur under water saturated condition of riversides.

River landslides and subsidences drive the sediment flux, sediment discharges tend to be spiky and can be weakly tied to water discharge. If most sediment input to river is landslide-generated, the stochastic nature of landslide can cause a mismatch between water and sediment discharges.

In Bagan- Nyaung Oo area, migrating sinuous river bends are visible. The bends are extending and translating downstream. This process is taking place at a stable and predictable rate, but is highly dependent on both up- and downstream conditions.

Within the last 15 years the river transformed from a straight channel to a sinuous channel. Only the middle bend of the river is currently capable of lateral migration. In the south the river is confined by resistant river banks. The incoming channel has changed its angle and has bifurcated into two channels from different directions. The discharge ratio of the two incoming channels determines the dominant flow direction and planform in the rest of this section, and with that determines the degree of sinuosity and related erosion of less resistant floodplains. The river will behave like a classic sinuous river when the incoming flow from the eastern direction is strongest, and behave like a straight channel when the incoming angle from the north-east is dominant. The physical boundaries of the river are evidently the resistant riverbanks, making the effects of the boundaries on free migration easy to predict.

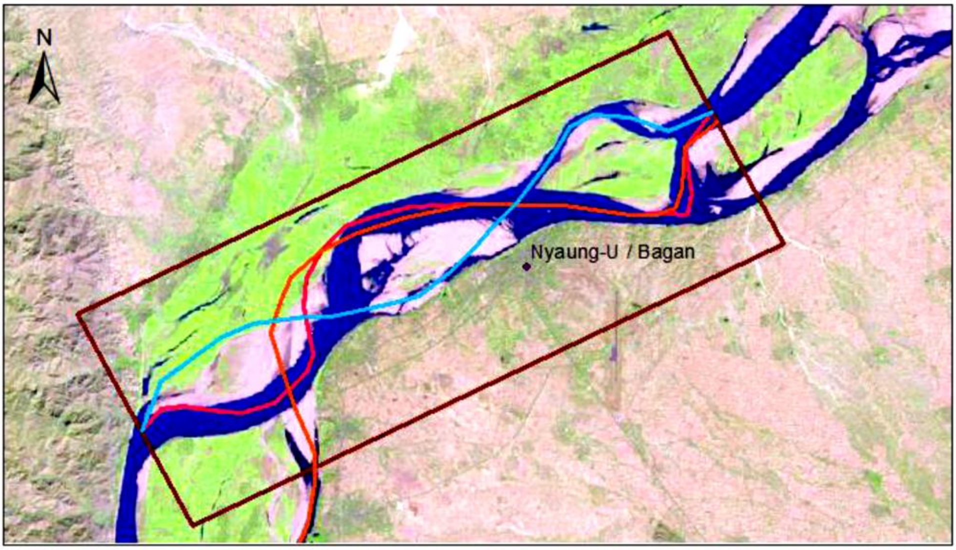

Figure 14: Ayeyarwaddy River's recent sinuosity between Bagan-Nyaung Oo and Mandalay Blue line represent 2015 river line. Red line represent 2018 river line.

For instance, in July 24th, 2017, at 3:40 pm, flood waters swallow Thiri Yadana Pyilone Chantha Pagoda sinking into the raging waters of the Ayeyarwady River in Magway Region, with shocked bystanders looking on as its golden spire collapsed beneath the waves (Figure 15).

"This pagoda was built in 2009, when it was far away from the river," Year by year, the river has eroded the land and now the pagoda has fallen into the river."

Flooding was common in the area during the monsoon that runs from May to October, but this year's floods caused alarming erosion. Some riverside villages have been washed away entirely.

Continuous periods of flooding are likely to 'wash away' the soil and contribute to landslip which can either be a gradual creeping of soil in a downward direction over a period of time, or a sudden movement, often associated with flash floods.

Figure 15: Subsidence due to Flash Flooding (Wash Landslide along the Ayeyarwaddy River Bank)

Engineering Properties of Soil and Flooding

In the research area, existing land use patterns are agricultural land, sparse forests and scrub, settlements, industrial, recreation centers, infrastructures and small land fill/ waste disposal sites. The research area has heterogeneous soil distribution character with different engineering properties.

Low to medium-bearing capacity (1.8 to 4 TS F) areas are concentrated in the area where active alluvial fan and river bed deposits have high permeability and low density.

Most plain area is a firm soil with a stable bearing capacity and so appropriate from small to medium scale construction purposes.

Gravel deposit in Nyaung-Oo area, being derived from landslide-induced active alluvial fans and river bed deposits by erosional forces, is locally developed on the both sides of the rivers and streams. It consists of sub-angular to pebbly and gravelly rounded quartzite, gneiss and phyllite with fine sand, silt and clay matrix.

Colluvial soil occurred at the base of slopes and consists of clay, silt and sand with angular gravel to cobble size fragments of shale, phyllite and quartzite/ meta-sandstone). These colluvial deposits are derived from old landslides.

In Bagan area, residual soil is developed in place on flat to gentle hill slopes. It mainly consists of clay, silt, and gravel size rock fragments. Mostly, the residual soil in New Bagan is derived from Irrawaddy Formation.

Four boreholes data measured by JICA Project and Ministry of Construction are used in engineering analysis for calculation of bearing capacities of each boreholes and test pits (Figure 16, 17 and 18).

We would like to conclude that the bearing capacity of gravel bed in Nyaung-Oo is sufficient for shallow foundation; however, without the compaction of gravel soil under the footing of the specific foundation, it is likely that the differential settlement will occur causing the foundation unstable due to the poorly sorted gravels. For Bagan area, since the residual soil comes from Irrawaddy Formation which has a bearing capacity of 2.9 – 4 TSF at the depth of 2m according to geotechnical analysis, shallow foundation with square footing for two to three-storey houses and hotels are suitable for construction. In spite of the availability, the Ministry of Construction restricts only to build structures of 30ft high with two levels.

Depth	Bearing Capacity
2.1 Ft	1.7 TSf
3.2 Ft	2.5 TSf
4.3 Ft	2.3 TSf
5.3 Ft	2.4 TSf
6.5 Ft	2.7 TSf
7.5 Ft	2.8 TSf
8.6 Ft	2.9 TSf

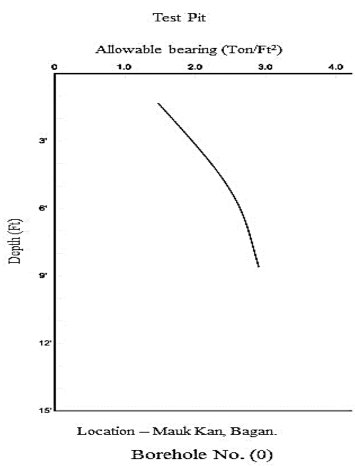

Figure 16: Test Pit Result of Borehole No.(0), Mauk Kan, Bagan

Depth	Bearing Capacity
2.1 Ft	2.9 TSf
3.2 Ft	3.3 TSf
4.3 Ft	3.7 TSf
5.4 Ft	3.8 TSf
6.5 Ft	4 TSf

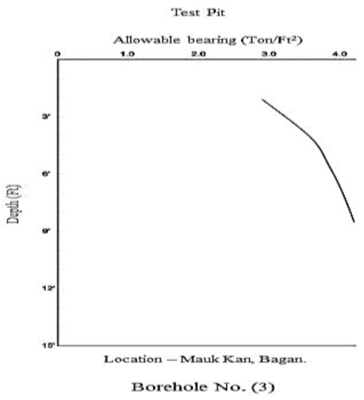

Figure 17: Test Pit Result of Borehole No. (3), Mauk Kan, Bagan

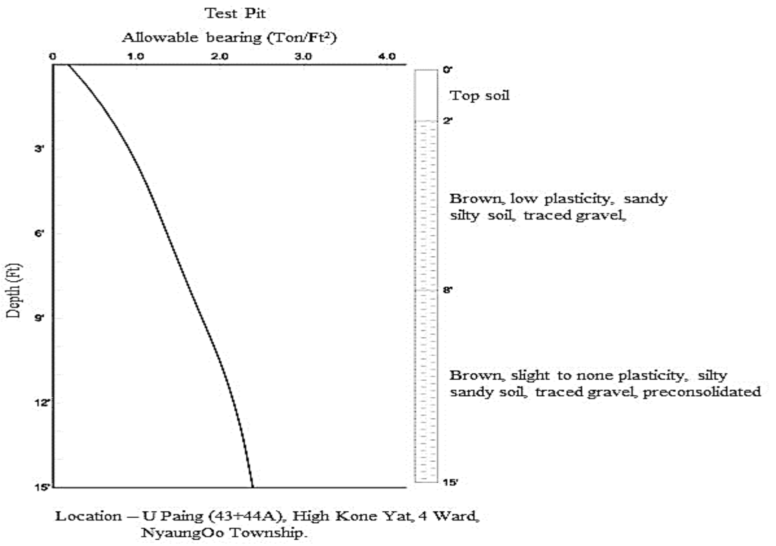

Figure 18: Test Pit Result of Nyaung Oo Township

Figure 19: Subsidence in Temple No. 1752 at Bagan Area

The temple No. 1752, believed to have built in 13th century, buckles after weeks of heavy rain. Only 20% of the original structure remains due to rainwater –induced subisidences. The temple was previously damaged by an earthquake in 1975, renovated to the tune of 2.5 million kyats, and now suffered from structural degradation by unusual rainfall in Bagan area. (Occurred at 12th August 2015)

Pagodas in Bagan area are affected by subsidence which can be caused by the movement of the ground with changing weather conditions Figure (19). The time of year (the height of summer) when warmer temperatures and drying ground often occur leads to subsidence.

The amount by which the ground can shrink and/or swell is determined by the water content in the near-surface. Fine-grained clay-rich soils can absorb large quantities of water after rainfall, becoming sticky and heavy. Conversely, they can also become very hard when dry, resulting in shrinking and cracking of the ground. This hardening and softening is known as ‘shrink-swell’ behaviour.

Shrink–swell occurs as a result of changes in the moisture content of clay-rich soils. This is reflected in a change in volume of the ground through shrinking or swelling. Swelling pressure can cause heaving, or lifting, of structures whilst shrinkage can cause differential settlement. This shrink–swell behaviour is the most damaging geohazard.

The rock formation (Irrawaddy Formation) the most susceptible to shrink-swell behaviour are found mainly in Bagan –Nyaung Oo area. Other superficial deposits such as alluvium, peat and laminated clays can also be susceptible to soil subsidence and heave.

Subsidence has the potential to cause engineering problems such as damage to foundations, buildings and infrastructures. Properties built on clay soils or with shallow foundations are more at risk of subsidence. This is because clay-based soils shrink and swell according to their moisture content. If previously dry clay is overloaded with too much moisture, it expands causing ground heave. This is the upward movement of the ground beneath part or all of a building. Leaking or damaged drains are a key contributor; they are usually unseen, will build up moisture levels over times and repeatedly soften and swell the soil

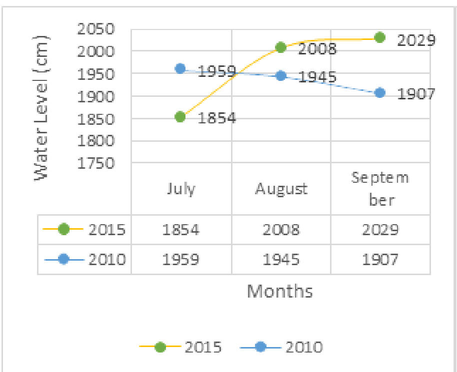

Figure 20: Monthly Mean Water Level of Research Area in 2010 and 2015

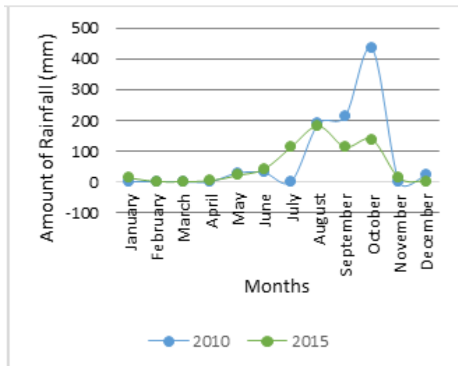

Figure: 21: Monthly Rainfall of Research Area in 2010 and 2015

Land Use

In the research area, existing land use patterns are agricultural land, sparse forests and scrub, settlements, industrial, recreation centers, infrastructures and small land fill/ waste disposal sites.

(1) Agricultural and Scrub Lands

Most of the flat, lowlands in the plain along the river bank and hilly sides are covered by sparse forests and scrubs. Open forests, swamp forest, orchard, palm trees, scrub, bush and grass are categorized in the research area. Low angle sloping lands (hill sides) are good for dry cultivation (maize, millet, wheat and cereals).

(2) Urban Settlement and Industrial Areas

Urban settlements are existing area, planned area, proposed area, and expanded area. Proper drainage system in Nyaung Oo and Bagan is adequate in now. Crucial area of man-made pollution is located in the east of Nyaung Oo.In the banks of the Ayeyarwaddy River, squatters' settlements are creating.

(3) Recreation Centers and Open Spaces

Lawkananda reserve forest near new Bagan is the only existing public and natural park in the area. The research area has religious and cultural values where most of deities are located form north to south. Bagan golf field and Recreation Park is located west of Nyaung Oo beside of the main highway road.

(4) Landfill and Waste Disposal Sites

Nyaung Oo municipality is lack sanitary landfill site to manage safe disposal of its solid wastes produced from the urban settlement and industries. Municipality is temporarily dumping its daily wastes into the river bank.

Engineering Approach to Land Use for Construction

The research area has heterogeneous soil distribution character with different engineering properties.

Low to medium-bearing capacity (1.8 to 4 TS F) areas are concentrated in the area where active alluvial fan and river bed deposits have high permeability and loose density.

Most plain area is a firm soil with a stable bearing capacity and so appropriate form small to medium scale construction purposes.

Gravel deposit in Nyaung-Oo area, being derived from landslide-induced active alluvial fans and river bed deposits by erosional forces, is locally developed on the both sides of the rivers and streams. It consists of sub-angular to pebbly and gravelly rounded quartzite, gneiss and phyllite with fine sand, silt and clay matrix.

Colluvial soil occurred at the base of slopes and consists of clay, silt and sand with angular gravel to cobble size fragments of shale, phyllite and quartzite/ meta-sandstone). These colluvial deposits are derived from old landslides.

In Bagan area, residual soil is developed in place on flat to gentle hill slopes. It mainly consists of clay, silt, and gravel size rock fragments. Mostly, the residual soil in New Bagan is derived from Irrawaddy Formation.

Four boreholes data measured by JICA Project and Ministry of Construction are used in engineering analysis for calculation of bearing capacities of each boreholes and test pits.

We would like to conclude that the bearing capacity of gravel bed in Nyaung-Oo is sufficient for shallow foundation, however, without the compaction of gravel soil under the footing of the specific foundation, it is likely that the differential settlement will occur causing the foundation unstable due to the poorly sorted gravels.

Figure 22: Land Use Map of the Research Area

For Bagan area, since the residual soil comes from Irrawaddy Formation which has a bearing capacity of 2.9 – 4 TSF at the depth of 2m according to geotechnical analysis, shallow foundation with square footing for two to three-storey houses and hotels are suitable for construction. In spite of the availability, the Ministry of Construction restricts only to build structures of 30ft high with twolevels.

Conclusion

1. The study showed that remote sensing techniques are useful tools for assessing and analyzing the geological purposes.. The study focuses on understanding of the river's dynamic morphological behavior within the project area. Water levels between the cold season and the hot season (monsoon period) vary up to 10 meters.
2. Bagan stands on the east bank of the Ayeyarwaddy River whichforms an important navigational artery for trading and recreational use. The river is very dynamic in its platform changes, which are largely dependent on the discharge regime. This variation in water levels and the dynamic morphology of the river create navigational problems.
3. Landslides are found inriver flanks between Bagan and Nyaung Oo.
4. Floods are the most common and the most destructive geologic hazard. We need to control by non-structural approach through sound flood plain management and engineering efforts such as artificial levees, flood-control dam and channelization. Heavy rains cause major problems in flood and subsidence.
5. Heavy rains in Bagan-Nyaung Oo area lead to the collapse and sinking of pagodas in 2014. Subsidence is a lowering or collapse of the ground. It can be triggered by man-made disturbance, a change in drainage patterns, heavy rain or by water abstraction
6. TM images are analyzed to identify the major structural patterns and lithology and LULC.
7. Squatters' settlements of the banks of the Ayeyarwaddy River are creating an alarming threat of encroachment of the river bank and flood plain.

8. Effects of disasters will be different, past and present depending on density of population and sophisticated structures.
9. We suggest that more accelerated research on river bank protection and assessment. Thus, remedial measures, including pruning or removing trees, investigating and repairing damaged/ leaking drains, restoring brickwork and underpinning (strengthening and deepening the foundations) are required.
10. We suggest that more preparedness for mitigation of natural hazards in all-time necessary.

Recommendations

1. **Restriction of groundwater extraction**

   This measure is very important for counteracting human-induced subsidence. In vulnerable areas extraction of groundwater should be reduced or completely phased out.

2. **Natural and artificial recharge of aquifers**

   When addressed consistently and effectively, the reduction of groundwater mining can eliminate one of the primary causes of land subsidence.

3. **Development of alternative water supply (instead of groundwater)**

   To meet the increasing (urban) water demand, an alternative water supply for industry and domestic users is required.

4. **Integrated (urban) flood water management Improved groundwater management and subsidence**

   Water resources management should be linked to flood mitigation. Ultimately, land subsidence is closely linked to integrated land and water management, including surface as well as subsurface resources and constraints.

5. **Improving governance and decision-making**

   This involves (public) awareness, encouraging (public) participation, cooperation and coordination between stakeholders at different scales and levels,

6. **Decision support models and tools**

   To support good decision-making, models and tools are needed.

   It is especially important to analyse the relationship between groundwater levels and subsidence, develop modeling and forecasting capabilities by implementing an integrated groundwater–subsidence monitoring and analytical model. Moreover, it is essential that local agencies have the expertise and tools to conduct studies, and that they are engaged in ongoing capacity building, training, and knowledge exchange.

7. **Appropriate monitoring and database system**

   Ongoing studies show that the weak spot in efforts to reduce subsidence and related flood risks is accessed to reliable ground truth data.

8. **Integration of geotechnical aspects in planning and design of buildings and infrastructure.**

   In the planning and design of (heavy) buildings and road infrastructure, geotechnical research and modelling of the subsoil should be taken into account in order to avoid subsidence problems including differential settlements, in the short or long term.

9. **Asset management, financing and public-private-partnerships (PPP)**

   To minimize damage caused by subsidence, the main financial risks associated with investments and maintenance of assets (buildings, infrastructure) should be assessed.

10. **Exchange of knowledge and best practices**

    Through international conferences, workshops, expert meetings, and courses, knowledge and best practices can be exchanged to extend the common knowledge base efficiently and effectively. This step can be further supported by development of collaborative research projects preferably in the framework of international (research) networks and initiatives such as the UNESCO, and the Delta Alliance.

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PETROLOGY, RADIOMETRIC DATING AND ECONOMIC ASPECTS OF GRANITOID ROCKS IN NWALABO TAUNG AREA, PAUNG TOWNSHIP, MON STATE

Su Su Khine*

Abstract

NwalaboTaung is located 4.5 km northeast of Paung in Mon State and it lies on Yangon -Mawlamyine car road. The study area is principally composed of granitoid rocks, viz, foliated porphyritic biotite granite, porphyritic biotite granite, gneissose granite, biotite microgranite and tourmaline granite. Biotite microgranite and tourmaline granite occur as small stocks. Microgranite, pegmatite and schorl rocks are found as dykes and aplite and quartzofelspathic veins are also observed. Microdioritic xenoliths are also recognized in this area. Granitoid rocks intruded Taungnyo Formation and Martaban Beds. In this area, old local worksites of tin and tungsten are found at the place about 2.5 km north of Natkyigyaung village. Minor amounts of stibnite and pyrite occur in the northeastern part of the study area. Beside Banbwegon quarry, eastern and western Yetagon quarries near Sinywa yield huge quantity of porphyritic biotite granite for extraction of high quality dimension slabs as well as construction and road materials.

Introduction

The study area lies between Latitude 16˚35′00″ N to 16˚40′00″ N, and Longitude 97˚26′00″ E to 97˚32′00″ E. Nwalabo Taung is located 4.5 km northeast of Paung. It extends about 9.65 km from east to west and 8.05 km from north to south, covering approximately 77.7 square kilometers. Paung is located about 281.75 km southeast from Yangon and 29 km from Mawlamyine.

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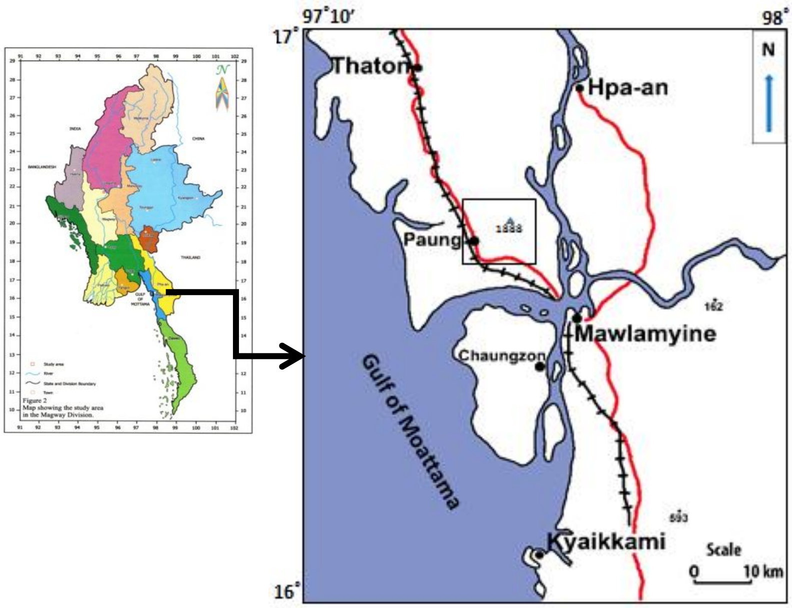

Figure 1: Location map of the study area

Petrology

The exposures of porphyritic biotite granite and foliated porphyritic biotite granite are mostly found as large and good exposures, large boulder sand large high cliffs. These rock units commonly show as vertical jointed nature and exfoliation. Large boulders of gneissose granite are also observed. In some places, granite exposure shows bedded nature and feldspar phenocrysts are nearly sub-parallel in alignment, generally NNW-SSE in direction, which is similar to the general trend of the granite body. Porphyritic biotite granite is the major rock unit covering about 70 percent of the total exposed surface area. Foliated porphyritic biotite granite is exposed in the western part and gneissose granite is exposed the westernmost part. Biotite microgranite, pegmatite and schorl rock dykes, and aplite, quartzofelspathic and quartz veins intrude the porphyritic biotite granite. Biotite microgranite and tourmaline granite occur as small stocks in the central part of the area.

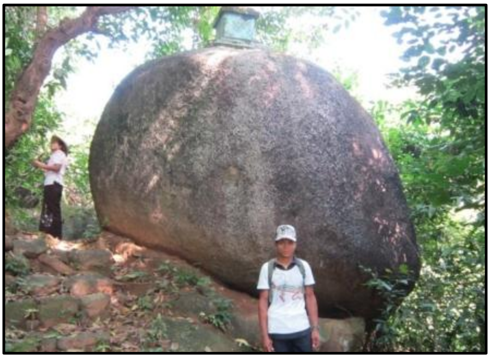

Figure 2: Large boulder of porphyritic biotite granite in Banbwegon San at (16˚36′33″N and 97˚28′50″E)

Figure 3: Bedded nature of porphyritic biotite granite at Banbwegon quarry (16˚36′20″N and 97˚29′55″E)

Figure 4: Vertically jointed nature of Porphyritic biotite granite at YetagonChaung (16˚39′ 33″N and 97˚ 30′ 40″E)

Figure 5: Exfoliated of porphyritic biotite granite at (16˚39′23″N and 97˚28′52″E)

Table :1 Rock Sequences of the Study Area

Igneous Rocks	
Dykes and Veins (Microgranite, Pegmatite and schorl rock dykes, Aplite, Quartzofelspathic and Quartz veins)	Late Cretaceous
Tourmaline granite	Late Cretaceous
Biotitemicrogranite	Late Cretaceous
Gneissose granite	
Porphyritic biotite granite	
Foliated porphyritic biotite granite	

Foliated Porphyritic Biotite Granite

Field and Megascopic Studies

In the study area, this unit is faulted contact with gneissose granite in the west. It is lying between gneissose granite and porphyritic biotite granite. The difference between this unit and porphyritic biotite granite is the presence of biotite alignment showing foliated texture in this unit. These rocks are coarse-grained, showing porphyritic texture and the phenocrysts of feldspar are between 10 to 5 cm in length and 1 to 2 cm in width.

Microscopic Studies

Microscopically, it is mainly composed of alkalifeldspar, quartz, plagioclase and biotite. Accessory minerals are apatite, sphene, zircon and magnetite. Some biotites show curved cleavage and pleochroic haloes in biotite are noted. Sphene crystals and minute crystals of zircon are observed. Zoned plagioclase feldspars are observed. Alkalifeldspars are represented by orthoclase, perthitic orthoclase, microcline and microcline microperthite. Types of perthites are patch, vein andstring. Sericitization is common and epidotization occurs as small patches along the cleavage traces of these alkalifeldspar. Quartz occurs in two types; a single large crystal showing wavy extinction and recrystallized minute grains of quartz around orthoclase feldspar, showing mortor structure. In some slide, the grain contact of quartz and alkalifeldspar, quartz and plagioclase also show graphic texture.

Porphyritic biotite granite

Field and Megascopic Studies

Porphyritic biotite granite is the major rock type covering about 70 percent of the total area. It is the southern continuation of Kalama Taung granite, which has about 30 square miles in total exposed area. This unit lies between the foliated porphyritic biotite granite in the west and hornfels unit in the east. The western contact is a gradational contact whereas the eastern contact is sharp. The exposures are mostly weathered and exfoliation features are common. Large and good exposures of porphyritic biotite granite exposed in Shwebontharmonestry in Banbwegon village, Kyauk Kwe Taung, near Kywegyan village, Yetagon Chaung, Gangaw San and along the foot path of Nwalabo Taung. In some places, granitic exposure shows bedded nature. These phenocrysts mostly range in size between 1.5-7 cm in length and 1-3 cm in width.

Microscopic Studies

Microscopically, it shows coarse-grained, porphyritic texture and is mainly composed of alkali fekdspars, quartz, and plagioclase and biotite. Accessory minerals are apatite, sphene, zircon and pyrite. Myrmekitic texture is abundant at the grain contact of quartz and alkalifeldspar, quartz and plagioclase. Rim and intergranular myrmekites are common. Bulbous myrmekite indicates that the host rock has been deformed (Phillips, 1974). Plagioclase feldspar exhibits well albite twinned euhedral grains. Zoning is occasionally developed. Euhedral megacrysts of perthites are string, vein, patch and braid perthites. These perthites are believed to be formed under temperature (about 500˚C) by exsolution process, where string perthites formed at any early stage in the evolution of feldspar and film perthites is probably formed at a later stage than string perthite (Alling, 1932). By further replacement of the alkali feldspar (microcline) by albite, braid and vein perthites grade into patch type perthite. Patches of kaolinization and sericitization occur along the cleavage traces of alkali feldspars.

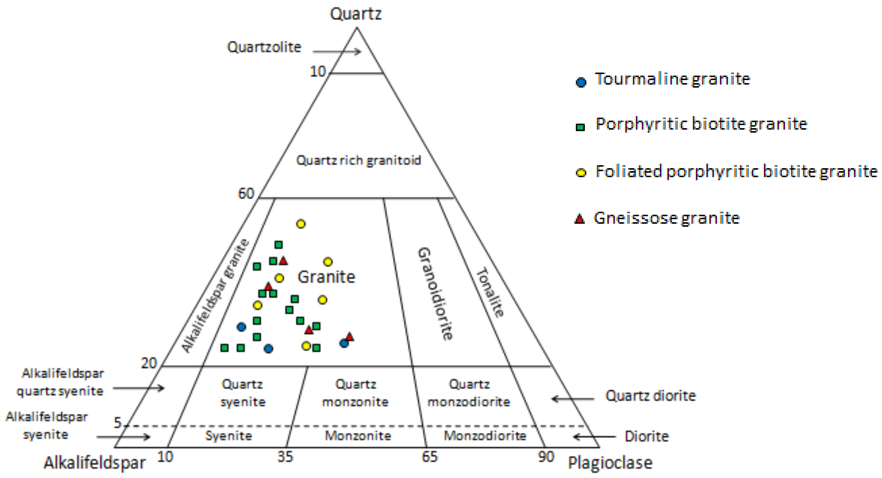

Figure 6: Igneous rocks in the study area plotted on the I.U.G.S classification diagram of Le-Maitre, 2001

Figure 7: Foliated porphyritic biotite granite in Kyaukmandut at (16˚35′45″N and 97˚29′31″ E)

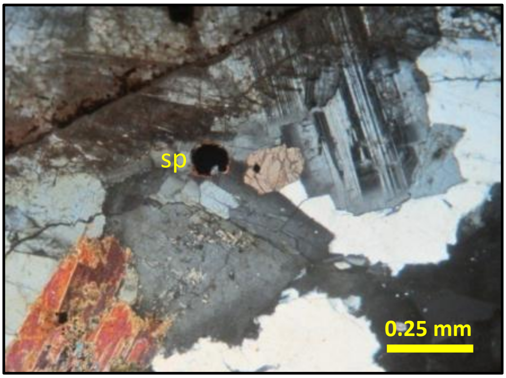

Figure 8: Sphene crystal in foliated porphyritic biotite granite, Between XN

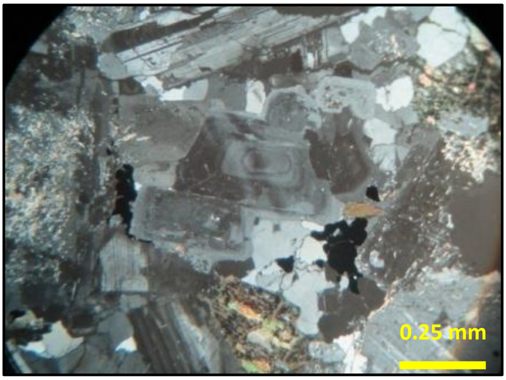

Figure 9: Zoned plagioclase in foliated porphyritic biotite granite, Between XN

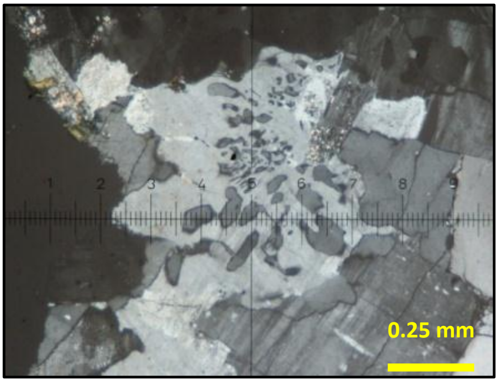

Figure 10: Graphic texture in foliated porphyritic biotite granite, Between XN

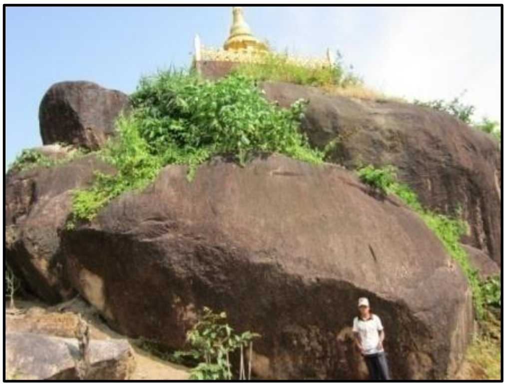

Figure 11: Porphyritic Biotite Granite exposed in Banbwegon at (16˚35′57″N and 97˚29′42″E)

Figure 12: Porphyritic biotite granite in YetagonChaung at (16˚39′33″N and 97˚ 30′40″E)

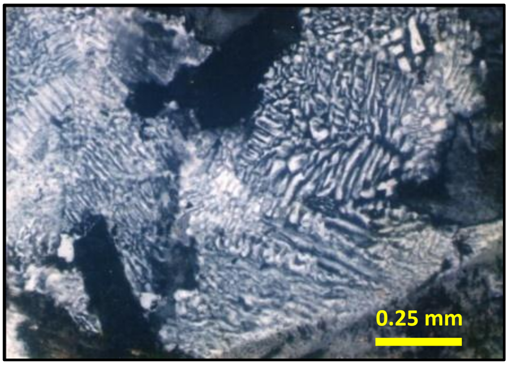

Figure 13 Myrmekitic texture in porphyritic biotite granite, Between XN

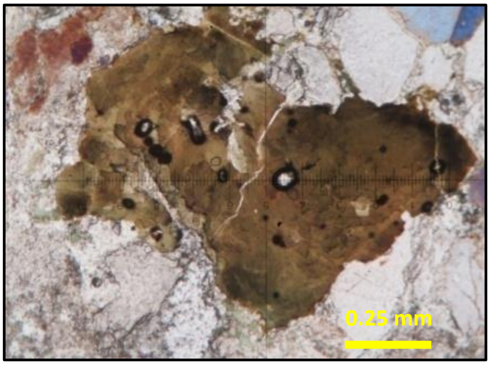

Figure 14: Pleochroic haloes in biotite flake found in porphyritic biotite granite, Under PPL

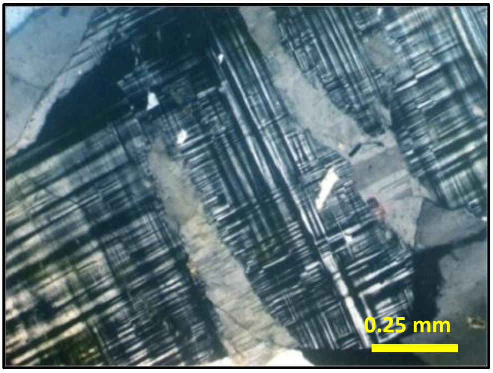

Figure 15: Cross–hatched microcline in porphyritic biotite granite, Between XN

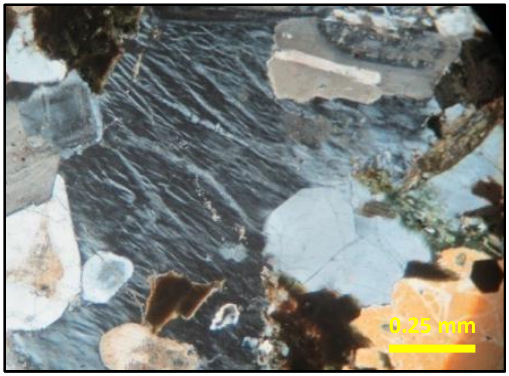

Figure 16: String perthite in porphyritic biotite granite, Between XN

Gneissose granite

Field and Megascopic Studies

This unit observed at the westernmost part of the study area near Paung Town, Dawezu and Mone quarters. This unit is separated from foliated porphyritic biotite granite with faulted contact occurs at the eastern margin of this unit. The gneissose granite is nearby foliated porphyritic biotite granite. They are well exposed and some are moderately weathered. Biotite and other mafic minerals occur as foliations around augen like quartzofelspathic minerals. Soaugen texture is common on both weathered and fresh surfaces. The trend of foliation is generally NNW-SSE which is similar to the regional trend of the igneous body. Most feldspar porphyroblasts are 1 to 2 cm in length and 0.5 to 1 cm in width.

Microscopic Studies

Microscopically, it is medium to coarse-grained, showing gneissose texture and mainly composed of alkalifeldspar, quartz, plagioclase, hornblende, biotite and minute flakes of muscovite. Zircon, sphene and magnetite occur as accessory minerals. Alkalifeldspars are orthoclase, microcline and microperthites. Orthoclase feldspar porphyroblasts surrounded by fine-grained recrystallized quartz and biotite flakes. Marginal granulation of quartz around orthoclase feldspar is found in gneissose granite. Most feldspar crystals are surrounded by recrystallized quartz and biotite flakes resulting in augen texture. Minute grains of recrystallized quartz occur and are infiltrating into cracks, fractures and interspaces between the grains. Large crystals of quartz show wavy extinction. Biotite occurs as elongated flakes, aligned between the feldspar porphyroblasts. Some biotite shows bending of cleavage and some are altered to chlorite. Minute flakes of muscovite (sericite) occur in the fractures between large plagioclase feldspar grains. Vein perthite, string and film perthite are still observed. Sericitization is also noticed.

Figure 17: Exposure of gneissose granite on the top of Sutaungpye Taung (16° 37′28.6″N and 97° 27′36.8″E)

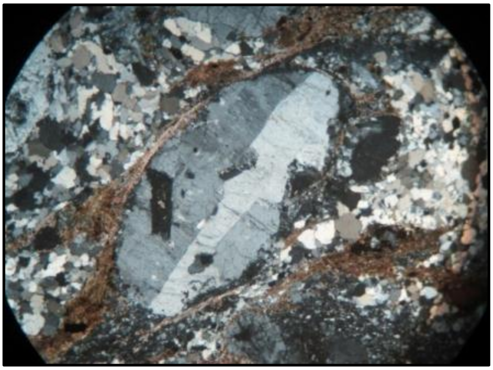

Figure 18: Orthoclase feldspar porphyroblasts surrounded by fine-grained recrystallized quartz and biotite flakes in gneissose granite, Between XN

Figure 19: Exposure of biotite microgranite occurs at (16°38′42″N and 97°27′54″E)

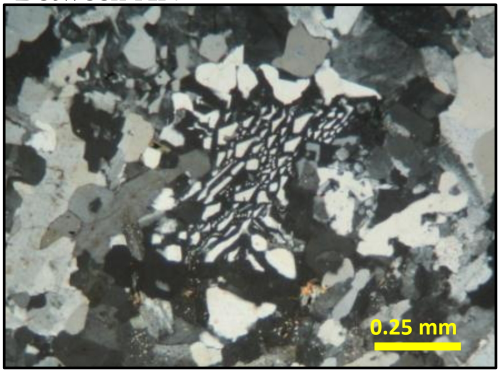

Figure 20: Graphic texture result from eutectic crystallization of quartz and alkali feldspar found in biotitemicrogranite, Between XN

BiotiteMicrogranite

Field and Megascopic Studies

Biotite microgranite intruded into porphyritic biotite granite and foliated porphyritic biotite granite. Exfoliation features are also observed. The trend of this unit is mostly NNW-SSE in direction.

Microscopic Studies

Microscopically, it has medium-grained and hypidiomorphic granular texture and is mainly composed of orthoclase, microcline, quartz, plagioclase and biotite. Graphic texture is shown in and spherulitic feldspar fibres are observed in this rock. Zircon crystals are found as accessory minerals.

Tourmaline Granite

Field and Megascopic Studie

Tourmaline granite occurs as small stock and quartz and tourmaline segregation develops in some places. Segregation pockets are up to 2 feet in diameter. It is exposed as the transition zone, between schorl rock and porphyritic biotite granite. It shows coarse-grained texture and mainly consists of quartz, feldspar and tourmaline. Acicular black tourmaline crystals are radially exposed in granite, where biotite is absent.

Microscopic Studies

Microscopically, it is mainly composed of quartz, alkalifeldspar, plagioclase, tourmaline and muscovite. Pyrite is present as opaque mineral. Quartz occurs as anhedral large grains, with some showing wavy extinction. Contact Carlsbad twinned orthoclase and spherulitic feldspar fibres are present in this rock. Triangular and prismatic crystals of tourmaline aggregate occur. Tourmaline is mostly occurs in prismatic section. Small muscovite flakes occur as interstitial minerals. Euhedral crystals of apatite and zircon occur as accessory minerals.

Figure 21: Tourmaline Granite exposed at (16˚38′51″N and 97˚29′52″E, Facing 125˚)

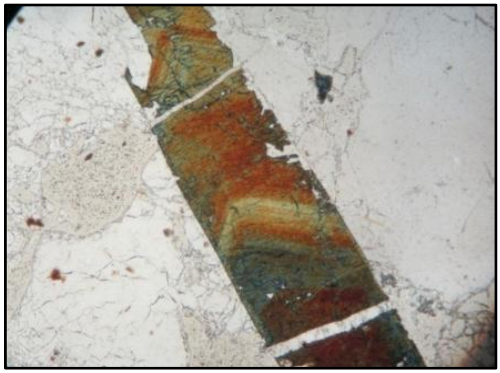

Figure 22: Prismatic section of tourmaline crystal in tourmaline granite, Under, PPL

Dykes and Veins

In the study area, microgranite and pegmatite occur as dykes and, aplite, numerous quartz veins and quartzofelspathic veins are observed. Microgranite dyke intruded into the porphyritic biotite granite. Pegmatite dyke intruded into porphyritic biotite granite and foliated porphyritic biotite granite. Aplite and quartzofelspathic veins also intruded into the porphyritic biotite granite. Numerous quartz veins intruded into porphyritic biotite granite and foliated porphyritic biotite granite. The trends of the dykes are mostly NNW-SSE and NE-SW in direction. The contact between dyke and host rock is sharp.

Radiometric Dating

The representative samples of some igneous rocks collected from the Nwalabo Taung area were sent to the geochemical and isotope laboratory in the University of Tasmania for LA-ICP-MS geochronological studies. Four rock samples (A5-16˚38′42″N and 97˚ 27′54″E- biotite microgranite, K3-16˚38′42″N and 97˚27′20″Egneissose granite,B12-16˚ 39′03″N and 97˚ 29′40″E-Porphyritic biotite granite, C5-16˚ 37′29″N and 97˚ 28′08″E-foliated porphyritic biotite granite) from the study area were analyzed for radiometric dating. The U-Pb zircon ages of the analyzed rocks are listed in Table (2).The age of biotite microgranite was 67.24± 0.66 Ma, gneissose granite was 71.42

± 0.75 Ma, porphyritic biotite granite was 72.07 ± 0.78 Ma and foliated porphyritic biotite granite was 73.1 ± 1.4 Ma.

Thus radiometric dating of the granitoid rocks emplaced in Late Cretaceous age.

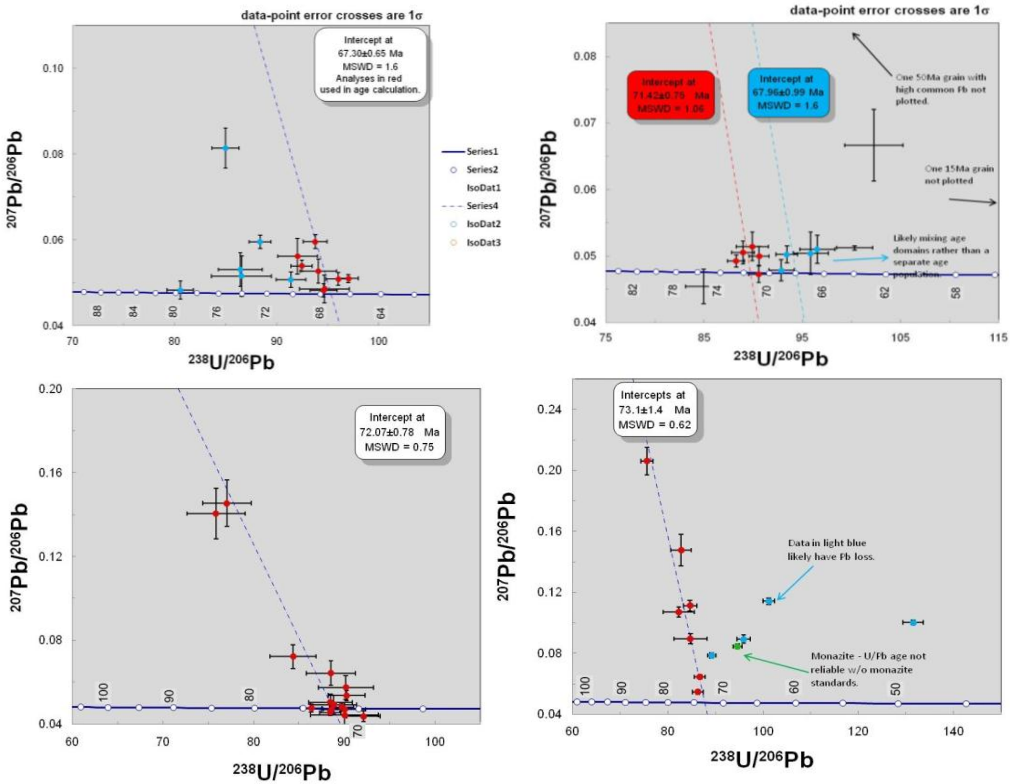

Figure 23: The Concordia diagram for $^{238}U/^{206}Pb$ - ^{207}Pb / ^{206}Pb of separated zircon from A5- biotite microgranite, .K3- gneissose granite, B12- porphyritic biotite granite and C5- foliated porphyritic biotite granite of NwalaboTaung Area

Economic Aspects

In the study area, economically workable important mineral deposits have not yet been found. But abandoned, old local tin and tungsten mines are found about 2.5 km north of Natkyigyaung village. Minor amounts of stibnite and pyrite occur in the northeastern part of the study area. Construction and road materials can be extracted in huge quantity.

Construction and Road Materials

The porphyritic biotite granite in Banbwegon quarry was extracted for construction and road materials. The Banbwegon quarry has been extracted since in 1998. Crusher plant is situated between Banbwegon and Kyonka villages. The quarry is regarded as most reliable source of supply of less than 200 mm, 20 mm to 5 mm and less than 5 mm size of crushed granite. Finished products ranging from 20 mm to 5 mm in size are a graded granite aggregate used for high grade concrete. In 1998, the granite quarry also produced good quality dimension slabs. Since 2001, this quarry has not extracted granite slabs.

Today, this quarry stopped their production because of mining accident. This quarry is close to the residential in Banbwegon and Kyonka villages and large blocks of granite frequently fell onto the houses during mining. In the study area, Myanmar Ye Man Co. Ltd., Global Vertex Co. Ltd., Shwe Myint Mo Tun Co. Ltd. and Yamanya United Co. Ltd., are extracting porphyritic biotite granite for construction and road materials and dimension slabs. These quarries have been started in 2012-13.They use 120 tons/hr small-sized mobile crusher plant, 250 tons/hr medium-sized mobile crusher plant and 450 tons/hr large-sized mobile crusher plants. It is well organized, modern quarry with systematic bench blasting. The crusher plant is a high capacity structure consisting of jaw and cone crushers with synchronized electrical systems.

These quarries produce the granite aggregate by systematic bench blasting, level by level. Before completion of the main access road to the higher part of the hill, temporary working face was used to produce graded granite aggregate. The production is based on blasting at 120 m-130 m level. In these quarries, they extract crushed granite (9 inches x 6 inches), (5 inches x 3 inches) and (2 inches x 1 inch). Finished products having (2 inches x 1 inch) size are a quality controlled graded granite aggregate used for high grade concrete. Particles less than 1 inch can also be used for construction such as hollow blocks, road materials and line concrete. Besides, these quarries also produce good quality dimension slabs (1 ft x 1 ft) for foreign export.

Ore Minerals (Tin and Tungsten, Stibnite and Pyrite)

At about 2.5 km north of Natkyigyaung village, there are three sites of tin and tungsten mine, locally known as San-She mine. Up to 1993, this mine produced tin and tungsten but the mine ceased to operation at the present. It is economically not workable and these sites are covered by soil and thick vegetation.

In this area, stibnite occurs along the contact between Taungnyo Formation and intrusive igneous bodies. It shows acicular to irregular form, lead gray colour and metallic lustre. They are frequently associated with biotite microgranite. It is not economically workable.

In the northeastern part of the area, pyrite is mainly hosted in the porphyritic biotite granite. Cubic and octahedron pyrite crystals are observed along the fractures and some crystals are associated with tourmaline granite. But it is not economically important as the quantity is trivial.

(a)

(b)

Figure 24: (a) Myanmar Ye Man Co. Ltd.,(b) Global Vertex Co. Ltd. extracting porphyritic biotite granite for construction and road materials and quality dimension slabs.

(c) (d)

Figure 24: (c) Shwe Myint Mo Tun Co. Ltd., and (d) Yamanya United co. Ltd., extracting porphyritic biotite granite for construction and road materials and quality dimension slabs.

(a) (b)

Figure 25: (a and b) Exploration adits of tin and tungsten deposit, locally known as San-She mine, 2.5 km north of Natkyigyaung village. (southwest facing)

Summary and Conclusions

The Nwalabo Taung area is principally composed of foliated porphyritic biotite granite, porphyritic biotite granite, gneissose granite, biotite microgranite and tourmaline granites. Biotite microgranite and tourmaline granite occur as small stocks. Microgranite, pegmatite and schorl rocks found as dykes and, aplite and quartzofelspathic veins are also observed. The representative samples from Nwalabo Taung area were sent to the geochemical and isotope laboratory of the University of Tasmania in Australia. The results from zircon crystallization age suggest that granitic rocks from the study area were emplaced in the Late Cretaceous time. In this area, old local tin and tungsten mine was found 2.5 km north of Natkyigyaung village. Minor amounts of stibnite and pyrite occur in the northeastern part of the study area. Construction and road materials and granite slab can be extracted in huge quantity from this area.

Acknowledgement

I am greatly indebted to Acting Rector Dr Theingi Shwe in Dawei University and Dr Khin May Aung and Dr Cho Cho Myint (Pro-Rectors in Dawei University) for the permission to study the Nwalabo Taung area.

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THE ANALYSIS OF ENGINEERING PROPERTIES OF SOILS FACILITATING THE MECHANISM OF LANDSLIDES IN HAKHA AREA, CHIN STATE, MYANMAR

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Abstract

The most destructive landslides had happened in Hakha on 27th July 2015and fortunately, no one faced to death in this event. However, the huge size posed a great impact on vulnerability of the town infrastructure, housings and inhabitants. In order to support the local people and regional planners, landslide investigation was carried out to produce potential landslide hazard zonation map. This paper mainly aims to present which factors play the main role in failure mechanism in this study area. Three types of landslides had been recorded in this area and the phenomena of landslides were detail investigated especially landslides in Mt. Rung and Hakha environs. The occurrence of numerous cracks on the middle and bottom potion of the landslide slope caused the critical condition for the ability to sustain this area. Therefore, to analyze this hazardous condition, the engineering properties such as physical, mechanical properties and dispersive nature of landslide materials were analyzed. From the analysis of grain size distribution and Atterberg's limit test results, those landslide materials are low plasticity Clayey SILT (ML)by the application of unified soil classification system(USCS). The several controlling factors of landslides were noted from the field investigation and laboratory analysis in which the most crucial factor of dispersive nature to accelerate landslide when it combines with intense rainfall had been verified in this paper.

Keywords: Landslides, Hakha, numerous cracks, Mt. Rung, dispersive nature

Introduction

The disastrous landslides were happened in most areas of Chin state due to abnormal heavy rainfall especially in July, 2015. Hakha is about 128 miles far from Kalay and about 2309 m above sea level which is the city

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of Chin State (UTM map 2293/10, one inch one mile map 84E/10). It is situated on steep slope (over 30°) of north south trending mountain ranges which is part of western ranges of Myanmar. In rainy season, Hakha area usually receives the annual rainfall intensity about 100 inches and the temperature in winter ranges from (-)6 °C to 37.8°C. Before the critical event of landslides in Hakha, antecedent rainfall intensity, a triggering event, became over the normal historical rainfall range that greatly changed the soil water condition in that area. The initial crack signs on the slopes, the abrupt increase of water level on the roads and the deterioration of houses gave the warning signs to move local people that saved the loss of human lives. On 27^{th} July,2015, the saturation the soil caused a disastrous landslide which was a remarkable event in the history of Chin State. The rapid debris flow together with the breach of lake on the slope of Mt.Rung, numerous cracks in middle and lower portion in western part of its slope including along the ring road, very huge landslides in 2/2mile post along the way of Hakha –Gantgaw road as well as 3/3 mile post on Hakha -Titein road were successively happened due to this triggering event. As a consequence of this, the schools and 540 numbers of houses in Myohaung quarter could not withstand to continue to living in this dangerous area. Based on those facts, staff and members from Department of Geology and Survey Enterprise (DGSE) and Myanmar Geoscience society (MGS) had collaboratively investigated to produce hazard zonation map of Hakha area to support the local authorities. Apart from landslide zonation map, this paper mainly emphasizes on the engineering properties of soil that generate the failure mechanism of landslides in that area.

Regional Geology Around Hakha Environs

In this area, Kennedy Sandstone Formation (Middle to upper Eocene), Chunsung Mudstone-Turbidite Formation (Middle Eocene to Paleocene), Falam Mudstone-Micrite Formation(upper Cretaceous) and recent alluvial/colluvial formation are regionally exposed. The regional geological map is shown in figure 1. Due to tectonic process of Indo-Burma plate, heavily jointed nature and numerous local folds are observed. Most of the beddings show not only west but also east dipping in the study area as shown in figure. Around Mt. Rung and Hakha envions, Falam Mudstone, Chungsung mudstone turbidities and colluvial soils are well exposed.

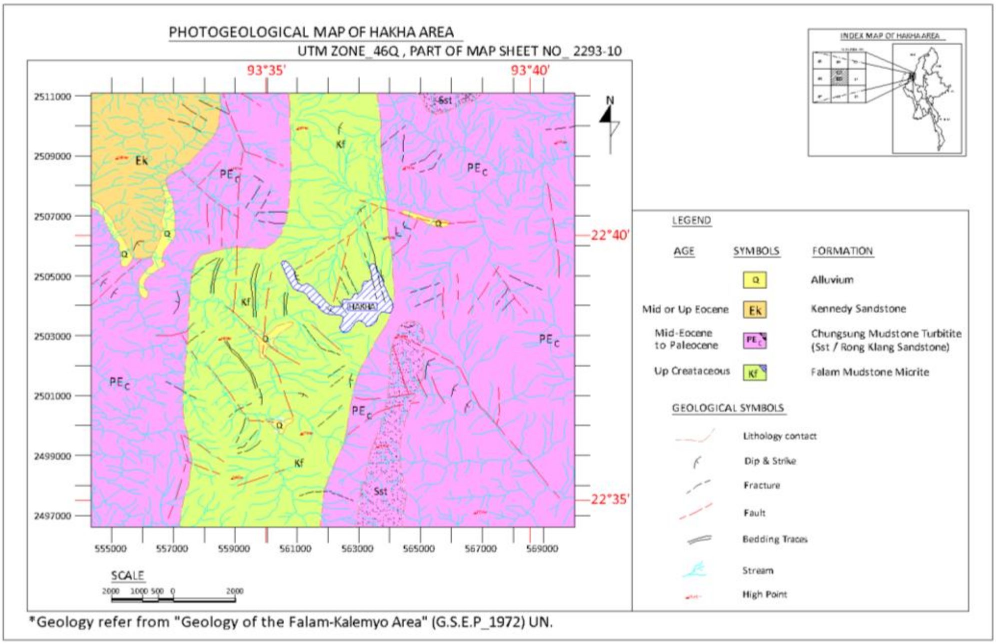


Figure 1: Regional geology of the Hakha enviorns

Triggering Event

Karnawati (1996 &2000) suggested that the triggering rainfall characteristics are strongly controlled by the permeability of soil/rock covering the slope and the initial groundwater table.

The monthly rainfall data from May to October (1989-2015) was collected from department of hydrology and meteorology. The precipitation was collected to figure out the triggering event and their relation to landslide is shown in figure. The rainfall in July 2015 is abnormally higher than other months of previous years. There was about 30 inches of daily rainfall from 26 to 31 in landslide events. Before this tragedy, there was no record or evidence of earthquake during this landslide event. The heavy rainfall from the consequence of recent storm and antecedent rainfall from this effect are the major triggering factors to cause those disastrous landslides. Large scale landslides in different places of Hakha environ were subsequently happened.

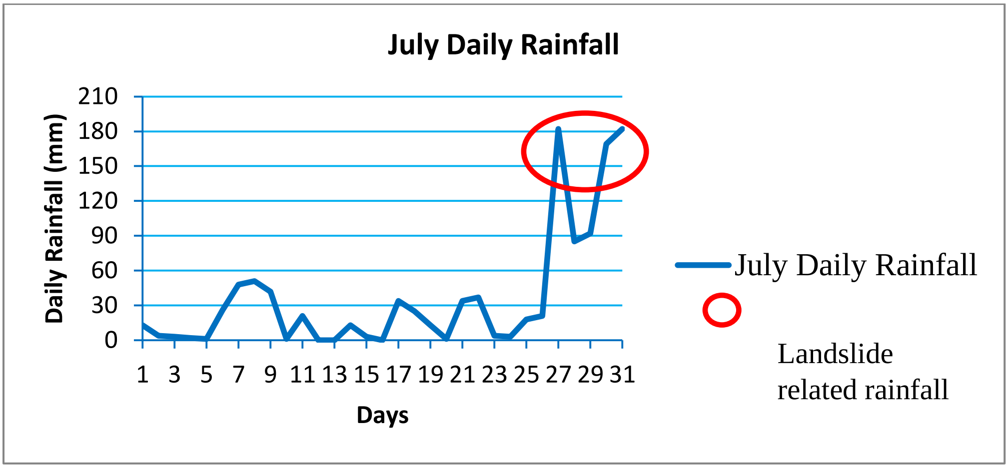


Figure 2: The daily rainfall in the month of July 2015

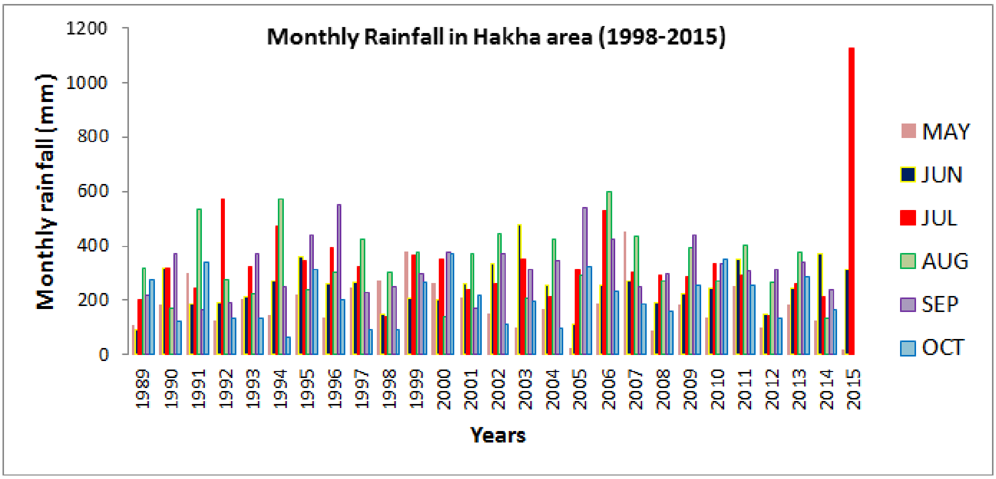


Figure 3: The monthly rainfall of Hakha area from 1998 to 2015

Landslide Investigation

Myo Haung quarter is located in the middle and base of Mt. Rung slope and the occurrences of destructions of Pagoda, churches, about 540 numbers of bulidings/houses, schools, retaining walls and numerous cracks almost all over the road were recorded and shown in figures 4 (a-i). Among those landslides, some failures showed that the slides happened again on former landslide materials. The types of landslides are based on inclination of slope, heterogeneity, weathering grade, bedding nature and types of lithology. Three types of landslides are classified in the study area according to the classification of Varnes 1978 .

(a) (b) (c)

(d) (e) (f)

(g) (h) (i)

Figure 4: The destructions of houses school and houses in Myohaung quarter (a to i)

The most common destructive type is deep seated rotational slide, the second is flow type and the third is translational type or plane failure. Among them, Mt.Rung is the biggest and it is reactivated on ancient giant old landslide which can be inferred from the Landsat images.

The landslide crown can be sharply observed on the top of the Mt. Rung which is about 500m wide. Before this event, the lake was situated in the middle of this slope and currently there was no trace of it and left only the landslide materials. On the slope face, the small seepages from indurated shale layer were observed which is one of the critical factors to cause this failure. The landslide materials in Mt. Rung slope are composed of colluvial soils consist of various sizes of sandstone and mudstone fragments such as 3cm to 6cm and some consist of 30 cm to boulder size sandstone. Under this colluvial soil, very thin bedded, very fissile indurated shale from which the groundwater seepages are common and thick bedded sandstone are interbedded. Those medium to thick sandstone beds are well exposed on the top of the Mt. Rung, dipping the same direction of the landslide direction and this is also one of the critical factors to failure. Another factor is the heterogeneity and unconsolidated condition of colluvial soils which appeals the infiltration of water that increase the pore pressure together with decrease of effective stress based on the intensity and duration of rainfall, permeable and less impermeable characteristics of the layers of the slope.

Based on thorough field investigation, the ancient landslide scars on top of the Mt. Rung from Landsat images and relation to landslide materials and failure conditions, all those cracks and failures are interconnected on this slope. As a result, the length of the Mt. Rung slide is about1000m to the bottom. Therefore, this can be concluded that this Mt. Rung landslide is reactivated deep seated rotational slide as shown in figure (5).

The flow type of failure can be clearly observed at 2/2 mile post of Hakha-Gantgaw Road. They can be usually observed on very steep slope with narrow valley composed of highly jointed rock or soil. The rain water shall be trapped temporarily due to collapse of soil from valley side and abruptly flow down with very high speed after intense rainfall. Another huge landslide was recorded beside this and two fish farms near the base of the slope covered with those landslide deposits.

The translational slide or plane failures are very common along the high way road. The slope cutting and bedding direction are in the same direction and this has the effect of causing the plane failure. The typical plane failure at 3/3 mile post of Hakha-Matupi road is shown in figure (6).

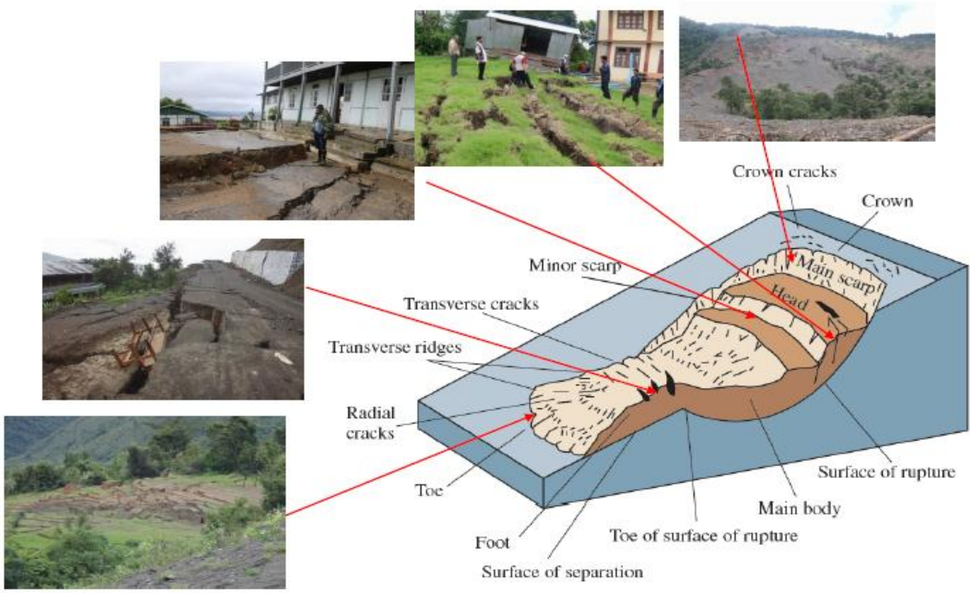
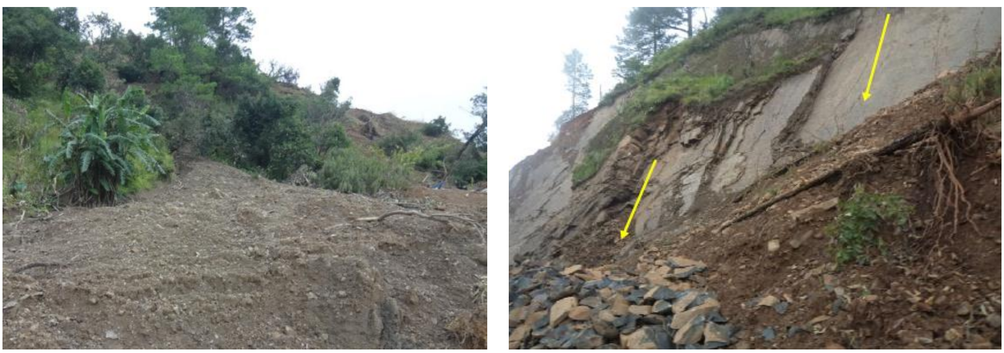


Figure 5: Reactivated deep seated rotational slide of Mt. Rung



(a) (b)

Figure 6: Flow type failure in (a) and Plane failure in (b)

Engineering properties of Soil

The samples were collected from the landslide materials for the determination of their physical and mechanical properties. The grain size distribution test, Atterberg limit test, triaxial test and the dispersive tests were carried out. The samples from the depth of 4 ft and 12 ft in the Saling Church compound, from the middle area of the Mt. Rung slope, proposed new settlement area, Chaunsung indurated shales were analyzed and the result are shown in table. According to Unified Soil Classification System, the landslide materials are low plasitcity clayey silt (CL,ML)with PI value of 6.25 to 11.27. Most of the landslides are found in indurated shale of Chunsung Mudstone - Turbitide Formation and the samples were remolded for triaxial test and dispersive test. The result of remolded samples show the cohesion values 165-167 MPa and the friction angle value 23º-28º. This higher strength value is resulted due to the remolded sample conditon.

Dispersive nature of Landslide materials

During field investigation, the numerous cracks are observed on the slopes. There were traces of forcibily break out natures on the soil surfaces among the cracks. Those natures in landslide of Hakha area are not quite common as usual tension cracks of landslide in other places. The uplifting of some soil blocks among the cracks are noticebly seen in figure (7). This fact needs to be explained by the determination of dispersive test.

Dispersive clays have a higher relative content of dissolved sodium in pore water. Dispersive clays have an imbalance in the electrochemical forces between particles. This imbalance causes the minute soil particles in a dispersive clay to be repulsed rather than attracted to one another. Consequently, dispersive clay particles tend to react as single-grained particles and not as an aggregated mass of particles.Dispersive clays are defined as the condition of slurry in which the idividual clay particles do not aggregate into flocs. Dispersion occur in those soil wherein the repulsive forces between the particles when saturated exceeds the attractive forces. This is caused by the reduction in concentration of cations in pore fluids, resulting in deflocculation and dispersal of the clay particles. Therefore when the soil is in the presence of relatively pure water, the clay particles repel each other and go into suspensions. (Reeves et.al 2006).

(a) (b)

(a) (b)

Figure 7: The nature of forcibly break down of cracks on the slope (a-e)

The collected samples from the landslide areas were tested with distilled water according to ASTM D It is divided into four Grade; Grade I-no reaction: no colloidal cloud develops. Even though the crumb may slake and particles spread away from the original clod because of this slaking activity, no trace of a colloidal cloud is observed in the water.

Grade II- slight reaction: A colloidal cloud is observable, but only immediately surrounding the original clod. The cloud has not spread any appreciable distance from the crumb. Grade III- moderate reaction : a colloidal cloud emanates an appreciable distance from the crumb. However, the cloud does not cover the bottom of the glass, and it does not meet on the opposite side of the glass bottom from the crumb. Grade IV- severe reaction: The colloidal cloud spreads completely around the circumference of the glass.

The cloud may not completely obscure the bottom of the glass, but the cloud does completely cover the circumference of the glass. In extreme cases, the entire bottom of the glass is covered by the colloidal cloud.

4ft(0:02 Sec) 4ft(0:45 Sec) 4ft (1:01Sec)

Result: Grade3(Moderate reaction)

Figure 8: Dispersive test on the sample (depth- 4ft) from Sangling Church, Hakha, GPS Point: (0563476 E, 2504958 N)

12ft (0:11 Sec) 12ft (0:40 Sec) 12ft (1:02 Sec)

Result: Grade3(Moderate reaction)

Figure 9: Dispersive test on the sample (depth- 12ft) from Sangling Church, Hakha GPS Point: (0563476 E, 2504958 N)

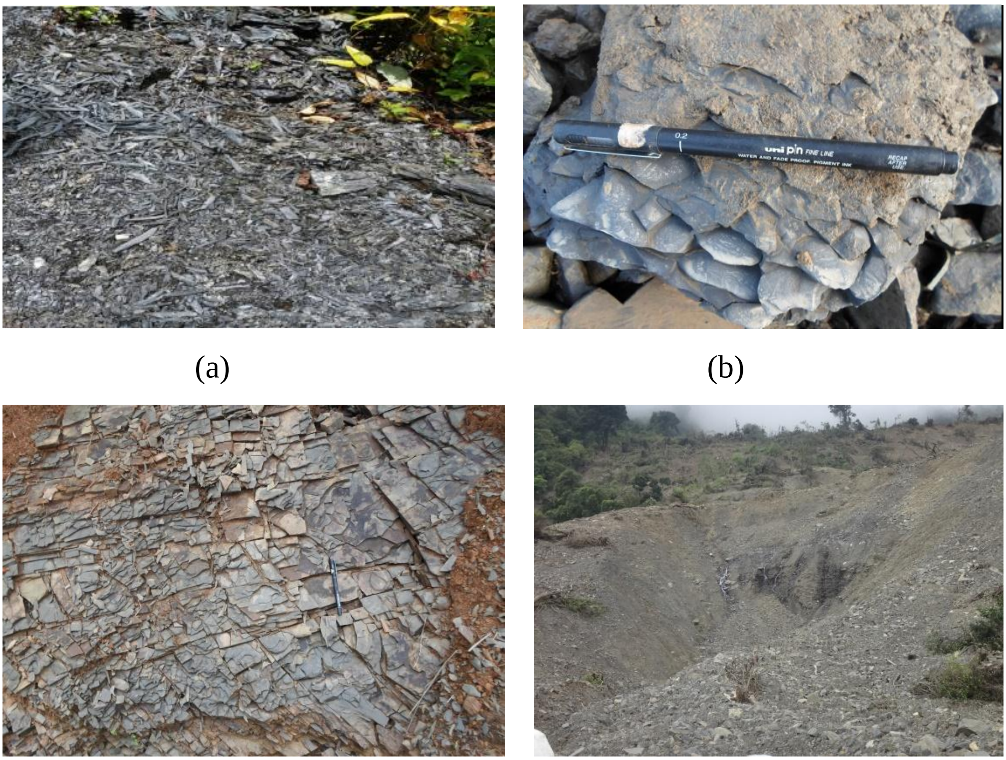
Indurated Shale (0:00 Sec) Indurated Shale (0:46 Sec) Induratd Shale (1:26 Sec)

Grade 4: Severe reaction

Figure 10: Dispersive test on the sample from the lope Surface of Chunsung Mudstone (Indurated Shale) GPS Point: 0560517E, 2506832N

The samples shows Grade 3 (moderate reaction) to Grade 4 (severe condition) as shown in figure (8-10). From the dispersive test, the formation of cracks are due to high content of sodium content in soil when they in contact with rainwater and forcibly break down.

The soils are derived from the weathering of parent materials of chunsung mudstone Formation. Not only the soil but also the weathering nature of indurated shale shows the numerous cracks and small pieces of rock fragments as shown in figure (11). On landslide surface, the black colour small pieces of rock flour from which the water seep out as in figure (11- d)can be observed. Those rock flour samples were collected for dispersive test and the result show Grade IV severe reaction when in contact with distilled water.



(a) (b)

(c) (d)

Figure 11: The dispersive nature of rock fragment (indurated shale)from Chunsung Formation

Conclusion

According to laboratory result, the occurrence of numerous cracks in the middle and at the bottom potion of the landslide slope in which the dispersive nature of soils or rocks not only on the surface but also in subsurface are the most crucial factors to sustain the stability of the slope. The dispersive nature of soils has to be clearly understood prior to the appropriate landslide mitigation measures taken. Although dispersive nature is well understood and easy to control the surface condition, it is still difficult to control the extent of those soils in subsurface condition and related water.

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PETROLOGICAL AND GEOCHEMICAL STUDIES OF GRANITE HOSTED W-SN DEPOSIT IN TAGU TAUNG AREA, TANINTHARYI REGION

Aye Pyae Phyo[1] and Aung Zaw Myint[2]

Abstract

Tagu Taung area is situated about 59 km southeast of Myeik, Tanintharyi Region. In the study area, porphyritic granite intrudes the metasediments of the Carboniferous to Early Permian Mergui Group. Porphyritic granite is medium- to coarse-grained and characterized by the phenocrysts of feldspar. It is mainly composed of quartz, plagioclase, microcline, perthite, orthoclase, muscovite, biotite, chlorite and zircon. Geochemical data indicates that the granites from the study area have A/CNK ratio (1.2-1.4) is greater than 1.1 expressing peraluminous and S-type. When plotted in the (Y+Nb) / Rb discrimination diagram, Tagu Taung granites occupy syn-COLG (syncollisional granite) setting. Therefore, it can be said that these S-type granites are formed at syncollisional setting. The W-Sn mineralization is spatially and genetically associated with porphyritic granite. W-Sn ores are associated with sulfide bearing quartz veins that intrude the graywacke and granite. There are two stages of mineralization: namely greisen stage and vein stage. Molybdenite, chalcopyrite and sphalerite were deposited during the greisenization process (early stage). Successively, wolframite, cassiterite, arsenopyrite, pyrite, chalcopyrite, bismuth and sphalerite formed in the vein stage. The Sn-W mineralization is genetically related to the S-type granite emplacement that is resulted from the partial melting of the crust.

Keywords: Petrology, Geochemistry, S-type granite, Paragenetic sequence, W-Sn mineralization

Introduction

Tanintharyi Region is located at the southern part of Myanmar and it is geologically famous for its tin-tungsten mineral deposits. Tagu Taung is one of the famous mine in the region and situated about 59 km southeast of Myeik (Figure 1).

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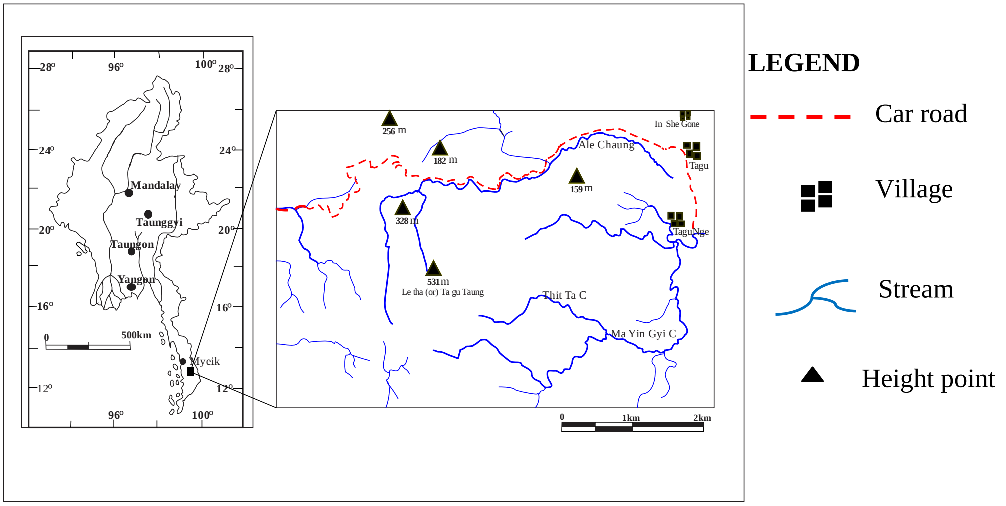


Figure 1: Location map of the study area

Regional Geologic Setting

Regionally, different stratigraphic units are exposed in the Tagu Taung and its environs (Figure 2). Mostly, Tertiary rocks occur along the Tanintharyi Valley. It is mainly composed of sandstone, slate, and conglomerate. Small belts or basins of non-marine sandstone, conglomerate and shale of Late Tertiary age, locally containing minor amount of oil shale and lignitic coal also occur.

The name of Mergui Series was given by Oldham (1956) to the unfossiliferous strata consisting of shales, agglomerates, limestones and quartzites which exposed within the Tanintharyi Region. It is redefined as Mergui group that is the oldest rock unit in this area. It is widely distributed unit in the study area. It is composed of a thick sequence of folded phyllites, argillites, greywackes and shales, with subordinate amount of conglomerates, sandstones, quartzites, limestone, tuffs and agglomerates. Tin-tungsten bearing granites intrude the Mergui Group.

Granitoids of this region are appeared as southern extension of granitoids from Dawei area and passes southward to Kawthaung. The granitoids intrude the metasedimentary rocks of Mergui group and they can be grouped into three ranges; the western frontier range, the central range and the eastern range. The Mergui pluton is elongate NNW-SSE and parallel trends to the country rocks which are affected by greenschist to lower amphibolite facies metamorphism. Biotite granite and biotite-muscovite granite are most abundant rocks with subordinate amount of porphyritic biotite, hornblende granite, granodiorite and tourmaline-muscovite granite.

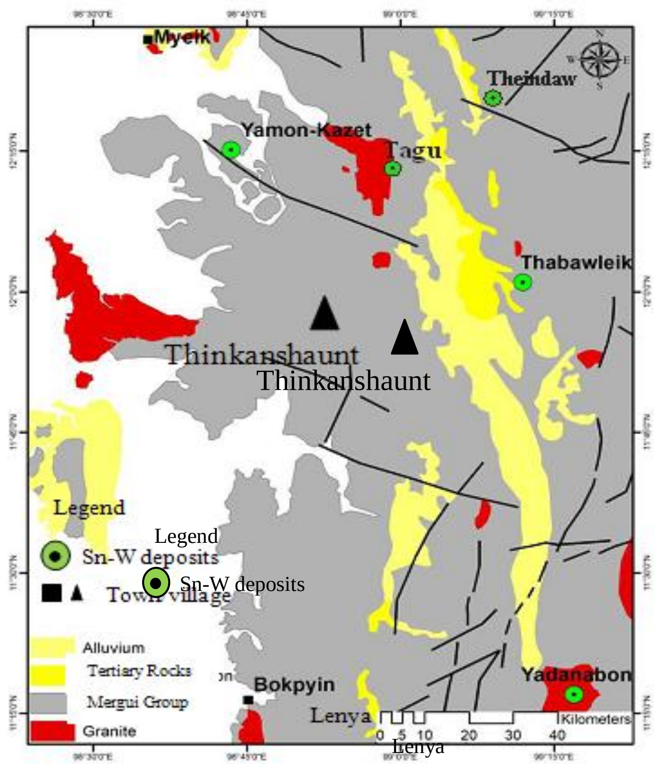


Figure 2: Regional geological map of Tagu Taung and its environs (Aung Zaw Myint, 2016)

Deposit Geology

The study area is composed of the metasedimentary rocks of Carboniferous - Permian Mergui Group and granitic rocks (Figure 3). The Mergui Group is widely distributed around the study area. In the study area, the prominent rock unit of the Mergui Group is greywacke, and Greywacke occurs as well exposed along the study area. Greywackes are dark grey, fine-grained, compact and highly jointed (Figure 4a). It strikes nearly east-west with north dipping between 70° to 80° inclination.

Porphyritic granite intrudes the metasediments of the Mergui Group. It is mainly composed of quartz, feldspar, biotite and minor amount of muscovite. Zoned feldspars occur as phenocrysts in the granite demonstrating the porphyritic texture (Figure 4b).

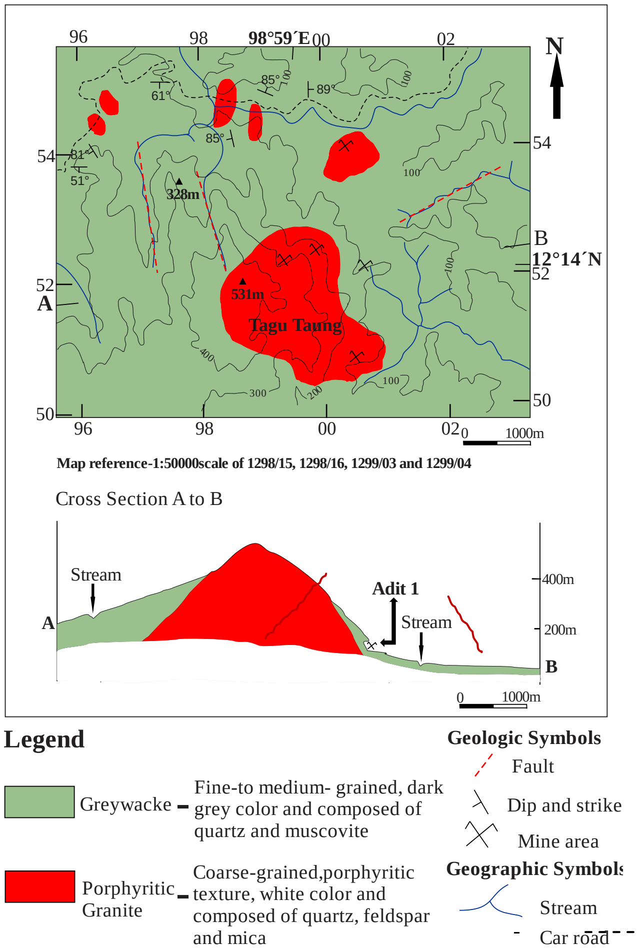


Figure 3: Geological map of the Tagu Taung area

Figure 4: Photographs showing (a) the greywacke unit of the Mergui Group and (b) the phenocrysts of zoned feldspar dispersed in the porphyritic granite

Petrography

Porphyritic granite

Megascopically, it is coarse-grained and porphyritic texture. The color is yellowish white on weathered surface and white on fresh surface. It is mainly composed of quartz, feldspar and mica which form an interlocking and equigranular matrix of feldspar and quartz with scattered muscovite and biotite mica. The feldspar is found as major phenocrysts of the rock and presents zoning (Figure 5).

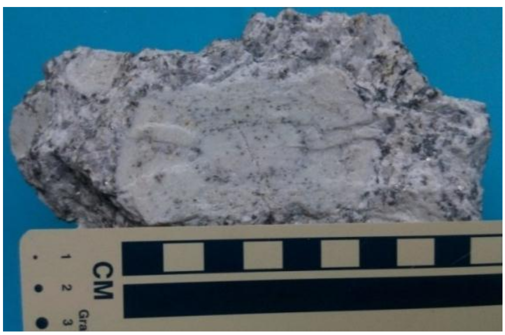


Figure 5: Hand specimen of porphyritic granite presenting feldspar phenocryst

Under Microscopic study, it shows medium- to coarse-grained texture and porphyritic texture. It is mainly composed of quartz, plagioclase, microcline, perthite, orthoclase, muscovite, biotite, chlorite and zircon. The proportion of quartz and feldspar (Plagioclase, microcline, prethite and orthoclase) is more than 75% of the whole rock. Quartz grains are found as bleb-like intergrowth in the microcline and perthite (Figure 6a). Subhedral plagioclase shows multiple twining and the grain size ranges from 0.4 mm to 1.2 mm. Plagioclase is slightly altered to saussurite and sericite (Figure 6b). Some fine-grained plagioclases are found as inclusions in the microcline. Alkali feldspars are microcline, perthite and orthoclase occurring as subhedral minerals and their grain size ranges from 0.55 to 1.3 mm. Microcline phenocryst often hosts microcline and plagioclase inclusions (Figure 6c).

Biotite is mostly altered to chlorite (Figure 7a), and also has the dark haloes where if hosts zircon inclusion (Figure 7b). Perthite is intergrowth texture of albite and orthoclase. The formation temperature of perthite may be nearly 590°C and it can be formed near the crust. So, according to petrographically, the study area of Tagu Taung's granite may be peraluminous and S type granite. Zircon inclusion can be observed in the orthoclase (Figure 7c).

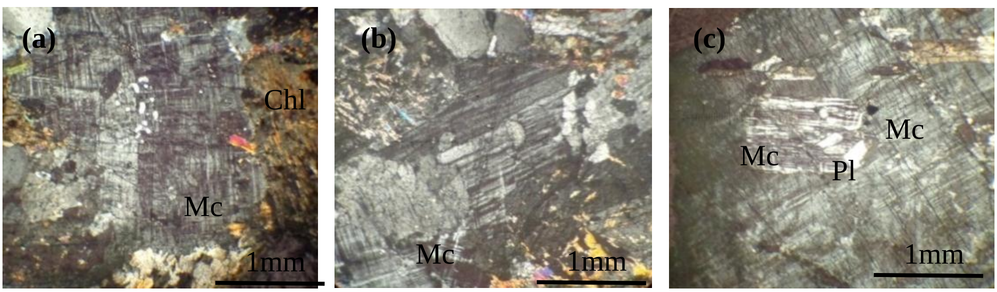


Figure 6: Photomicrographs showing (a) the bleb-like intergrowth of quartz in microcline and biotite altered to chlorite, (b) the microcline, perthite and plagioclase; the intensive sericitization occurs in the plagioclase and (c) microcline and plagioclase inclusions in microcline phenocryst (Mc-Microcline, Chl- Chlorite, Pl-Plagioclase)

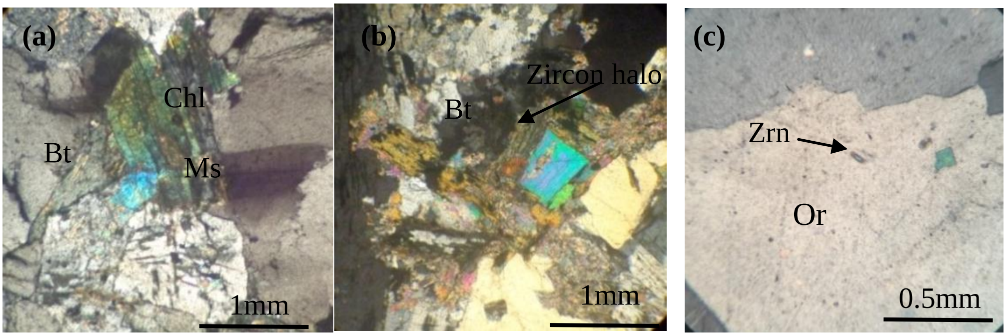


Figure 7: Photomicrographs showing (a) the muscovite, biotite and chlorite, (b) the zircon haloes in biotite and (c) the zircon in the orthoclase (Bt- Biotite, Ms- Muscovite, Chl- Chlorite, Zrn-Zircon)

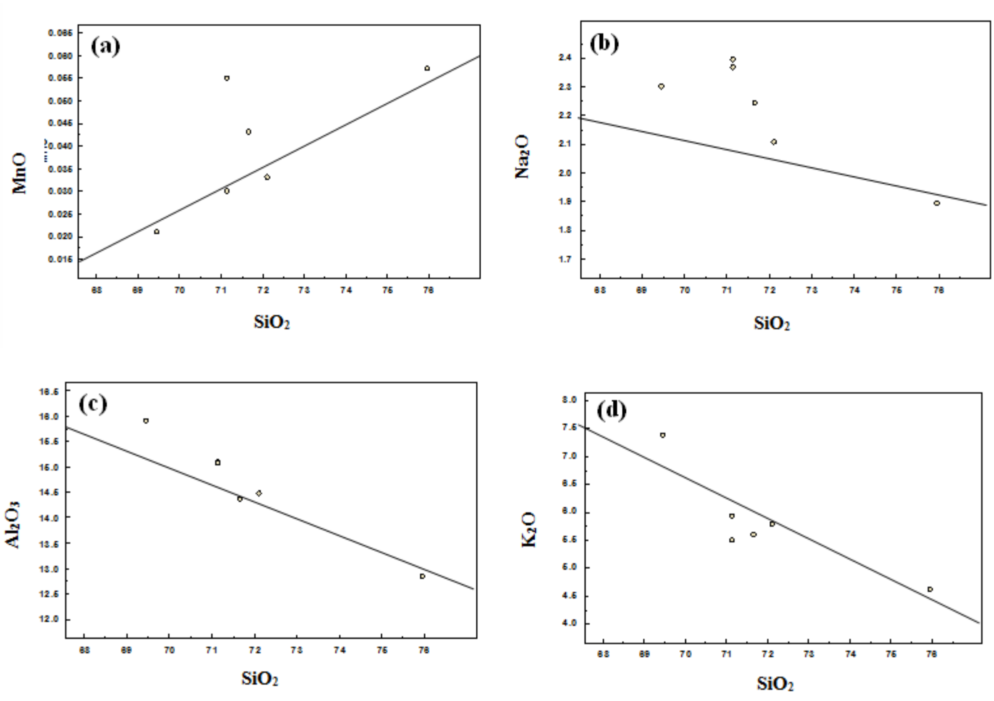
Geochemistry

Granite geochemistry

XRF geochemical data reveals that the granite samples contain SiO_2 (69-76%), Na_2O (1.89-2.39%), MgO (0.57-0.72%), Al_2O_3 (12.8-15.88%), P_2O_5 (0.14-0.18%), K_2O (4.6-7.3%), CaO (0.61-1.18%), TiO_2 (0.27-0.36%), MnO (0.02-0.06%) and FeO (1.58-2.18%). The concentrations of trace elements are V (17-31 ppm), Co (26 to 41 ppm), Ni (13-16 ppm), Cu (3-97 ppm), Zn (23-179 ppm), Pb (52-109 ppm), Mo (11-18 ppm), Rb (677-846 ppm), Sr (25-66 ppm), Y (31-40 ppm), Zr (158-214 ppm), Nb (23-36 ppm), Sn (47-152ppm), W (8-349ppm), Th (44-58ppm) and U(13-29ppm).

SiO_2 shows positive correlation with MnO and it means that the value of SiO_2 increases with the value of these major elements increase (Figure 8a). SiO_2 has the negative correlation with Na_2O, Al_2O_3 and K_2O, indicating that the value of SiO_2 increase with the value of these major elements decrease (Figures 8b, 8c & 8d). SiO_2 has positive correlation with W and Sn. It means that the value of SiO_2 increase with the value of these trace elements increase (Figures 8e & 8f). SiO_2 shows Negative correlation with Sr. It reveals that the value of SiO_2 increases with the value of these trace elements decrease (Figure 8g). The SiO_2 and the ratio of Rb/Sr concentration is also positive correlation (Figure 8h).

CIPW normative corundum contains 2.886 to 3.97 and this indicates that the granite of Tagu Taung area is S-type granite (Chappell and White, 1974 and 2001). The SiO_2 / (Na_2O+K_2O) diagram indicates that granite conditions (after Cox-Bell-Pank, 1979) (Figure 9a). According to alumina saturation index diagram, A/CNK ratio is greater than 1.1 and it can be said that the granite is peraluminous and S-type (Shand, 1943) (Figure 9b). These granites have high content of Rb (677-946 ppm) and Ba (234-437 ppm) with low content of Sr (25-66 ppm). The Rb-Sr-Ba triangular plot reveals the highly differentiated nature of the granite (EL Bouseily and El Sokkary, 1975) (Figure 10a). When plotted on the (Y+Nb) / Rb discrimination diagram, Tagu Taung granites occupy syn-COLG (syncollisional granite) setting (Pearce et.al, 1984) (Figure 10b). R1-R2 plot also indicate the syncollision tectonic setting (Batchelor and Bowden, 1985) (Figure 10c). Thus, it can be said that granite from Tagu Taung area are S-type granite which are formed at syncollisional setting.



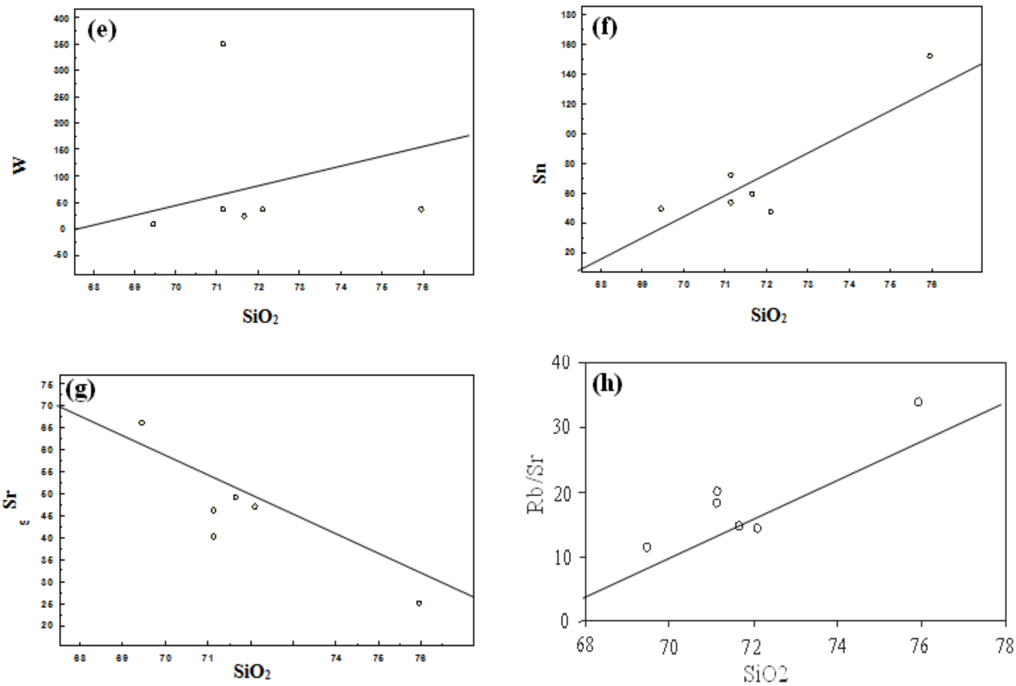


Figure 8: Variation diagram showing (a) the positive correlation between SiO_2 and MnO, (b,c,d) the negative correlation between SiO_2 and Na_2O, Al_2O_3, K_2O, (e.f,g) the positive correlation between SiO_2 and W, Sn and Sr and (h) positive correlation between SiO_2 and Rb/Sr

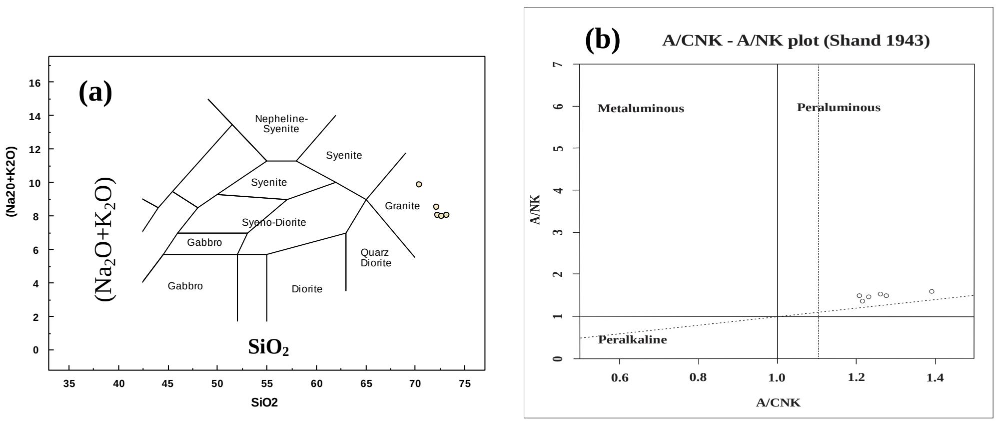


Figure 9: (a) SiO_2 / (Na_2O+K_2O) plot diagram data showing granite conditions of Tagu Taung area (Cox-Bell-Pank, 1979) and (b) Alumina saturation plot diagram showing Peraluminius nature of Tagu Taung area (Shand 1943)

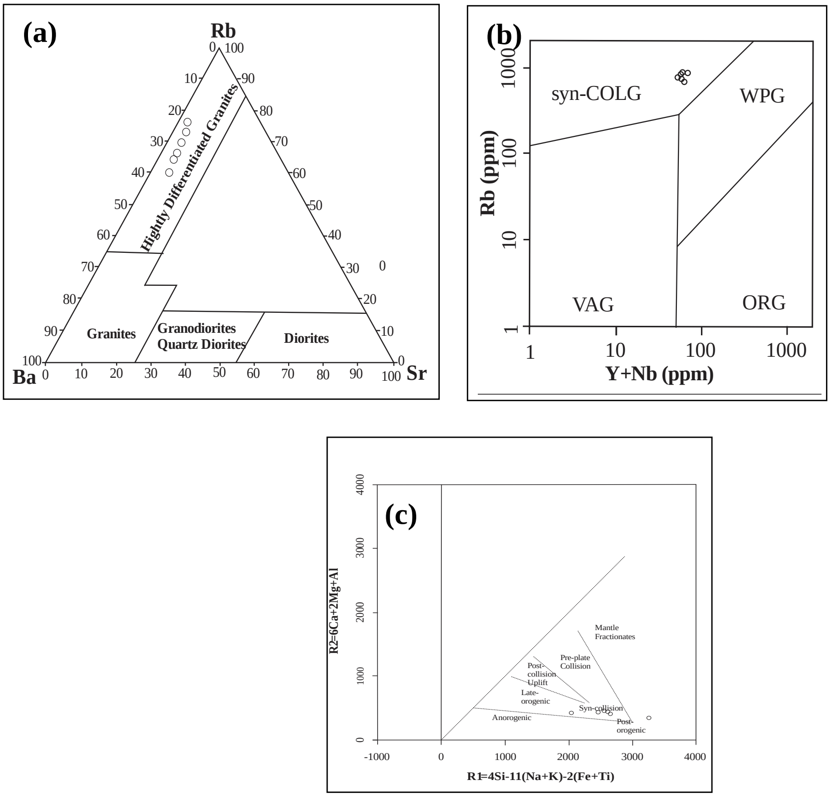


Figure 10: (a) Rb-Ba-Sr triangular plot of Tagu Taung granite (EL Bouseily and El Sokkary, 1975); (b) (Y+Nb)/Rb plot of (Pearce al, 1984) and (c) R1-R2 plot of (Batchelor and Bowden, 1985)

Alteration and Mineralization

Alteration

According to the field observation and microscopic studies, the common alterations associated with W-Sn mineralization are greisenization and silicification.

Greisen systems are resulted from complex and late- to post-magmatic metasomatic processes that affect and take place within a nearly consolidated granitic mass and the adjacent country rocks. Greisenization is typically linked with highly fractionated magmas (Pirajno, 2009). In Tagu deposit, greisenization occurs near the granite intrusion, especially at adit 2 and adit 3. Typically, greisen mainly consists of quartz and muscovite with accessories of tourmaline, topaz, apatite, fluorite, and iron oxide. In the study area, greisen is associated with quartz veins. Greisen is reddish grey with mica flakes (muscovite) in weathered surface and bluish grey color in fresh surface (Figure 11a). It is mainly composed of quartz, muscovite, apatite and the most common ore is molybdenite (Figure 11b). Under the microscopic study, quartz is prevalent. The quartz is anhedral and the edges of the quartz are jagged. It is associated with muscovite (Figure 12a). Muscovites is predominant and coarse-grained texture. The molybdenite is associated with mouscovite flakes (Figure 12b). The deformed and fractured apatite is also found within the coarse-grained mouscovite (Figure 12c).

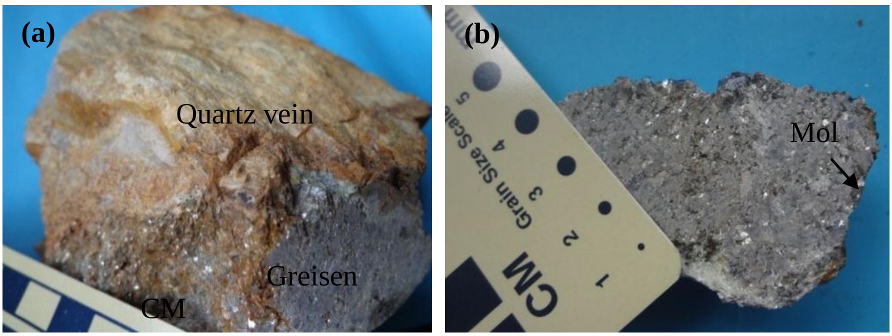


Figure 11: Hand specimen of (a) greisen and quartz vein at the Tagu deposit and (b) molybdenite bearing greisen surface at the Tagu deposit

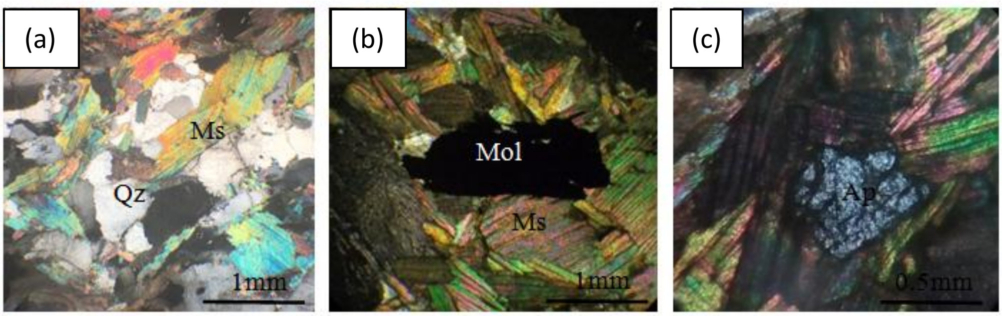


Figure 12: Photomicrograph showing (a) the nature of quartz and muscovite in the greisen, (b) the molybdenite with muscovite in the greisen and (c) the subhedral apatite in the greisen (Qz- quartz, Ms- muscovite, Mol- molybdenite, Ap- apatite)

Silicification is prominent alteration type in the study area and mainly occurs within the metasedimentary rocks intruded by quartz veins around the adit 1. Outcrop nature, it is red to pale brown color, hard and compact than other metasediment. Megascopically, it can be found more lighter color than other metasediment. Quartz veinlets occur at the surface. Under the microscopic study, quartzs are wavy extinction and mostly are irregular shape (Figure 13a). Silicification related by quartz veins intrusion. These veins intrude the metasediment and silica solution emplacement formed as silicification (Fig 13.b).

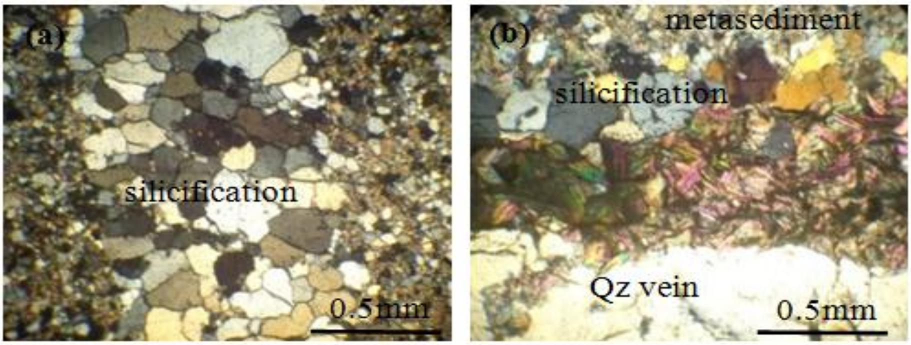


Figure 13: Photomicrograph showing the nature of silicification in the metasedimentary rock near the adit-1

Mineralization

The mineralization style of the Tagu (also known as Kontapin) deposit is designated as a vein type deposit which is hosted by the porphyritic granite and metasedimentary rocks. In mineralized area, veins can be sub-divided into three types as (i) quartz vein, (ii) mica-bordered quartz vein, (iii) sulfide bearing quartz vein. W-Sn mineralization is associated with the sulfide bearing quartz vein. Veins trend mostly east-west direction with nearly vertical to various amount of inclination.

The adit-1, parallel quartz veins cut into the metasediment (Figure 14a). These quartz veins are shifted by the minor faults and taper upwards. Adit-1 is located in the metasedimentary rocks while adit-2 is hosted within the granite. The elevation of adit-2 is 360 m height. The vertical quartz veins intruded by the granite and this quartz vein is adit-3. The elevation of adit-3 is

395m height. In (Figure 14b) is mica bearing quartz vein at the adit-1 are mica segregation occurs in the margin of quartz vein. In (Figure 14c) ore bearing sulfide-quartz vein intrude into the metasedimentary rocks. In (Figure 15a) is the ore bearing mineralized quartz veins and its width is 35cm. The two tunnels and one vertical shaft occur along this vein. All ore minerals occur as irregular patches and disseminated (Figure 15b). The ore bearing sulfide zone occurs in this vein. Ore productions are mostly extracted from this vein. Schematic diagrams of the adit location map of the Tagu Taung deposit is shown in Figure (16).

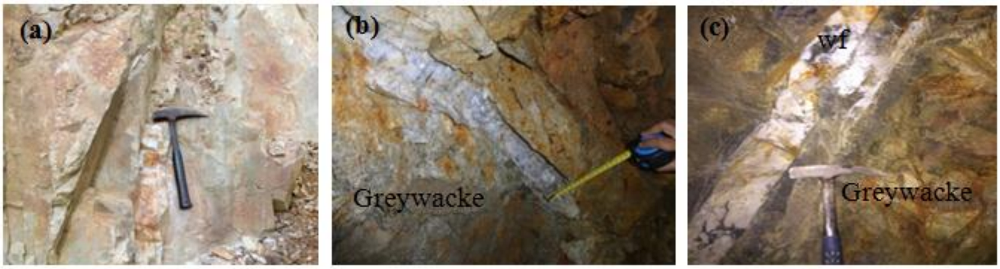


Figure 14: Outcrop showing (a) the quartz vein in the metasediment of the Mergui Group at the back of adit-1, (b) the mica segregation along the margin of quartz vein in the adit-1 and (c) the sulfide bearing quartz vein with wolframite

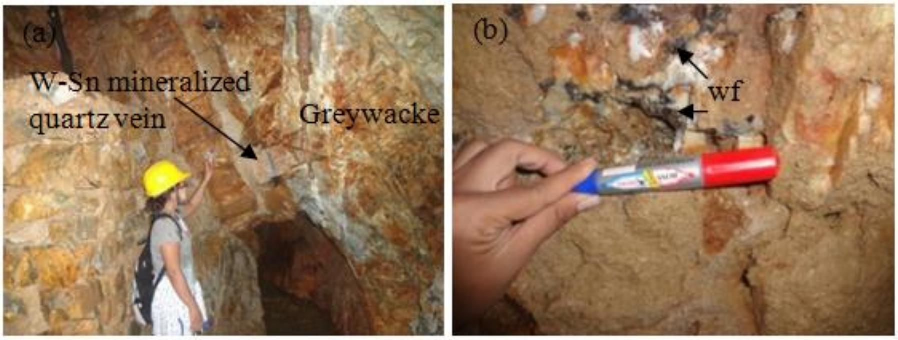


Figure 15: Outcrop showing (a) the W-Sn mineralized quartz vein in the adit-1 and (b) the patches of wolframite in the adit-1

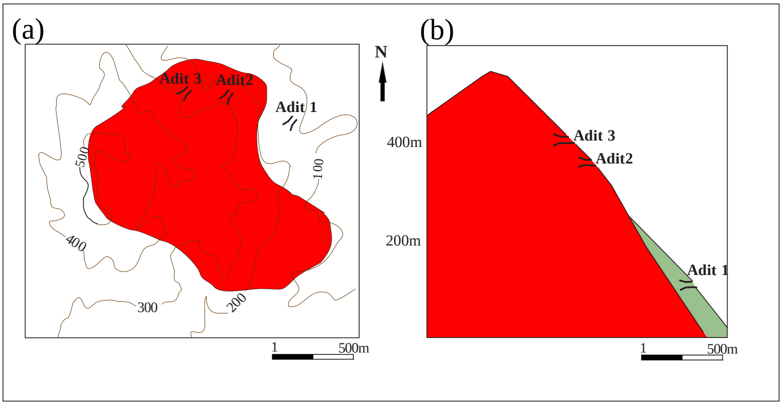


Figure 16: Schematic diagrams of the adits location map of the Tagu deposit (a) plan view and (b) vertical view

Thit Ta prospect

Thit Ta prospect area, W-Sn mineralization is hosted within the granite. The silicified and mineralized zone is well exposed in the Thit Ta area (Figure 17a). Pyrite veins of up to 5cm width cut the silicified body (Figure 17b). In the silicified body, arsenopyrite is widely disseminated and associated with pyrite in some places. Wolframite occurs as disseminated grains within the silicified body (Figure 17c).

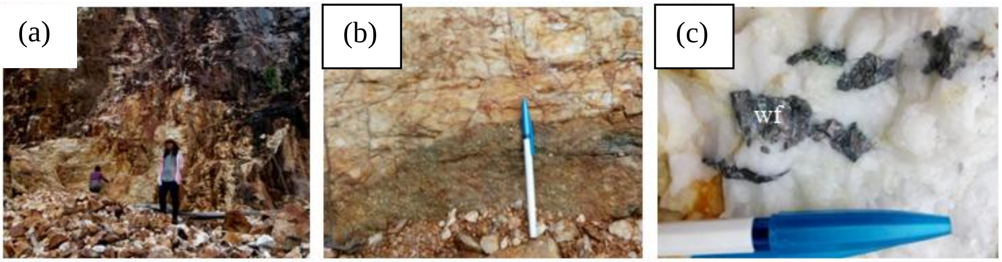


Figure 17: Outcrop showing (a) the Thit Ta prospect, (b) the contact line between silicified body and sulfide vein and (c) the disseminated wolframite in silicified body

Ore Mineralogy

Tagu deposit

In Tagu deposit, the main ore is wolframite which is associated with cassiterite, arsenopyrite and pyrite. In hand specimen, wolframite is dark brown to black color with brownish black streak and bladed form. In (Figure 18a), wolframite occurs within the vein boundary as bladed form. Cassiterite is the main tin mineral in in Tagu Taung deposit possessing brown and black color and short or slender prismatic or pyramidal form. Wolframite and cassiterite occur together along the margin of vein (Figure 18b).

Arsenopyrite is common sulfide ore mineral at the adit-1. The grain size of arsenopyrite is generally 1 cm in length. Arsenopyrite is associated with pyrite. Pyrite is major sulfide ore mineral in the Tagu Taung mine and molybdenite occurs near adit-3.

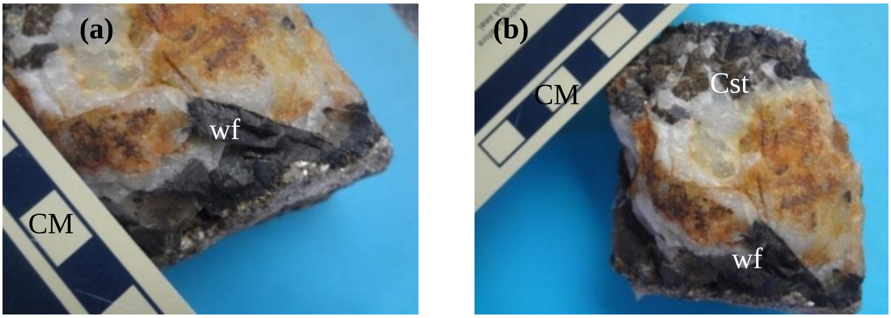


Figure 18: Hand specimen of wolframite and cassiterite in adit-1 of Tagu deposit

Ore microscopic description

Common ore mineral is wolframite which is associated with cassiterite and sulfides such as arsenopyrite, pyrite, chalcopyrite and sphalerite. Bismuth and molybdenite are also found as minor minerals. Common gangue minerals are quartz, and muscovite.

Wolframite is the principle ore mineral of tungsten-tin mineralization of the study area. Wolframite is found as massive, subhedral tabular lamellar form. Wolframite is closely associated with chalcopyrite, pyrite and sphalerite which marginally replaced by these sulfides (Figures 19a & b). Cassiterite is the major tin ore of the Tagu deposit and usually associated with wolframite. Unknown oxide minerals are enclosed in the cassiterite and they may be columbite (Figure 19c). Under transmitted light, cassiterite is brownish grey color with yellow to yellow brown internal reflection, distinct bireflectance, colorless to yellow pleochroism, color banding and two set of cleavages (Figure 20a). Cassiterite is rarely associated with sulfide minerals.

Arsenopyrite and pyrite common sulfides of the Tagu Taung deposit and Thit Ta prospect area. The color of arsenopyrite is white with pale yellow tint. Pyrite is yellowish white, lighter than chalcopyrite, high reflectance and usually isotropic. Bismuth is creamy white color, highly reflective and weak bireflectance. Chalcopyrite is yellow to brassy yellow color and usually occurs as anhedral grains. Sphalerite can be found as anhedral disseminated grains or associated with other sulfides as arsenopyrite, pyrite, chalcopyrite and molybdenite. In (Figure 20b) arsenopyrites are found as large crystals that host chalcopyrite, sphalerite and bismuth. In some places, chalcopyrite occurs as emulsoid texture in sphalerite (Figure 21a). Subhedral molybdenite can be found within the mica flakes. The size of molybdenite is about 10 mm (Figure 21b).

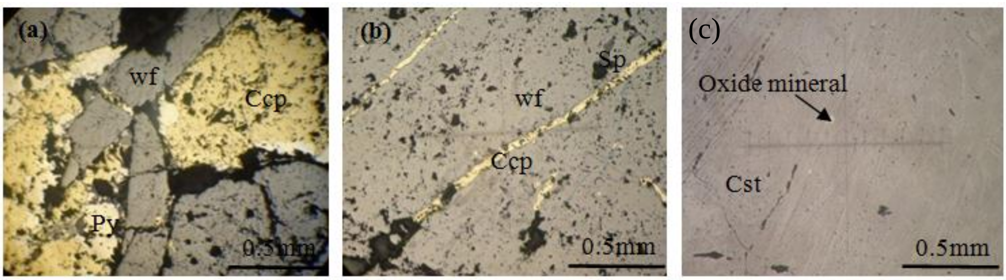


Figure 19: Photomicrographs showing (a) the nature of bladed, subhedral tabular wolframite replaced by chalcopyrite and pyrite, (b) the wolframite veined by chalcopyrite and replaced by disseminated sphalerite grains and (c) the oxide mineral inclusions (probably columbite) in cassiterite (under reflected light) (wf- wolframite, Ccp- chalcopyrite, Py- pyrite, Sp- sphalerite, Cst- cassiterite)

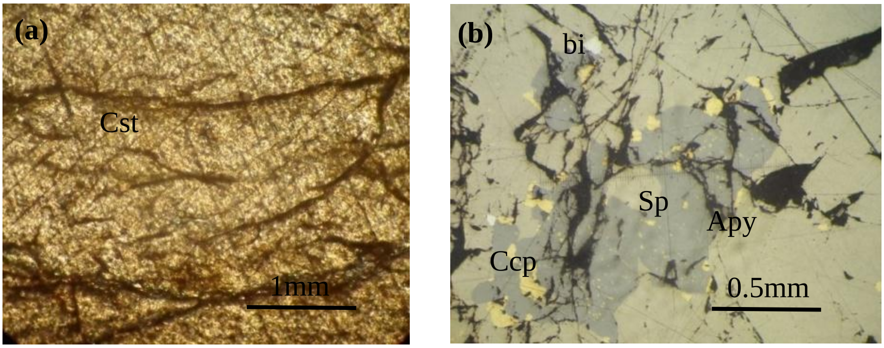


Figure 20: Photomicrographs showing (a) the two set of cleavage in cassiterite (under transmitted light), (b) the intergrowth texture of sphalerite and chalcopyrite; sphalerite, chalcopyrite and bismuth replaced the arsenopyrite (under reflected light) (Cst- cassiterite, Apy- arsenopyrite, Ccp- chalcopyrite, Sp- sphalerite, bi- bismuth)

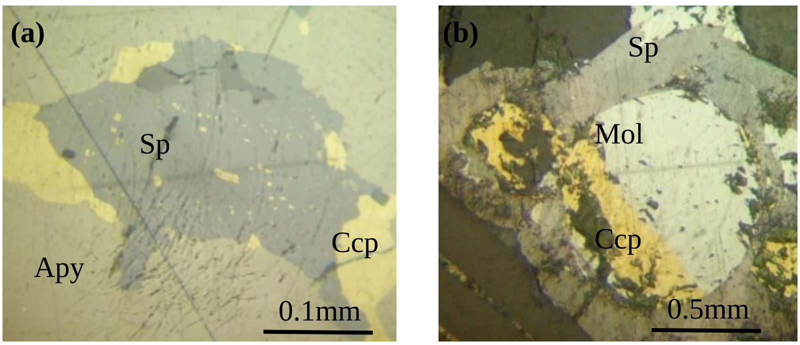


Figure 21: Photomicrographs showing (a) emulsion texture of the chalcopyrite and sphalerite and (b) the replacement texture of molybdenite, chalcopyrite and sphalerite in greisen (under reflected light) (Apy- Arsenopyrite, Ccp-Chalcopyrite, Sp- Sphalerite, Mol- Molybdenite)

Paragenetic sequence

By the study of ore microscopy, nature of ore minerals and their textural relationship, the minerals paragenetic sequence of ore minerals in Tagu deposit can be illustrated below (Figure 22). There are two major stages such as greisen stage and vein stage found in the Tagu deposit.

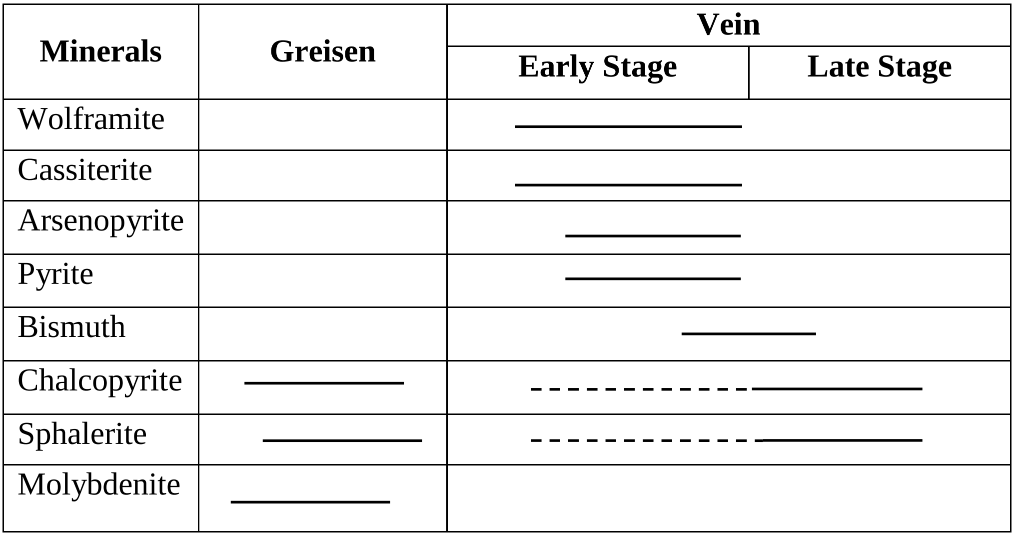


Figure 22: Paragenetic sequence of the ore minerals at the Tagu deposit

Summary and Conclusions

According to petrological and geochemical studies, Tagu Taung granites are peraluminous and S-type. Rb-Sr-Ba triangular plot indicates Tagu Taung granite is highly fractionated. These granites are located in the field of syn-COLG (syncollisional granite) setting (Pearce al, 1984; Batchelor and Bowden, 1985). The Sn-W mineralization is genetically related to the S-type granite that is resulted from the partial melting of the crust.

The common alterations associated with W-Sn mineralization are greisenization and silicification. Greisen is mainly composed of quartz, muscovite, apatite and the most common ore is molybdenite. Silicification is the prominent alteration type in the study area. Silicification mainly occur within the metasediment rocks intruded by quartz veins. W-Sn mineralization is associated with the sulfide bearing quartz vein. Veins are trending mostly east-west with nearly vertical to highly inclined.

Vein ore mineralogical studies provide the paragenetic sequence demonstrating two stages of ore deposition. Greisen stage is presented by the deposition of molybdenite, chalcopyrite and sphalerite whereas quartz vein stage is characterized by wolframite, cassiterite, arsenopyrite, pyrite, chalcopyrite, bismuth and sphalerite.

According to field observation, wolframite is associated with cassiterite and/or sulfide minerals such as arsenopyrite, pyrite, chalcopyrite and sphalerite. However, cassiterite is not commonly associated with sulfide minerals and only associated with wolframite and oxides.

According to the granite petrological and geochemical data, mineralization style and ore mineralogy, W-Sn mineralization of Tagu Taung area can be termed as the granite-related hydrothermal system.

Acknowledgements

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A GEOGRAPHICAL ANALYSIS ON DISTRIBUTION OF MARKETS IN SITTWAY TOWNSHIP

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Abstract

Theoretically, markets are located in the place where demand and supply meet together. However, other factors are differences in market, variations and transportation system and different nature of customers. This paper attempts to find out the factors that controls the development of markets in Sittway Township. Official statistics related to population, markets, etc. are collected from Township Administrative Office, Land Records Department, Meteorology and Hydrology Department, Department of Municipal and Ministry of Immigration and Population. These statistics are verified by field observation and recorded on Geographic Information Systems. Then, spatial analysis is conducted by using ArcGIS Version 9.3 software. Based on derived results, some markets are selected to conduct a questionnaire survey and to examine the controlling factors of location. Based on the analysis of derived data by using Microsoft Excel database, markets location are evaluated. The results reveal that markets are systematically (in hierarchical and functional patterns) located in Sittway Township. These patterns are controlled by accessibility, preference based on specific items, and sellers' strategy of business.

Introduction

Market is defined as an occasion when people buy and sell, on open area or building (Oxford Advanced Learner's Dictionary 8th edition CD-ROM, 2010). In practice, however, the definition and location of markets are very complicated rather than simply defined by supply and demand. Its location is controlled by others such as social, infrastructure, relative location, etc. Thus, the locational factors controlling the distribution of market are necessary to know from geographic point of view.

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Research Question

(1) How does spatial distribution of markets vary in size and function?
(2) What are the major controlling factors of market location?

Research Hypothesis

(1) Spatial distribution of markets is variable in size and function within the study area.
(2) These variation are operated by demand, supply, infrastructure and government policy.

Data and Method

First research hypothesis is that there are variations in the distribution of markets in terms of function and size in the study area. To prove this hypothesis secondary data are collected from Market Department, Sittway Town Development Committee. The level of markets, area, number of shops, date of establishment and selling items, etc. are involved in these data. By using ArcGIS 9.3 software, the above data were depicted as distribution map for visual and preliminary analysis.

Second research hypothesis is related to the controlling factors within the above market distribution variation. In order words, it is concerned with location factors of markets in the study area. There are four major hypotheses for controlling factors of markets location: customers, sellers, infrastructure (accessibility to market) and government policy.

To analyze the customer factor, population and population density of each ward in the study area was collected from Ministry of Immigration and Population. Then, it was analyzed by using total number of shops in the market derived from Market Department of Sittway Town. Furthermore, customers from each market were interviewed about the current buying items and their preference in the purchasing of different items. Structure interviews were conducted to 529 customers from 11 markets. It is considered desirable to establish the true mean's limits with a probability of 95 percent and the standard error is 3.

As sellers factor, each market was interviewed about their purchasing linkages and customer linkages in spatial regions. Altogether, 543 sellers were interviewed to examine the supply factor. To examine the infrastructure aspect, number of bus lines and ship line, number of buses and ships and average number of passengers were collected from Sittway Town.

Geographical Factors

Physical Factors

Sittway Township is located between 20º 7' N and 20º 17' N latitudes and 92º 46' E and 92º 56' E longitudes. It has an area of 231.59 square kilometre or 57228 acres (89.42 square miles) in Figure 1and 2. It is bounded by Rathetaung and Ponnagyun townships on the north, Mrauk-U Township on the east, Pauktaw Township on the southeast and Bay of Bengal on the south and west. The study area consists of seven townships in the Rakhine State, which comprises 32 wards and 27 village tracts in Figure 3. It is mainly composed of alluvial plain. It is built up by Mayu, Kalandan and Lemyo rivers. This plain is well known Sittway Plain. The most prominent river is Kalandan, which is 482.80 kilometres (300 miles) and passes through southward of Sittway Town. It enters the Bay of Bengal in the east of Sittway Township. Other tributaries are Satyogya, Mingan, Kala, Kamaung and Htaung creeks. These creeks are tidal in action.

Figure 1: Location of Rakhine State within Myanmar
Source: Myanmar Survey Department

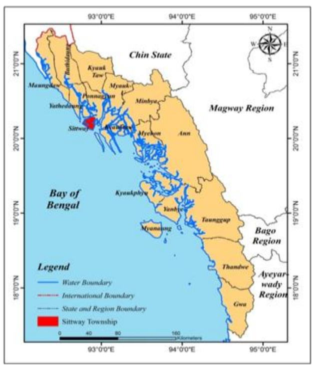

Figure 2: Location of Sittway Township within Rakhine State
Source: Myanmar Survey Department

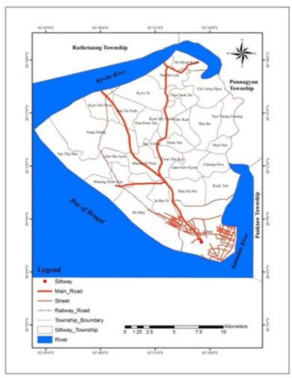

Figure 3: Location of Sittway Township
Source: Survey Department

Human Factors

Population is an important factor of market distribution in Sittway Township. The total population was 219421 persons in 2002-2003 and 147899 persons in 2013-2014. In the study area decrease of population is influenced on main factors as out migration to other areas.

The population of Sittway Township is unevenly distributed between 2002-03 and 2013-14. Myoma (Urban ward) is mostly accessible to all village tracts in Sittway Township and other townships. Bumay, Aungtine, Maungnipyin, Theinganat and Inbari were easily connected to Sittway Town and surrounding village tracts. The population distribution is highly concentrated in Sittway Township Figure 4. The most densely populated areas were Myoma Ward from 6884 persons to 5084 persons per square kilometre, Nar Yi Kan Village Tract; 1289 persons to 2303 persons per square kilometer, Pa Da Leik Village Tract; 299 persons to 599 persons per square kilometre and Kyay Taw Village Tract; 595 persons to 760 persons per square kilometre between 2002-03 and 2013-14. Moreover, the lowest densely populated area are Bumay Village Tract; 648 persons to 10 persons per square kilometre, Inbari Village Tract; 722 persons to 44 persons per square kilometre between 2002-03 and 2013-14. Because, Bumay and Inbari village tracts are near the Sittway Town and main factors as out migration to other areas. Figure 5 and 6 show the density of population in Sittway Township from 2002-03 to 2013-14. Khaung Doke Kar was lowest density with 210 persons per square kilometre in 2002-03 and 3 persons per square kilometre in 2013-14.

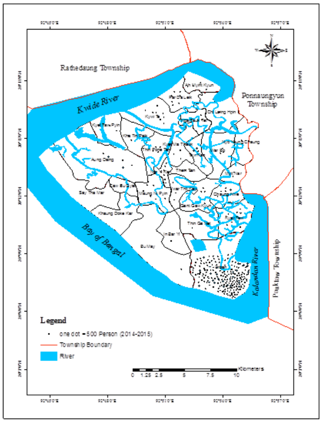

Figure 4: Population Distribution of Sittway Township (2013-14)

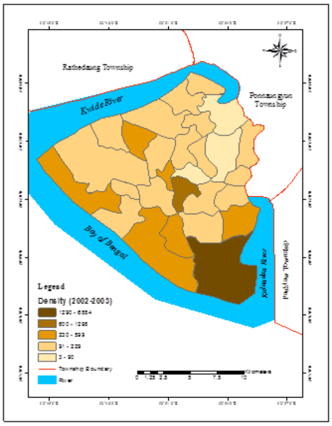

Figure 5: Population Density of Sittway Township (2002-03)

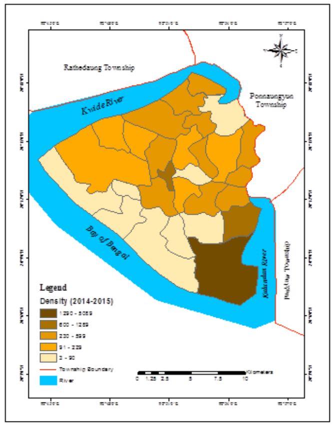

Figure 6: Population Density of Sittway Township (2013-14)

Findings and Discussion

Market Types

The study area has two types of markets such as permanent and street vendor markets. Permanent markets were established based on population pressure and good transportation network. This type of market sells various kinds of thing in the permanent market on permanent shops. When the number of sellers increase second type of market appear on road side which are defined as street vendor market. As a distinguished point many of street vendor markets are doing business only in the mornings, evenings while others in both morning and evening. Sittway Township has 2 permanent markets: Myoma Market (New Municipal Market) located on the Market Street and Mayyu Market located on the Mayyu Street and 18 street vendor markets their locations (Figure 6) are as follow: Both morning and evening street vendor markets are:

(1) Navy Market on the Satmue Lan Haung Street,

(2) Thatkapyin Market in the Thatkapyin Village,

(3) Thandawli Market in the Thandawli Village,

(4) Taychaung Market in the Taychaung Village,

(5) Paryame Market in the Padalake Village,

(6) Chatawpyar Market on the Shwepyazay Street,

(7) Amyinkyun Market in the Amyinkyun Village.

(8) Darpine Market in the Darpine Village,

(9) Panlinpyin Market in the Panlinpyin Village,

(10) Byinphuywa Market in the Byinphuywa Village,

(11) Minzan Market on the Ywagyi Street

(12) Konetan Market on the Konetan Street,

(13) Sanpya Market on the Hotel Sin Street,

(14) South Ywagyi Market on the Ngapain Street,

(15) North Ywagyi Market on the Waset Street,

(16) Makyeemyine Market on the Makyeemyine Street,

(17) Bumay Market in the Bumay Village,

(18) Mingan Market on the Mingan Awin Street.

Shop Types

Markets have different shops selling different items. For the analysis, items selling in the markets of Sittway Township are categorized as follows:

(1) Meat, Fishes, Prawns and Vegetables

(2) Grocery and Dry goods

(3) Clothes and Garments

(4) Medicines and Cosmetics

(5) Hardware and Electronics

(6) Others

Meat, fishes, prawns and vegetables are the items that customers need to buy on daily basis. It includes all types of meat, fishes, prawns, vegetables, fruits and flowers, the items that are perishable without refrigeration. Grocery goods and dry goods include milk, sugar, beverages like tea and coffee, rice, oil, salt, dried fish, dried prawn, paste fish, beans, etc. that are used in kitchen and could be kept under natural environment for some period without refrigeration. Clothes and garments refer to all items of clothes, bags, and fabrics. Those items are usually purchased only two or three times a year for average income person. Medicines and cosmetics sometime are needed occasionally. Cosmetic is also referred to as luxury good. It is not a basic requirement for low income people. Hardware and electronic goods are sometimes referred to as construction goods that are needed in construction and renovation of houses.

Variations in Number of Shops among the Permanent Markets

Total number of shops varies among the permanent markets in Sittway Township. Myoma Market (New Municipal) has the largest number of shops and Mayyu Market has the smallest number of shops. Myoma Market has 738 shops while Mayyu Market has only 150 shops. The variation in number of shop depends on the environmental condition of the market and the availability of items. A market is also highly related to accessibility. When a market has good accessibility, people from a long distance will come to the market.

Variations in Shop Types within the Permanent Markets

Types of shops also varies in each market. Table 1 shows shop types of permanent markets. Myoma (New Municipal) Market comprises 118 meat, fishes, prawns and vegetables shops, 395 grocery shops, 146 cloth and garment shops, 73 medicines and cosmetics shops, 24 hardware and electronic goods shops and 94 others shops. Mayyu Market includes 18 meats, fishes, prawns and vegetables shops, 5 grocery shops, 126 cloth and garment shops, and 1 other shop. In general, Myoma (New Municipal) market has all types of shop while Mayyu Market is occupied by three types only. Since shop types are categorized based on the customer's requirement (buying) interval, which is functional variation and level of market in the study area. Myoma (New Municipal) Market has the highest level function and support all kind of items that customer need. On the other hand, Mayyu Market serves only clothe and garment, meat, fishes, prawn and vegetables, grocery and dry goods. Thus, it is a localized market and customers who need to buy cosmetic and gold, etc. have to use higher level market like Myoma (New Municipal) Market.

Table 1: Shop Types at Permanent Markets (January, 2013)

No	Market	Meat, Fish, Prawn and Veges	Groc. and Dry goods	Clo. and Gar.	Med. and Cos.	Hardware and Elect.	Others	Total
1	Myoma	118	395	146	73	24	94	738
2	Mayyu	18	5	126	-	-	1	150

Source: Market Department, Sittway City Development Committee.

Variations in Total Number of Shops among the Street Vendors

These markets also vary in terms of the number of shops. Paryame Market has the largest number of shops and South Ywagyi Market has the smallest number. Although all these street vendors were developed based on the local demand of customer, their size varies, based on market area. Markets with wider market areas have larger number of shops in Table 2.

Variations in Shop Types within the Street Vendors

Navy Market comprises 32 meat, fish, prawn and vegetable shops, 23 grocery and dry shops, 9 cloth and garment shops, 3 medicine and cosmetic shops and 6 others. Thatkapyin Market comprises 28 meat, fish, prawn and vegetable shops, 19 grocery and dry shops, 13 clothe and garment shops, 5 medicine and cosmetic shops, 4 hardware and electronic goods shops and 3 others.

Taychaung Market has 36 meat, fish, prawn and vegetable shops, 18 grocery and dry shops, 8 clothe and garment shops, 3 medicine and cosmetic shops and 4 hardware and electronic goods shops. Paryame Market consists 33 meat, fish, prawn and vegetable shops, 32 grocery and dry shops, 24 clothe and garment shops, 13 medicine and cosmetic shops and 1 hardware and electronic goods shops. Chatawpyar Market includes 15 meat, fish, prawn and vegetable shops, 6 grocery and dry shops and 2 clothe and garment shops. Amyinkyun Market comprises 16 meat, fish, prawn and vegetable shops, 6 grocery and dry shops, 5 clothe and garment shops and 2 medicine and cosmetic shops.

Darpine Market contains 28 meat, fish, prawn and vegetable shops, 14 grocery and dry shops, 5 clothe and garment shops, 3 medicine and cosmetic shops, 3 hardware and electronic goods shops and 2 others. Panlinpyin Market has 27 meat, fish, prawn and vegetable shops, 17 grocery and dry shops, 7 clothe and garment shops, 5 medicine and cosmetic shops and 2 hardware and electronic goods shops. Byinphuywa Market consists 13 meat, fish, prawn and vegetable shops, 9 grocery and dry shops, 2 clothe and garment shops and 1 medicine and cosmetic shop. Minzan Market comprises 18 meat, fish, prawn and vegetable shops, 3 grocery and dry shops and 2 clothe and garment shops. Konetan Market includes 18 meat, fish, prawn and vegetable shops, 2 grocery and dry shops and 3 clothe and garment shops.

Table 2: Variations in Total Number of Shop among Street Vendors

No	Markets	Meat, Fish, Prawn and Vegetable (not room)	Grocery and Dry goods	Clothes and Garments	Medicines and Cosmetics	Hardware and Electronics	Others	shop room
1	Navy	32	23	9	3	-	6	41
2	Thatkapyin	28	19	13	5	4	3	44
3	Thandawli	17	18	12	7	2	-	39
4	Taychaung	36	18	8	3	4	-	33
5	Paryame	33	32	24	13	1	17	87
6	Chatawpyar	15	6	2	-	-	-	8
7	Amyinkhun	16	6	5	2	-	-	13
8	Darpine	28	14	5	3	3	2	27
9	Panlinpyin	27	17	7	5	2	-	31
10	Byinphuywa	13	9	2	1	-	-	12
11	Minzan	18	3	2	-	-	-	5
12	Konetan	18	2	3	-	-	-	5
13	Sanpya	21	6	-	-	1	-	7
14	South Ywagyi	22	-	3	-	-	-	3
15	North Ywagyi	25	6	3	-	-	-	9
16	Makyeemyine	37	13	1	3	-	-	17
17	Bumay	38	16	9	4	3	3	35
18	Mingan	25	10	1	-	-	1	12

Source: Market Department, Sittway City Development Committee

Sanpya Market has 21 meat, fish, prawn and vegetable shops, 6 grocery and dry shops and 1hardware and electronic goods shop. Thandawli Market includes 17 meat, fish, prawn and vegetable shops, 18 grocery and dry shops 12 clothe and garment shops, 7 medicine and cosmetic shops and 2 hardware and electronic goods shops. South Ywagyi Market contains 22 meat, fish, prawn and vegetable shops and 3 clothe and garment shops. North Ywagyi Market consists 25 meat, fish, prawn and vegetable shops, 6 grocery and dry shops and 3 clothe and garment shops. Makyeemyine Market comprises 37 meat, fish, prawn and vegetable shops, 13 grocery and dry shops, 1 clothe and garment shop and 3 medicine and cosmetic shops. Bumay Market has 38 meat, fish, prawn and vegetable shops, 16 grocery and dry shops, 9 clothe and garment shops, 4 medicine and cosmetic shops, 3 hardware and electronic goods shops and 3 others. Mingan Market contains 25 meats, fish, prawn and vegetable shops, 10 grocery and dry shops and 1 clothe and garment shop. There are 18 street vendors in the study area. Although there are variations in the total number of shops in each street vendor market, most of them are selling meat, fish, prawn and vegetables, grocery and dry goods and clothe and garment in Table 2.2. It reveals the fact that street vendors have developed based on the local customers' daily needs.

Spatial Distribution and Functional Variations of Markets in Sittway Township

There are 20 markets in Sittway Township. Of these, two are permanent markets and eighteen are street vendor markets. Myoma (New Municipal) Market is established early in Sittway Township. It was established in 1956. Remaining markets were opened after 1980. Between 1980 and 1990, 6 markets were established among the markets. After 1991, 13 markets were opened in the study area. Mayyu Market is largest market of the area and it has the largest area with 12261.88 square metre and Byinphuywa Market is the smallest market with 65.03 square metre.

The level of markets is based on the type of building and items sold in the market. In this categorization, Myoma Market sold all items and Mayyu Market sold 3 items these markets construct brick building. Therefore, these markets are known as high level markets. All street vendor markets sold basic items needed and are constructed with brick, timber, bamboo, dhani and iron sheet. Street vendor markets are both medium and small level (Table 3).

Distribution of Markets

Table 3 and Figure 6 show the spatial distribution and functional variations of markets with the number of shops and level of markets in the study area. High level markets are sometimes closely located to low level markets. This figure showed the location of markets spatially as well as functionally.

Table 3: Some Facts of Markets in Sittway Township

No.	Market Name	Area (Sq. Metre)	Year of Establishment	Level of Market	Number of Shops	Building Type
1	Myoma	10902.15	1956	Large	738	Brick Building & 1 storey
2	Mayyu	12261.88	1992	Large	150	Brick Building & 1 storey
3	Navy	929.03	1980	Medium	41	Timber & Iron Sheet
4	Thatkapyin	116.13	1985	Medium	44	Timber, Bamboo & Iron Sheet
5	Thandawli	4532.44	1987	Medium	39	Timber, Bamboo & Iron Sheet
6	Taychaung	83.61	1989	Small	33	Timber & Iron Sheet
7	Paryame	371.61	1990	Medium	87	Timber & Iron Sheet
8	Chatawpyar	74.32	1990	Small	8	Brick Building, Timber & 1 storey
9	Amyinkhun	4046.83	1992	Small	13	Timber, Bamboo & Iron Sheet
10	Darpine	111.48	1993	Small	27	Timber, Bamboo & Iron Sheet
11	Panlinpyin	129.32	1993	Small	31	Timber, Bamboo & Iron Sheet
12	Byinphuywa	65.03	1994	Small	12	Bamboo, Dhani & Iron Sheet
13	Minzan	139.35	1998	Small	5	Bamboo, Dhani
14	Konetan	750.00	1998	Small	5	Timber & Iron Sheet
15	Sanpya	74.32	1998	Small	7	Timber, Bamboo & Iron Sheet
16	South Ywagyi	4046.83	1999	Small	3	Bamboo, Dhani
17	North Ywagyi	236.90	1999	Small	9	Timber, Bamboo & Iron Sheet
18	Makyeemyine	139.35	2000	Small	17	Brick Building , Timber & 1 storey
19	Bumay	222.97	2000	Medium	35	Timber, Bamboo & Iron Sheet
20	Mingan	492.39	2001	Small	12	Timber & Iron Sheet

Source: Market Department, Sittway City Development Committee.

Variations of Functions among the Markets

Figure 7 expresses the spatial distribution and functional varation of markets. From this figure, it is clearly understandable that large and medium markets of Myoma, Mayyu, Navy, Thandawli, Thatkapyin, Bumay and Paryame are located at terminal point of north, south and west to cover the whole township. These seven large and medium markets have all functions (items sold) to support the residents of the township. Remaining small markets are located within the above seven large and medium markets. But these small markets could not supply all items that are available in large markets. These small markets sell only meat, vegetable and grocery which are basic need for daily life. Location of this small market also takes the point at the nearest distance compared to other luxury goods. In general, this figure consists the level and functional variation in location of market in Sittway Township.

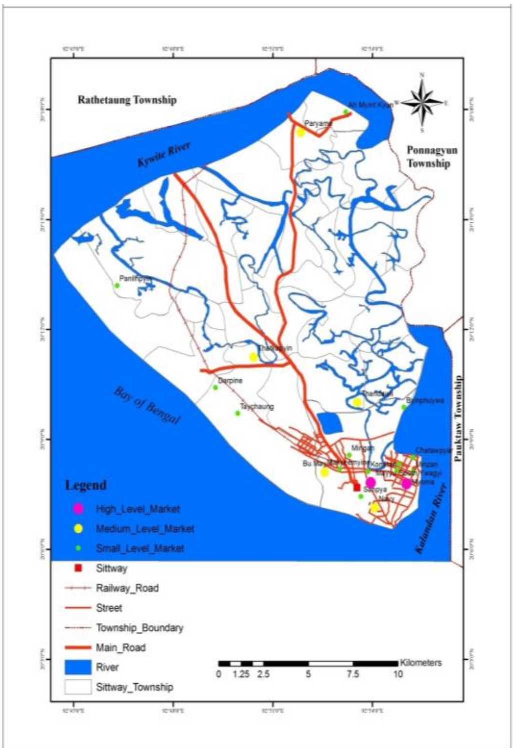

Figure 6: Distribution of Markets in Sittway Township
Source: Based on Table 3

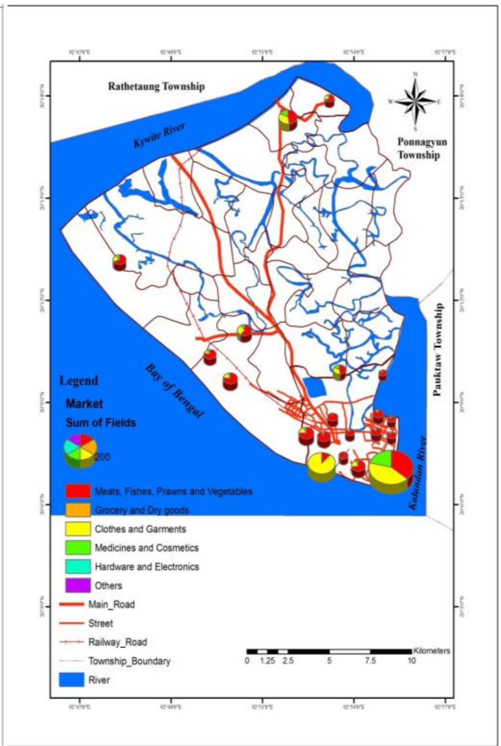

Figure 7: Variations in Markets by type of Commodities Sold
Source: Based on Table 2

Controlling Factors on the Distribution Pattern of Markets

Commodities can be classified into groups based on frequency of buyers such as daily consumption goods, luxury goods and long-term consumption goods. Daily consumption goods refer to daily need, these markets should be located in a short distance. Large number of people has to commute to this kind of market daily. On the other hand, luxury goods and expensive goods are bought only once or twice a year. In this case, customers may take long distance to markets to buy such selective goods. Market growth and distribution is mainly considered by population and status of population as a main factor of demand and location of market. In previous part there are differences level of the market and their location. Thus, part examines the possible controlling factors of market location in study area. First, population factor was examined from the total population and population density point of view in the study area. Then, customer preference and seller type were analyzed by using data derived from field and questionnaires survey. Finally, accessibility of each market was analyzed as an infrastructure for location of market.

Population as a Factor of Demand and Markets Location

Figure 8 shows the population density by ward and village tracts and market level in the study area. Location and size of markets are also presented on the same figure. From this figure, distributions of market are related to the population of wards and village tracts where market is located.

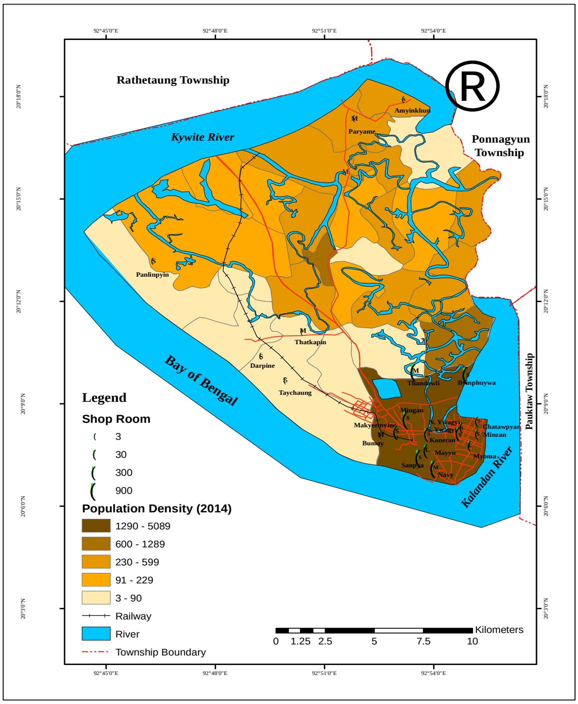

Figure 8: Numbers of Shops, Total Population and Population Density Used in Correlation Analysis

Source: Market data are derived from Market Department, Sittway City and population data was obtained from Ministry of Immigration and Population in Sittway City

To analyse in more detail Pearson's Product Moment Correlation Coefficient Analysis was conducted. Correlation coefficient value (r^2) between the total number of shop and population of ward and village tracts where market located is (0.03). It presents that population and number of shops are not related. Population density was used as second variable in correlation analysis. The resulted correlation coefficient between number of shops in market and population density of the ward is (0.04). It shows that there is fair correlation between these two variables. Thus, population density is not highly contributed to the location of markets. In this correlation, the population variables are not strongly determined by location of market.

Customers Aspect on Markets Location

Questionnaires surveys were conducted to customer preference on various markets. 523 customers were interviewed from 11 markets because remaining 9 markets were in limited situation for field survey. Firstly, customers were asked about the items that they were going to buy in the market. 272 out of 523 respondents (52 percent) they are buying meat and vegetables, 104 persons (20 percent) of customer are buying grocery and dry goods, 76 persons (15 percent) are buying the cloth and garment, 34 persons (7 percent) are buying cosmetic and medicine, 30 persons (6 percent) are buying electronic and hardware goods and 7 person (1 percent) buying food and drink in Table 4. It is clear that classification of goods used in the previous part has consistency with actual buying pattern of customers. One different point is gold and jewellery that was not counted in the previous classification because gold shops are lacking in the market except Makyimying Market.

Generally, customers have similar behaviours in Myanmar because the use of refrigerator is not expanded in Myanmar. The style of customers purchase meat, fish, prawn and vegetables for daily consumption, grocery and dry goods for median-term consumption, clothe and garment for long-term consumption, cosmetic and medicine for occasional consumption, gold and jewellery for very infrequent consumption. Based on purchasing behaviours depend on various patterns customer commuting markets are also varied. They use small market and street vendor near their home for meat, fish, prawn, fruit and vegetables. Most of the customers buy cloth and garment from the Myoma and Mayyu markets (large market) to sell back both township and other townships. They use medium size markets to buy cloth and garment. For luxury or cosmetic and medicine customer mostly use roadside store that are usually located near large junctions. For gold and jewellery purchase customers use outside the large market such as Kyaybingyi and Odan wards.

Table 4: Purchase Items of Customers in Shopping

Purchase Items	Customers	Percent
Meat and Vegetable	272	52
Grocery and Dry Goods	104	20
Clothe and Garment	76	15
Cosmetic and Medicine	34	7
Electronic and Hardware Goods	30	6
Food and Drink	7	1
Total	**523**	**0**

Source: Based on Questionnaire Survey.

Distance Decay

Distance affects transportation cost, time span and energy to use. The larger the distance, the longer the time will take and higher the transportation cost. Other things being equal, the customers will buy goods from the nearest market. In Table 5, most of the customers buy the daily needs from the nearest market from their resident or village tract and some their customers buy from far market for selling.

Table 5: Means of Customers Commute to Market

Type of Commute Pattern	Respondents	Percent
Foot	217	41.2
Cycle	108	20.5
Trishaw	50	9.5
Bicycle	46	8.7
Boat	45	8.5
Car	36	6.8
Cycle Taxi	23	4.4
Tawlargyi	2	0.4
Total	**527**	**100**

Source: Based on Structured interview, January, 2014 (n= 523)

According to questionnaires, 77 percent of the customers spend less than 15 minutes and remaining spend between 20 minutes and 7 hours. Table 6 reveals in each market that the number of customers decrease with increasing distance within the customer's resident and market. Generally the market with smaller number of shops like South Ywagyi Market, attract customer living only within distance while more shops, for example Myoma and Mayyu markets attract customer both within and longer distance.

Table 6: Location of Customers with Respect to Market

No.	Markets	Near	Far	Total
1	Myoma	150	71	221
2	Mayyu	27	22	49
3	Navy	34	6	40
4	Chatawpyar	23	2	25
5	Minzan	23	0	23
6	Konetan	22	2	24
7	Sanpya	22	2	24
8	South Ywagyi	21	2	23
9	North Ywagyi	26	4	30
10	Makyeemyine	29	6	35
11	Mingan	25	5	30

Source: Based on Structured interview, January, 2014 (n= 523)

Analysis from the Point of View of Sellers

Questionnaires surveys were conducted to sellers from 11markets because remaining markets were in limited situation. Altogether data from 540 sellers were collected during the survey. In the study area, 20 markets were classified into 3 groups: large markets, medium markets, and small markets on their functional differences. Large markets include Myoma and Mayyu markets. Medium markets include Navy, Thandawli, Thatkapyin, Bumay and Paryame markets. Small markets are Taychaung, Chatawpyar, Amyinkhun, Darpine, Panlinpyin, Byinphuywa, Minzan, Konetan, Sanpya, South Ywagyi, North Ywagyi, Makyeemyine, and Mingan markets.

The study area reveals the difference in selling types by different markets. Large markets have all types of selling. About 6 percent are retail shops, 12.46 percent in wholesale and 85.47 percent both wholesale and retail. In case of medium size markets, 100 percent of retail shop without wholesale. In case of small markets 94.64 percent are retail shop. Therefore, large markets not only serve the local customers, but also distribute their good for the reseller of other markets in terms of wholesale.

Furthermore, sellers in the study area were asked about the source of their selling materials. Table 7 presents the sources of their selling items. Sellers from small markets bought their selling material from the large markets located within the Sittway Township.

On the other hand, sellers from large markets bought the goods from directly or through companies, Yangon, Mandalay, Buthidaung, Maungdaw and other markets. Sellers from medium size markets have bought their good from various markets directly or through companies, Myoma, Yangon and other markets. This point also supports the function variation of markets within the Sittway Township.

Table 7: Sources of Commodities Sold in Markets of Sittway Township

Levels of Markets	Direct or Company	Yangon	Mandalay	Myoma	Mayyu	Buthidaung	Maungdaw	Others	Total
Large markets	100 (18.3)	232 (42.6)	127 (23.3)	6 (1.1)	0 (0)	3 (0.6)	6 (1.1)	71 (13)	545 (100)
Medium markets	16 (18.1)	6 (10.5)	0 (0)	32 (56.1)	0 (0)	0 (0)	0 (0)	3 (5.3)	57 (100)
Small markets	90 (29.3)	4 (1.3)	2 (0.7)	176 (57.3)	5 (1.6)	0(0)	0 (0)	30 (9.8)	307 (100)
Total	87 (19.2)	66 (14.6)	42 (9.3)	121 (26.8)	25 (5.5)	111 (24.6)	3 (1)	3 (1)	452 (100)

Source: Questionnaire survey to seller in 11 markets.

Note: Large markets include Myoma, Mayyu markets; Medium markets referred to Navy Market; Small markets are Taychaung, Chatawpyar, Amyinkyun, Darpine, Panlinpyin, Byinphuywa, Minzan, Konetan, Sanpya, South Ywagyi, North Ywagyi, Makyeemyine, and Mingan markets.

Finally, sellers are asked about the estimated location of customer buying in their shops. In small market level, customers come about 45 percent from the same ward where market is located and other ward. About 4.34 percent customers come from within township.

In case of medium market, about 50 percent come from the same ward and within ward of customers come from the study area. Large markets have their customer not only within the ward but from the Sittway Township and other townships related to the study area.

Transportation Infrastructure as a Location Factor of Markets

As observed in chapter, population of each ward alone could not well explain the location of market. It is because, majority of the customers serving by each market are not confined to the ward located by respective market.

Thus, it is necessary to consider the transportation infrastructure of each market. All markets have passed by road and street. Thus, location of Myoma market is originally both waterway and road transport. At present, Myoma Market passes through 2 bus lines with 31 buses and running 2 trips in daily. Furthermore, Myoma Market passes through 5 waterways with 8 boats and 9 private ships (Hi-fine) and running 1 trip in a day. To understand all above point, the number of bus line passing each market of Sittway Township, total number of trip by all passenger vehicles, and total number of passenger passing each market was calculated.

Then, total number of passenger for each bus line was summed up to get the total number of passenger passing each market. Table 8 shows the relationship between markets and number of bus line, and total passenger passing each market. Transportation infrastructure is very important for the location of markets in Sittway Township.

The number of passenger used in this analysis was as follows:

Cycle Taxi	- 1 passengers
Cycle Taxi (carrier)	- 15 passengers
Buses (Dyna)	- 30 passengers
Trishaw	- 2 passengers
Boat	- 500 Passengers
Private ship (Hi-fine)	- 200 Passengers

In case of Myoma Market, 2 bus lines and 2 water ways that connect Ponnagyun, Mrauk U, Kyauktaw, Pauktaw, Minbya, Maypone , Rathetaung, Buthitaung, Kyaukphyu and Taungkup townships and other townships. Thus, this market is not only serve the local people living around the market but also for people living in the Sittway Township and other more distance townships.

Table 8: Relationship between Markets and Transport Facility

Markets Name	Circle Taxi	Circle Taxi (carrier)	Trishaw	Bus	Boat	Private ship (Hi-fine)	1 Trip Passengers	Total Passengers
Myoma	38	50	50	26	8	9	7460	14920
Mayyu	38	50	7	26	-	-	1582	3164
Navy	-	-	-	-	-	-	-	-
Thatkapyin	6	7	0	5	-	-	261	1044
Thandawli	-	-	-	-	-	-	-	-
Taychaung	6	7	0	5	-	-	261	1044
Paryame	38	50	7	26	-	-	1582	6328
Chatawpyar	-	-	-	-	-	-	-	-
Amyinkhun	38	50	7	26	-	-	1582	6328
Darpine	10	15	0	12	-	-	595	2380
Panlinpyin	10	15	0	12	-	-	595	2380
Byinphuywa	38	50	7	26	-	-	1582	6328
Minzan	-	-	-	-	-	-	-	-
Konetan	-	-	-	-	-	-	-	-
Sanpya	-	-	-	-	-	-	-	-
South Ywagyi	-	-	-	-	-	-	-	-
North Ywagyi	-	-	-	-	-	-	-	-
Makyeemyine	-	-	-	-	-	-	-	-
Bumay	6	7	-	5	-	-	255	1020
Mingan	4	8	-	7	-	-	330	1320

Source: Field Survey and Office Data (Sittway City) (January, 2014).

Analysis on the Spatial Distribution of the Market

From the geographical point of view, the shops and markets are neither clustered nor uniformly distributed. In order to know the spatial distribution of markets, “Nearest Neighbours Analysis” is used. The calculated value by the formular concerned is expected mean distance 0.02, Nearest Neighbour Ratio 0.89, Z score - 0.98 and probability value is 0.32. Figure 9 shows that the distribution of 20 markets in the study area is random, rather than cluster or uniformly distributed. In this analysis the distribution pattern of Sittway Township is shown by using data obtained from market department, Sittway Town Development Committee, the controlling factors of market location is found out by using data collected from questionnaire surveys to sellers, structured interviews to customers.

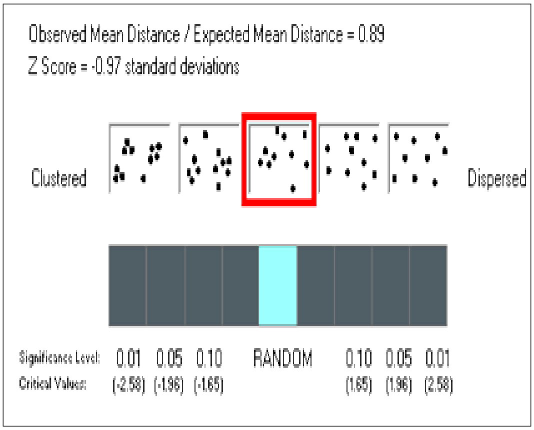

Figure 9: The Result of the Nearest Neighbour Analysis of the Markets Distribution in Sittway Township

Source: Market data are derived from Market Department, Sittway Town

Conclusion

Sittway Township consists of seven townships in the Rakhine State, which comprises 32 wards and 27 village tracts. It is mainly composed of alluvial plain. It is built up by Mayu, Kalandan and Lemyo rivers. This plain is well known Sittway Plain.

Sittway Township has 2 permanent markets and 18 street vendor markets. Type of shops also varies in each market. The level of markets is based on the type of building and items sold in the market. In this categorization, Myoma (New Municipal) Market sold all items and Mayyu Market sold only 3 items, these markets are brick buildings. Therefore, these markets are known as high level markets. All street vendor markets sold basic items needed and are constructed with brick, timber, bamboo, dhani and iron sheets. High level markets are sometimes closely located to low level markets.

Type of shops also varies in each market. Table 1 shows shop types of permanent markets. Myoma (New Municipal) Market comprises 118 meat, fishes, prawns and vegetables shops, 395 grocery and dry goods shops, 146 clothes and garment shops, 73 medicines and cosmetics shops, 24 hardware and electronic goods shops and 94 others shops. Mayyu Market includes 18 meat, fishes, prawns and vegetables shops, 5 grocery and dry goods shops, 126 clothes and garment shops, and 1 other shop.

In general, Myoma (New Municipal) market has all types of shop while Mayyu Market is occupied three types only. 18 street vendor markets also vary in terms of the number of shops. Paryame Market has the largest number of shops and South Ywagyi Market has the smallest number. Markets with wider market areas have larger number of shops in Table 2. By using ArcGIS 9.3 software, above data were depicted as distribution figure for visual and preliminary analysis.

Therefore, **Hypothesis 1 "**Spatial distribution of market is variable in size and function within the study area" is accepted.

Second research hypothesis is related to the controlling factors of market distribution variation. In order words, it is concerned with location factors of markets in the study area. There are four major controlling factors of markets location: customers, sellers, infrastructure (accessibility to market) and government policy.

Markets are systematically (level and function) distributed in Sittway Township. Some markets serve the residential wards, while others serve the whole township of even more wider region, including other townships near the Sittway Township. In the study area, 20 markets were classified into 3 groups: large markets, medium markets, and small markets on type of building and items sold in the market. Large markets include Myoma and Mayyu markets. Medium markets include Navy, Thandawli, Thatkapyin, Bumay and Paryame markets. Small markets are Taychaung, Chatawpyar, Amyinkhun, Darpine, Panlinpyin, Byinphuywa, Minzan, Konetan, Sanpya, South Ywagyi, North Ywagyi, Makyeemyine, and Mingan markets.

Above distribution patterns cannot explain the population served, but customer's preference based on buying items. Questionnaires surveys were conducted to customer preference in various markets. 523 customers were interviewed from 11 markets. Firstly, customers were asked about the items that they were going to buy. 272 out of 523 respondents (52 percent) answered that they are buying meat and vegetables, 104 persons (20 percent) of customer are buying grocery and dry goods, 76 persons (15 percent) are buying the clothe and garment, 34 persons (7 percent) are buying cosmetic and medicine, 30 persons (6 percent) are buying electronic and hardware goods and 7 person (1 percent) buying food and drink in Table 4.

Sellers also vary in each market, in terms of type of sale (retail and wholesale), selling items and sources of commodities purchased. Questionnaires surveys were conducted to sellers from 11markets because remaining markets were in limited situation. Altogether data from 540 sellers were collected during the survey. Table 7 presents the sources of their selling items. Seller from small markets bought their selling material from the large markets located within the Sittway Township. On the other hand, sellers from large markets bought the goods from directly or through companies, Yangon, Mandalay, Buthidaung, Maungdaw and other markets.

Transportation infrastructure is needed for each market, because all markets are connected by roads and streets. Thus, location of Myoma market is originally both waterway and road transport. At present, Myoma Market passes through 2 bus lines with 31 buses and running 2 trips daily. Furthermore, Myoma Market passes through 5 waterways with 8 boats and 9 private ships (Hi-fine) and running 1 trip per day. To understand all the above points, the number of bus lines passing each market of Sittway Township, total number of trip by all passenger vehicles, and total number of passenger passing each market was calculated (Table 8).

Location of 20 markets in Sittway Township is assessed by Nearest Neighbours Analysis method revealing randomly distributed and it can effectively explain by means of accessibility (Figure 9).

These are **Hypothesis 2 "**These variation are operated by demand, supply, infrastructure and government policy" is accepted.

Therefore, the growth of population, good accessibility and increase vehicles in Sittway Township may generate medium and low level markets to high level market. Furthermore, if deep sea port will be completed in the near future it can grow to large level market in the study area.

Acknowledgements

Special thanks are due to U Ko Ko Lwin, Head of Department of Geography, Sittway University, for his permission to do this research and support. Finally, all thanks those who have helped in the collection of data and information from different sources.

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EFFECT OF PADDY CULTIVATION ON ECONOMY OF NGAPUTAW TOWNSHIP, AYEYARWADY REGION

Tin Tin Khine *

Abstract

The paper tried to present paddy cultivation of Ngaputaw Township from the geographical point of view. Ngaputaw Township is one of the twenty six townships in Ayeyarwady Region and major economic activity of the area is paddy cultivation. In the area, the sown area of paddy increases yearly and paddy productivity differs from one variety to another. There are eight major paddy varieties in the area and price slightly differs one from another. The objectives of the paper are to analyze cultivated area and production of different paddy varieties in Ngaputaw Township, to examine the rent return of paddy cultivation caused by price fluctuation and to predict future prospect of the paddy cultivation in Ngaputaw Township. To present this paper, primary data will be mainly applied and it includes price, variety, inputs, etc. Primary data will be collected through interviews, questionnaire and focus group discussion with farmers, staff of agriculture department and authorities concerned. Secondary data such as climatic data, population, paddy cultivated area and productivity will be collected from departments concerned.

Keywords*:* paddy cultivation, varieties, economic return, price,

Introduction

Agriculture is still major economic activity in developing countries. Paddy is the most important food crop of Asian people. Cultivation of rice probably originated in the monsoon areas of South-East Asia.

Globally, paddy is a very important food crop. It is an ancient crop consumed as healthy and staple food by more than half of the world population (Shabu, Gyuse, Abawua, 2011). Paddy is consumed by over 4.8 billion people in 176 countries and is the most important food crop for over 2.89 billion people in Asia, over 40 million people in Africa and over 150.3 million people in America (Daramola, 2005).

Agriculture is the backbone of the Myanmar economy: the sector accounts for about 30% of GDP, over 50% of total employment and

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approximately 20% of exports. Cultivated land, covering 12.8 million hectares, has the potential to be increased by nearly 50%. As in neighbouring countries, smallholder paddy production dominates Myanmar's agricultural economy: paddy production accounts for roughly half of all cropped area (Agriculture in Myanmar, 2016).

Since 1970s, a substantial number of high yielding rice varieties (HYV) have been developed and released for rainfed lowland and irrigated ecologies. During the 1970s and early 1980s, the popular varieties were Shwe War Tun and Seintaly. Recently, Thi Htat Yin, Shwe Thwe Yin, and Sin Akari-2 (released after 1990) varieties are popular in rice-rice systems. More than 70 percent of lowland rice crops in 1994-95 were planted with new varieties (FAO, 2005). After cultivation new high varieties, productivity of paddy became higher and economic return of paddy cultivation gave higher income to the local people. But, income varies from one farmer to another due to different paddy productivities of new yields.

Ayeyarwady Region is known as rice granary and most of the agriculture land is occupied by paddy. But, many varieties are cultivated due to difference in soils, farmers' attitude and different productivity and price of paddy varieties. Although there are 37 varieties in Myanmar, eight paddy varieties: Palethwe, Sinthukha, Theehtupyin, Manawthukha, Pawsan, Meedone and Ngasein are cultivated in Ngaputaw Township. They give different yield per unit area and different economic return. To study different yield per unit area and different economic return of new paddy varieties from the geographical point of view, Ngaputaw Township was selected.

Study Area

Ngaputaw Township is one of the townships in Pathein District, Ayeyarwady Region and it lies on the south western-most part of the Region. It has an area of 3636.82 square kilometer and is the largest township among the 26 townships in Ayeyarwady Region. It is composed of 3 towns and 83 village tracts. Like other townships located in the deltaic area, it also has tropical monsoon climate that gives sufficient rainfall for monsoon paddy cultivation. 8 types of soils that are suitable for paddy cultivation are found in the study area.

Research Question

How do cultivated areas of paddy varieties differ from one to another?

Aim and objectives

The aim of the paper is to present the ways that support local farmers through paddy cultivation.

The objectives of the paper are:

- to analyze change in cultivated area in Ngaputaw Township
- to explore different production of different paddy varieties in Ngaputaw Township,
- to examine the rent return of paddy cultivation caused by price fluctuation and
- to predict future prospect of the paddy cultivation in Ngaputaw Township

Methodology

To collect primary data, 8 village tracts were chosen from 83 village tracts. Then, one rice farmer from each village tract was interviewed and 160 questionnaires were distributed to eight village tracts. Data collected from field observation, interviews and questionnaire survey such as size of rice farms, rice yield, income, and cost of farm inputs including fertilizer, pesticide/herbicide, seeds, labour and capital were applied. Secondary data were mainly used in presenting the paper and geographical methods are also used to illustrate changes in paddy cultivation. As analytical method, qualitative – quantitative mixed method was applied.

Geographical Background of Ngaputaw Township

Ngaputaw Township included in Pathein District, Ayeyarwady Region, lies on the south western-most part of the Region. It is situated between latitudes 15˚49'N and 16˚44'N and longitudes 94˚16'E and 94˚44'E. It has an area of 3636.82 square kilometer (1404.18 square miles). Ngaputaw Township is made up of 3 towns (7 wards) and 83 village tracts (420 villages). It is compact in shape.

As it is located on alluvial plain of the Ayeyarwady Delta, the area is suitable for agricultural activities. In the study area, although the western narrow coastal strip and area occupied by Rakhine Yoma and its Spurs are suitable for paddy cultivation, alluvial plain covering over half of total land area has an elevation of less than15.24m (50 feet) above mean sea level is suitable for paddy cultivation. The main drainage of Ngaputaw Township is the Ngawun River and other small Streams are Thandwe, Panmawadi, Hteik Thaung, Sinma, Thabyu, Shwe-O, Sinmon, Phoungdo, etc.

The annual mean temperature in Ngaputaw Township is 27˚C. The monthly maximum mean temperature is also highest in April with 36.9˚C and lowest in August with 30.5˚C. The monthly minimum temperature is lowest in January with 17.6˚C and highest in the May with 24.9˚C. Rainfall is received from May to October from the southwest monsoon and the mean annual rainfall is 3030.8mm (119.32 inches) and the rainy days were 131 days. The existing temperature and rainfall conditions support paddy cultivation.

Eight types of soils: Meadow Gley Soil, Meadow Swampy Soil, Meadow Swampy Meadow Soil, Dune forest and Beach Sand, Saline Mangrove Forest Soil, Red Brown Forest Soil, Yellow Brown Forest Soil and Saline Swampy Meadow Gley Soil are found and among them, meadow soil group is favourable for paddy cultivation in Ngaputaw Township.

The population of Ngaputaw Township in 2017 was 327 272 persons. It includes urban population 28,298 persons (9%) and rural population 298,974 persons (91%) in 2017.

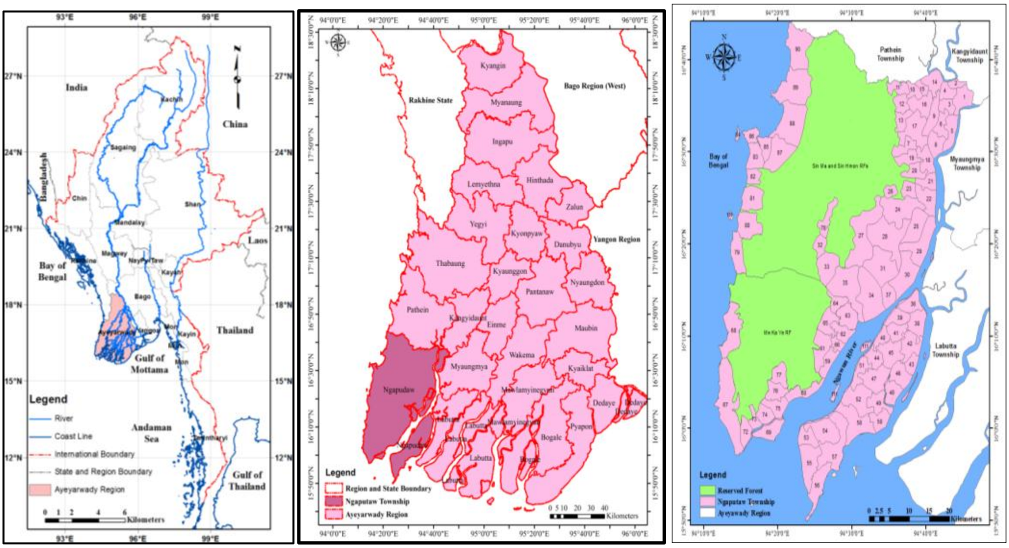

Figure 1: Location of Village Tracts, Ngaputaw Township, Ayeyawady Region

Source: Survey Department, Pathein

In 2017, the total population was 327,272 persons of 52 percent were engaged in agriculture, animal husbandry, and fishery. Agriculture land uses include le, kaing, garden and dhani land and le land ranked first with 84778 ha or 79 percent of the total agriculture land. Area of le land supports paddy cultivation, major crop of the study area.

Results and Findings

Paddy Cultivation of Ngaputaw Township

Like other townships in Ayeyarwady region, not only monsoon paddy but also summer paddy are cultivated in the area. Traditional rain fed monsoon paddy cultivation is practiced in the rainy season and summer paddy is cultivated as double crop on le land where irrigation water is available. Existing streams support irrigation water for summer paddy cultivation. Water is pumped from nearby streams but water requirement on sandy soils is high. In most areas, summer paddy is not cultivated due to high cost caused by high diesel use for irrigation.

Table 1: Change in Paddy Cultivated area in Ngaputaw Township

Year	Paddy Cultivated area (ha)	Year	Paddy Cultivated area (ha)
2007-2008	75642.3	2013-2014	75671.8
2008-2009	75641.0	2014-2015	79511.1
2009-2010	75641.0	2015-2016	82195.1
2010-2011	75641.0	2016-2017	82225.8
2011-2012	75671.8	2017-2018	84236.5
2012-2013	75671.8		

Source: Agriculture and Land management Statistics, Ngaputaw Township, 2017

Monsoon paddy and summer paddy cultivation

Monsoon paddy cultivated area was 204038 ha and summer paddy cultivated area 4109 ha in 2017. Most farmers whose paddy field located on the soils containing high sand content do not cultivate summer paddy due to high diesel cost. Therefore, in the area, monsoon paddy cultivated area is much higher than that of summer paddy.

Table 2: Monsoon and Summer Paddy Cultivation in Ngaputaw Township

Items	Cultivated area (ha)	Matured area (ha)	Yield per ha (ton)	Production (ton)
Monsoon Paddy	204038	204038	3.5	707093.689
Summer Paddy	4109	4109	4.3	17621.4465

Source: Agriculture and Land management Statistics, Ngaputaw Township, 2017

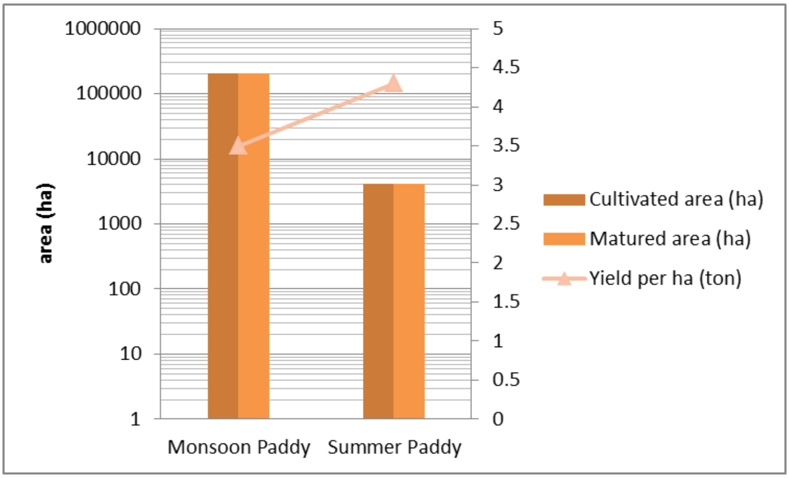

Figure 2: Monsoon and Summer Paddy Cultivation in Ngaputaw Township

Source: Table 2

Yield per unit area of monsoon paddy is lower than that of summer paddy in Ngaputaw Township. Monsoon paddy productivity is 3.5 ton per ha and that of summer paddy 4.3 ton per ha. High summer paddy productivity is due to higher input uses, less risk caused by untimely rain, etc.

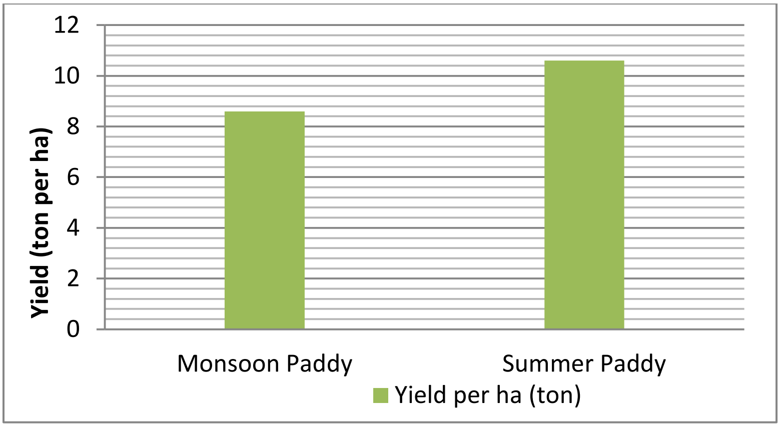

Figure 3: Productivity of Monsoon and Summer Paddy in Ngaputaw Township

Source: Table 2

Major paddy varieties and production

In the study area, major paddy varieties are Palethwe, Sinthukha, Sinthwelatt, Theehtupyin, Manawthukha, Pawsan, Meedone and Ngasein. Palethwe, Sinthukha, Theehtupyin and Manawthukha are high yield varieties. Manawthukha ranked first in paddy cultivated areas with 28495 ha of Ngaputaw Township.

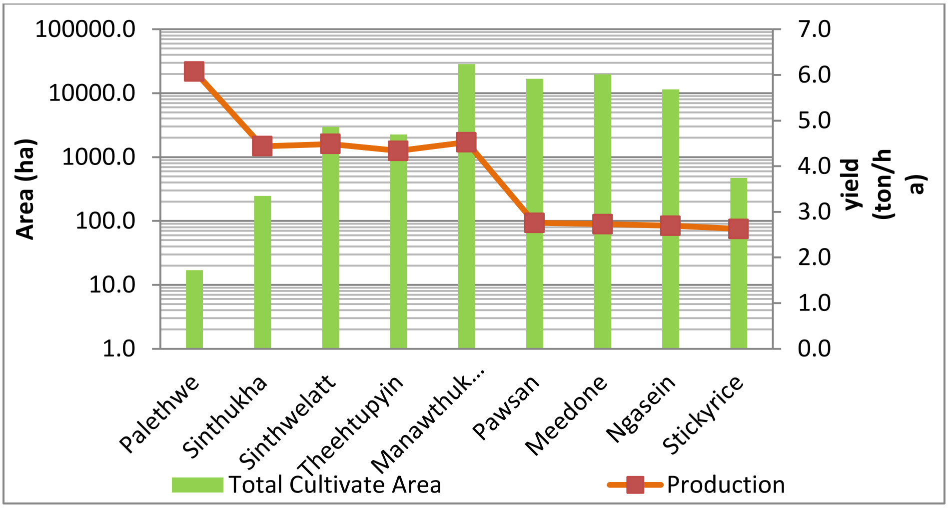

Figure 4: Cultivated area and yield per area of different paddy varieties in Ngaputaw Township

Source: Data of Agriculture and Land management Statistics, Ngaputaw Township, 2017

Local farmers mainly cultivate Manawthukha due to high yield. Local farmers think that existing soils are suitable for Manawthukha. Cultivated area of Meedone was 19707 ha and it ranked second because of high local demand. Palethwe ranked last in paddy cultivated area because of high cost of seed and high investment although productivity of it is high with 6.1 ton per ha. Productivity of Manawthukha ranks second with 4.5 ton per ha. Therefore, local farmers cultivated it due to suitability of soils, less investment and high productivity.

Price of Paddy (2009-2017)

In 2009, price of paddy was low with 220000 kyats per 100 baskets due to price instability caused by rice traders. Then, it gradually increased to 425000 kyats per 100 baskets in 2015. But, in 2016, paddy price distinctly decreased to 330000 kyats per 100 baskets due to price speculation created by rice entrepreneurs. *Prices* for monsoon *paddy rice* decline 10-per-cent compared with the price of 2015 (Eleven Myanmar, 2016).

Table 3: Price of Paddy (2009-2017)

	Paddy price (kyat per 100 baskets)	**Paddy price (kyat per ton)**
2009	220000	105465.0
2010	290000	139022.1
2011	310000	148609.8
2012	335000	160594.4
2013	380000	182166.8
2014	370000	177373.0
2015	425000	203739.2
2016	330000	158197.5
2017	540000	258868.6

Source: Interview with farmers, Ngaputaw Township

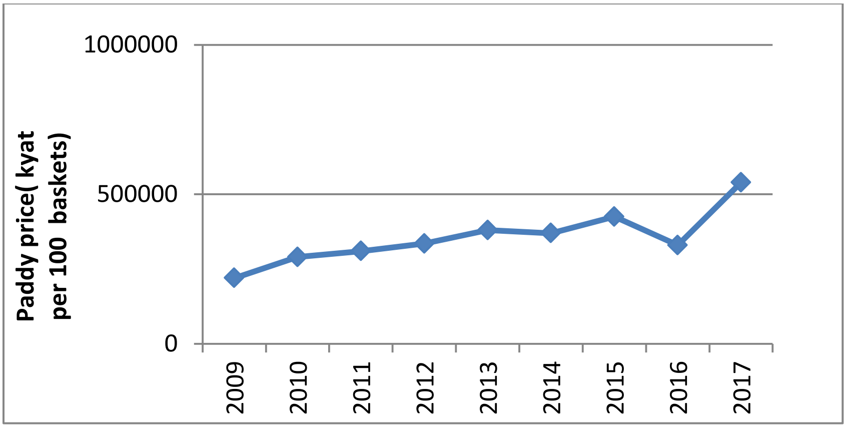

Figure 5: Price of Paddy (2009-2018)

Source: Table 3

Choice of paddy varieties in Ngaputaw Township

Choice of varieties mainly depends on physical factors

In the study area, three types of land: land with suitable water, sandy ridge land and salt intrusion area that are used for paddy cultivation. Area of land with suitable water was106217 ha in 2017 and it ranked first in areas of paddy cultivated land and paddy is cultivated not only in the rainy season but also in the dry period. Salt intruded paddy land was an area of 60354 ha and paddy is only cultivated in the rainy season. But, crop loss is found due to salt intrusion in the end of rainy season. Sandy ridge paddy land occupied area of 37466 ha and monsoon paddy is mainly cultivated because summer paddy is not grown in the area due to high diesel cost on sandy soils.

Palethwe, Sinthukha, Theehtupyin, Manawthukha varieties are suitable in land with suitable water areas and sandy ridge paddy field and short lived varieties such as Manawthukha, Pawsan, Meedone and Ngasein are suitable in salt intrusion areas.

Cost and Economic Return of Paddy Varieties

Cost and economic return are major factors affecting choice of varieties. Economic return of Palethwe is highest but most farmers do not grow Palethwe because of high cost. Palethwe needs many inputs such as chemical fertilizer although yield per unit area is highest among the varieties cultivated in Ngaputaw Township. Therefore, palethwe cultivated area ranks last in cultivated area of different varieties. In Meedone and Ngasein cultivation, low investment is needed but it gives low yield and low economic return. Because of low productivity and low return, there are small Meedone and Ngasein cultivated area in the study area. Theehtupyin and Manawthukha are mainly grown in the area due to less risk, low investment and high productivity.

Table 4: Cost and Economic Return of Paddy Varieties

	Cost (kyat per ha)	**Economic return (kyat per ha)**
Palethwe	790720	1359050
Sinthukha	691880	988400
Sinthwelatt	617750	1037820
Theehtupyin	617750	1037820
Manawthukha	543620	988400
Pawsan	469490	840140
Meedone	420070	741300
Ngasein	420070	741300

Source: field interviews (2017)

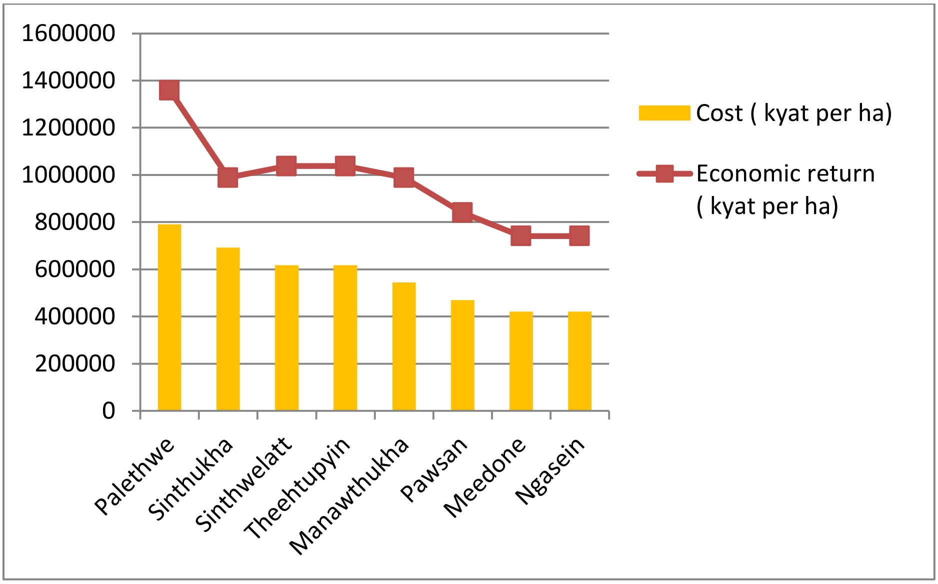

Figure 6: Cost and Economic Return of Paddy Varieties

Source: Table 4.

Problems on paddy cultivation in Ngaputaw Township

The major problems concerning paddy cultivation of Ngaputaw Township include seed availability, seed price, high input cost, etc.

Seed Availability

According to semi-structured interviews, more than 82 percent of the local farmers want to cultivate high yield varieties. The seed availability is one of the problems on paddy cultivation and it is difficult to get seeds from agriculture department. Therefore, they use the seeds from nearby farmers or relatives and it affects crop yield.

Seed Price

Seed price is one of the major problems in paddy cultivation. As the loan from agriculture bank is insufficient for paddy cultivation, farmers reduces the paddy cultivation cost. The high price of paddy seed is high and most farmers cannot afford to buy it. Therefore, they use local seeds and it is one of the factors causing low yield in paddy cultivation. According to semi-structured interviews, 63 percent of the local farmers said high price of seed is major factor affecting paddy production in the area.

High Input Cost

High input cost is also one of the major determinants on high yield varieties cultivation. High yield paddy varieties need sufficient fertilizer to get high yield. Most local farmers especially small holder farmers have low investment because of insufficient loan. On the other hand, price of input especially chemical fertilizer increases from 18000 ks per bag in 2015 and 22000 kyats per bags in 2018. According to semi-structured interviews, 91 percent of the local farmers said insufficient investment and high input cost are the problems in paddy cultivation.

Conclusion

Ngaputaw Township is located in deltaic area which is one of the best cultivated lands in Myanmar. Existing physical condition support the paddy cultivation. Topographically, it lies on low land suitable for paddy cultivation. The temperature and rainfall received are favourable for paddy cultivation. Most areas are covered with meadow soils that support paddy cultivation in the study area. Higher proportion of rural population support agriculture including paddy cultivation.

In the study area, monsoon paddy and summer paddy are cultivated and paddy cultivated area increased due to staple food and major economic activities. Monsoon paddy cultivated area is larger than that of summer paddy because of water availability and salt intrusion in the rainy season. Major varieties cultivated in the area are Palethwe, Sinthukha, Sinthwelatt, Theehtupyin, Manawthukha, Pawsan, Meedone and Ngasein of whcih Palethwe, Sinthukha, Sinthwelatt, Theehtupyin and Manawthukha are major high yield varieties. Manawthukha ranked first in paddy cultivated areas because farmers want to cultivate Manawthukha due to high yield. On the other hand, existing soils are suitable for Manawthukha.

Although productivity of Manawthukha ranks second with 4.5 ton per ha, it is mainly cultivated due to suitability of soils, less investment and high productivity. Price gradually increased in the study period and it is one of the factors supporting and choosing high yield varieties in the area. Paddy is cultivated on existing land with suitable water, sandy ridge land and salt intrusion area.

Palethwe gives high economic return but most farmers do not grow Palethwe because of high cost. Theehtupyin and Manawthukha are mainly grown in the area due to less risk, low investment and high productivity. Major problems concerning high yield varieties cultivation are seed availability, seed price, high input cost, etc.

In the future, the importance of paddy cultivation increases with increasing population and decreasing le land. Therefore, to get higher productivity, high yield varieties seeds should be provided to local farmers with reasonable price. It is important to get the help from the agriculture department of Ngaputaw Township for the purpose of getting technology for new varieties cultivation.

Further researches on input requirement and production, high yield seeds and their related problems such as pests, etc should be studied for the intention of getting better way to cultivate high yield paddy varieties to get higher economic return that supports local people economy.

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AN ENVIRONMENTAL APPROACH: IMPACT OF CHANNEL BANK CHANGE OF SITTAUNG RIVER IN KAWA TOWNSHIP

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Abstract

Severe bank erosion on the western part of Sittaung river mouth, especially the eastern part of Kawa and Thanatpin Townships of Bago Region has caused the economic and social problems since 2015. This paper is to identify the eroded eastern part of Kawa Township from 2015 until 2017. Moreover, it is to clarify the economic and social problems of the eroded eastern part of study area. Kawa is one of eight townships in Bago district that occupies the low-lying area of Sittaung and Bago rivers. The area of Kawa Township is about 1677 square kilometers (647.68 square miles) or 167667 hectares. The lost land area was during the seven years from 2010 to 2017 was about 163.16 square- kilometers (16317 hectares) which consist of waste land, le land and settlement area. The affected area due to bank collapse included 754 households and 3965 persons. Shifts in settlement area have resulted in the negative impacts on education, agriculture, animal husbandry and fishing industry and some households had to sell their cows, buffaloes and others to build their houses in the new places.

Keyword: bank erosion, collapse of land area, loss of Le land and shifts in settlement

Introduction

Bank erosion is the wearing away along banks of a stream or river. This is distinguished from erosion of the bed of water course, which is referred to as scour. After 2014, severe bank erosion on the western part of Sittaung river mouth originated, especially in the eastern part of Kawa and Thanatpin townships of Bago Region. The river bank erosion at the Sittaung river downstream area in Bago region can be found as mass failure. Therefore, in May, 2017, Kawa and Thanatpin Townships of Bago Region and Kyaikto, Bilin and Thaton townships within Mon State along the Sittaung river mouth were recognized as Ramsar Site of wetland area. Ramsar site is very

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important to erosion and flood controls and fisheries habitats. Aung Naing Gyi, War Taw, Kan Myint, Mamauk, Malauk and Sar Phyu Su villages in the eastern part of Kawa Township were identified as Ramsar site.

Research Problem

Severe bank erosion of Sittaung River mouth occurred in the eastern part of Kawa Township from 2014 until present time. Therefore, most of le land, pasture, settlement and other lands were destroyed due to severe mass erosion. Most of the villagers have to live in a hazardous area facing vulnerable loss of le land, shift to residential unit and other social problems.

Aim

This paper is to identify the eroded eastern part of Kawa Township from 2015 until 2017 and to reveal the economic and social problems of the eroded eastern part of the study area.

Research Methodology

Satellite images (Land sat TM 7 and TM 8) are used to study the increasing bank erosion rate in the study area during the period from 2010 to 2017. After studying the changes of Sittaung river mouth on satellite images, the ground check was done at fifteen points along the old Mamauk village. The secondary data including population data, rainfall data, the distribution of village tracts in township, bank eroded le and settlement areas and migrated population and villages are collected from Man Power Department and Department of Agriculture and Land Management Statistics in Kawa Town and relevant thesis. After collecting data, pilot field study to Mamauk village was conducted on 30 .5.2017. The fifty questionnaires were distributed and field observation was done to get necessary information in old and new Mamauk and Sar Phyu Su along the Sittaung river mouth on 22.6.2017. The questionnaires were distributed by using Ramdom Sampling Methods. Personal interviews with village leaders and head of the village concerned, Department of Agriculture and Land Management Statistics (Kawa Township) were conducted during the field study period. Qualitative and quantitative analysis method are used.

Background of Study Area

Kawa is one of eight townships in Bago district that occupies the low-lying area of Sittaung and Bago Rivers. It lies between 16˚ 46´23˝ and 17˚ 11´ 22˝ north latitudes and between 96˚ 22´48˝ and 97 ˚ 03´ 46˝ east longitudes. The boundary lines follows along Bago river in the west and Sittaung river in the east. The township is bordered by Thanatpin Township on the north, Khayan Township on the south, Kyaikhto Township on the east and Hlegu Township on the west. The area of Kawa Township is 1677 square kilometers (647.68 square miles) or 167667 hectares.

Relief and Drainage

Being the southern part of Sittaung river valley, the land is flat and low with no significant relief. The general elevation is about 3- 4.57 meters above sea level and the land gently slopes towards the south and the west. It is essentially built by the sediments deposited by the Sittaung and Bago rivers.

The Bago River serves as the western boundary of the township. Two main creeks namely Kawa and Paingkyon creeks flow into Bago River from the east.

The Sittaung River serves the western boundary of the township. Thandin and Takawkanat creeks flow from north to south in the middle of study area. Ngazin creek runs from east to west and enters the Thandin Creek. Waypadan Canal is the artificial canal, which can be used for local water transportation during the rainy season.

Climatic Condition of the Study Area

As Kawa has no weather station, the climatic data are taken from Bago station. The mean monthly temperature is highest in April with 31˚ C (75˚ F) and lowest in December 23.7˚ C (74.66˚F).

Table 1: The Temperature and Rainfall in Bago Station (from 2003 to 2017)

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average/ Total
Maximum Temperature (º C)	31.50	33.7	36.4	37.5	34.8	30.5	29.9	29.4	30.8	32.1	32.1	30.7	32.45
Mean Mini Temperature (º C)	16	16.9	20.5	23.5	24.3	23.5	23.6	23.5	23.7	23.1	20.9	16.7	21.35
Mean Annual Temperature (º C)	23.75	25.3	28.4	30.50	29.50	27	26.4	26.7	27.1	27.6	27.5	23.7	26.95
Rainfall (mm)	0.51	7.11	7.62	38.86	319.53	631.7	771.7	756.67	497.8	449.8	52.58	9.4	3543.08

Source: Meteorology Department, Bago

The maximum daytime temperature often reaches 40˚ C in the later part of hot dry season. The total annual rainfall from 2003 until 2013 was 3543 mm. The heavy rainfall received in June (631 mm), July (771mm) and August (756 mm) from 2003 to 2017. The severe erosion occurred in these month after 2015, especially in the high spring tide period.

Vegetation and Soil

The soil types in the western part of this township are classified as Meadow and meadow alluvial soils (*Gleysol and Fluvisol*), the Saline swampy and Meadow gley soils dominate in the eastern part of township occupying about 50 percent of township area. The mangrove forest soils are found on some area along the Sittaung river bank.

The vegetation types in most area of Kawa Township are wet tropical evergreen forest and tropical evergreen forest. But most of the forest area has been cleared for human uses. Teak plantation has been introduced on the Phalay Mountain.

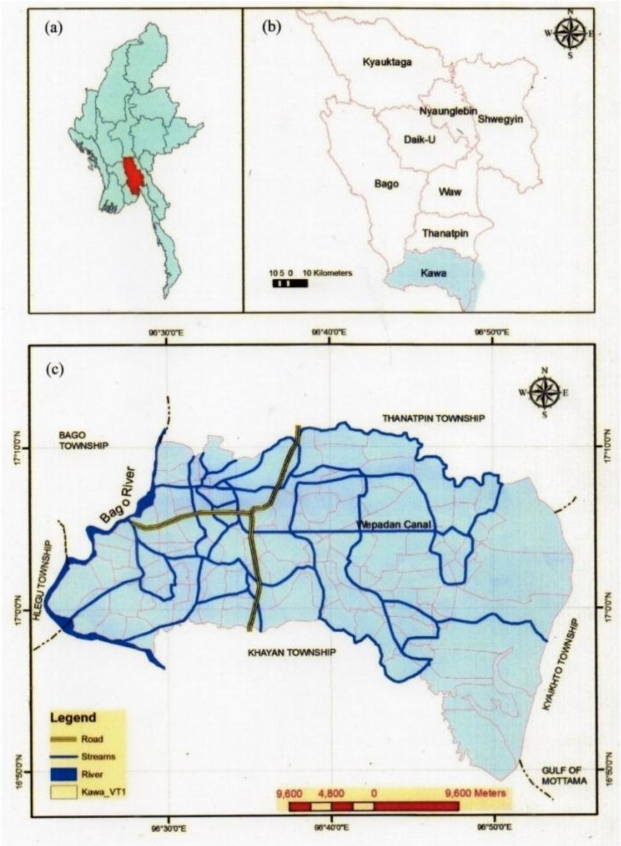

Figure 1: The Location Map of Kawa Township

Source: MIMU, Myanmar

Human Factors

Population, consumers as well as producers in primary economic activities especially paddy cultivation, is one of the most important social factors. According to 2014 census, the total population was over 197000 in Kawa Township. The number of households was over 46000 in 2014. . There were 4.2 persons living in each household and it indicated slightly less than the Union average. The proportion of productive working population between 15 and 64 years of age constituted 60.8 percent of total population. Compared to the union level, the percentage of working age-group (15-64) was smaller. The majority of the people in the township live in rural areas with only

8.8 percent living in urban area. The population density of the whole township was 118 persons per square kilometer. In Kawa township, 72.7 percent of employed persons were agricultural, forestry and fishery workers and highest in proportion. The second highest occupation was wholesale and retail trade, repair of motor vehicles and motorcycles representing 5.0 percent of the total workforce.

Findings and Discussion

Severe Erosion of Sittaung River Mouth in Kawa Township

The lost land area of Kawa amounted to about 62.15 square kilometers (6215,98 hectares) for five- year period from 2010 and 2015 .River bank sheet erosion seriously occurred and headed towards Kawa until present time, especially during the period of spring tide in one month.

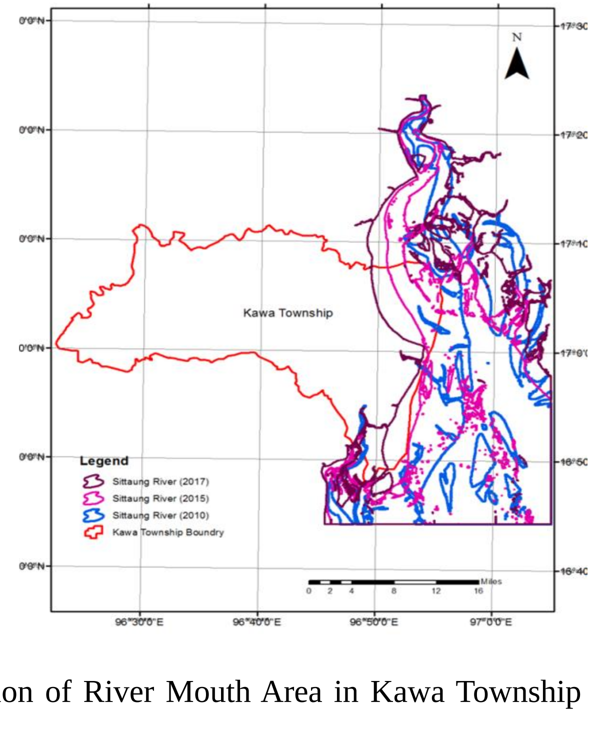

Figure 2: Extension of River Mouth Area in Kawa Township From 2010 to 2017

Source : Satellite Image (Landsat TM 7+ and Landsat 8)

The weather-beaten area by bank erosion seriously increased until present period. The eroded area was 101 square kilometers (14147 hectares) during three- year period from 2015 to 2017. Therefore, the total loss of land area during seven-year period from 2010 until 2017 was about 163.16 hectares (16317 hectares) which consisted of waste land, le land and settlement area.

Plate 1 and 2. Eroded Bank of Sittaung River Mouth in Mamauk Village, Kawa Township

Social Factors effected by the Collapse of Land

Relocation of Settlement Area

There were one monastery, one primary school and 235 households in **Shwe Tasok** village before the severe bank erosion in 2015. This village occupied about 29 hectares .This village faced with the Sittaung river bank erosion problem that eroded the settlement area during the rainy season in 2015. They had to shift to the western part of the village, where

Table 2: Shifted Households and populations at Kawa Township in 2017

Villages	No of Houses	No of households	No. of people	Monastery	Church	School
Shwe Tasok	235	239	1160	1		1
Sar Hpyu Su	89	89	415	1	1	1
Mamauk	426	426	2390	1		1
Total	**750**	**754**	**3965**	**3**	**1**	**3**

Source: Department of Agriculture and Land Management Statistics (Kawa Township) there was no erosion because it was one mile four furlong away from the Sittaung river bank. In 2017, 120 houses had been relocated in Aungmingalar village (Present Shwe Tasok Ywathit), 60 houses in Ngwe Taung Payarlay villlage and others in other areas because the resettlement area in 2016 disappeared by serious bank erosion.

Sar Hpyu Su village of Shwekan Village Tract had been relocated before 2016. One monastery, one church, one primary school and 89 homesteads were located in main Sar Hpyu Su village and 20 houses had been moved to surrounding area of Ta Dar U village. The effected settlement area in this village was 8.9 hectares.

Mamauk village had 426 homesteads, one monastery, one middle school and it was located along the western bank of Sittaung river mouth covering an area of 68 hectares. The le land and settlement area of Mamauk was damaged by the impact of severe river bank erosion after 2015. In 2017, 170 households of Mamauk village were moved to Mamauk Ywathit. The covering area of Mamauk Ywathit is 6.42 hectares which is located on le land along the Weapatan canal, in Ohnne Village Tract. In 2017, 150 households were still remaining in Mamauk village because these houses are located far from the river bank, but they are likely to be moved due to serious bank erosion. About 40 houses shifted to Aung Tha Byay Village, the southern part of main village. Only 15 households shifted to Bago city because they owned homes in Bago city before bank erosion and some rich persons bought houses in the city as they are under condition to move. New location of village is characterized by improper streets, unacceptable condition as settlement area, poor water quality and unavailability of sufficient portable water and so on. Low quality of lifestyle and very poor living conditions are not uncommon.

Le land and settlement area of **Bandar village** with about 300 houses with 950 populations was eroded in 2017. Loss of le land comprised about 2428 hectares, possessed 270 households. But these households moved to other location, along the Thanatpyin- Ohnne road within Ohnne Village tract, Kawa Township in March, 2018. It is called **Bandar Pin** village. Other 30 households remains at main Bandar village because their le land is good for cultivation. New area has good accessibility, fair earth roads, but in poor water quality with water shortage problem.

Aung Kan Kyaw village was established and named after combining three villages namely Aung Zayya, Kanya and Hngat Kyaw in 2018. It is located on the other road-side of Bandar Pin Village. The village is located on le land and its roads are fair earth roads constructed by landfill system. A pond for drinking water was dug up around the village.

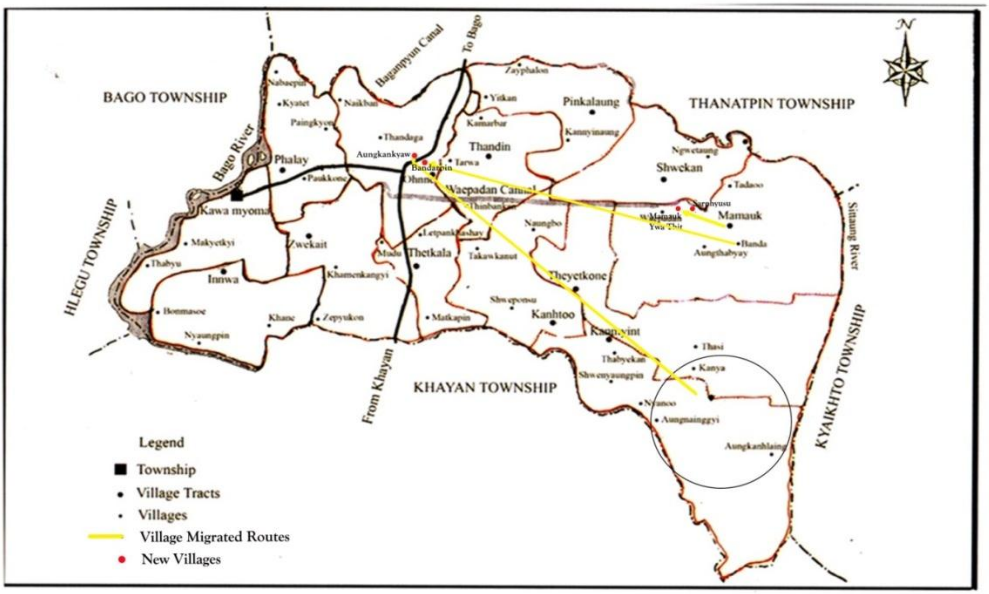

Figure 3: Locations of Relocated New Villages and Old Villages in Kawa Township

Source: Field Observation (30 .5.2017)

 

Plate (1) Shifting of destroyed home to new location

Plate (2) Sharing rice to Mamauk's Villagers by donors

 

Plate.3 Destroyed House moved to other Relocation Area

Plate.4. New houses built on the Le Land (Mamauk Relocation Area)

Plate 5 Infrastructure (Bridge) in Main Mamauk Village
Plate 6 Infrastructure (Phone Tower) in Main Mamauk Village

Education Condition

Case Study of Mamauk : Although the main Mamauk village has one state middle school with ten teachers and about 470 students before bank erosion, one teacher has to control one class from KG to grade.8. After moving to new location, these ten teachers were shared into three schools**,** due to the separation main Mamauk Village into three parts. One teacher teach about 50 students from Aungthabyay village. Another two teachers teach about 190 students from new Mamauk village including from primary to seventh standard. At present, four persons who passed matriculation help in teaching at this branch school. The main area has seven teachers and 226 students.

Plate-7 and 8 show that school buildings' condition within main Mamauk and newly located Mamauk. The major State primary school of main Mamauk is located not far from the site eroded by the Sittaung river and is facing the problem of flooding during rainy season. Therefore, this school is likely to be moved to new Mamauk village. The major education problem of Mamauk village is insufficient number of teachers and school infrastructures.


Plate -7 State Primary School Building in Main Mamauk Village (22.6.2017)
Plate -8 State High School Building in Mamauk- Ywa Thit After Moving on (22.6.2017)

Economic Conditions

Villagers of the study area were engaged mainly in the primary sector, particularly farming and fishing, around the Sittaung river mouth and surrounding area before bank erosion. After bank erosion, occupations were changed to general work, water transport related work (small boat owners and workers), sewing, sharecropping and so on.

Loss of Le Land

Agriculture is an important factor for economic development of rural village in the study area. Before 2014, Agriculture was dominant economy of this area because most kaing -kyun appeared along the Sittaung River mouth. But, after 2014 the Le Land had been damaged by severe bank erosion on the western part of the Sittaung River mouth.

According to the data from Department of Agriculture and Land Management Statistics, loss of le land area was witnessed by all village tracts, the eastern part of Kawa Township along the Sittaung river bank. Le lands of Shwetasok and Bandar Village tracts within Kawa Township were lost by the bank erosion in 2014, which increased seriously in the southern part of this township. Up to 2015-16, the le land area damaged by Sittaung river bank erosion was 304.72 hectares, possessed by belong to 91 farmers of Shwetasok village. The damaged le land area was 382.83 hectares belonged to 49 landowners of Aungmyektha village. About 492.5hectares of le land (194 landowners) in Mamauk, 231.88 hectares (owners 63 persons) in Tadaroo and 510 hectares (466 owners) in Bandar were also destroyed. The total loss of le land area was 1817 hectares which were owned by 453 farmers.

According to questionnaires to 25 head of households in Mamauk village, the farmers faced so many problems for life survival due to lack of income and having no work and they have to keep on waiting donors. Some members of farmer families went and engaged in jobs as sharecroppers and wage-earners in Thaton Township in order to get income during the rainy season, especially during the paddy growing period. Some family members went and worked at sewing industry in Intakaw Town and provide money to their family. Some ventured to go to foreign countries mainly to Malaysia and China. Most of le owners have no jobs and live in poverty. Some have become fishermen.

According to questionnaires to 25 heads of households in Bandar and Aung Kan Kyaw new villages in July, 2018, the main economy of the 96 % of villagers depended on agriculture. The land tenure patterns differed from 1.21 hectares to above 12.14 hectares and grew paddy during the rainy season and pulses in dry season. Five households or 20% had above 12.14 hectares, 16% owned above 8.3 hectares (20 acres), 24% possessed above 4.05 hectares and other 36 % owned under 4.05 hectares. But at present time (interview and questionnaire distribution), the farmers who own no land have various work because all le land were destroyed by bank eroding. About 63% are engaged to general works to get income but this area is difficult to get work. They work only seven days per month as general work, especially by raising ducks and chickens stocks, earning a daily income of 8000 kyats. Some went to Thaton and Naypyitaw for job and cash.

Livestock Breeding

Before 2015, according to questionnaires survey to 25 Mamauk villagers, 22 households or about 88 percent earned their living not only on farming but also on livestock breeding. Livestock agri-business comprises such animals as cows, buffalos, goats, ducks and chickens. The largest numbers of cows and buffalos were owned by three households with only 20 cows and buffalos. Six households ranked second in the numbers of livestock with less than ten. Other households had two or three cows and buffalos.

Table 3:Damaged *Le* Land by Sittaung river bank erosion at Kawa Township(2015-16)

No	Village Name	Land use pattern	No of land holders	Damaged hectares
1	Aungmitha	Le	49	382.83
2	Shwetasoak	Le	91	304.73
3	Mamouk	Le	194	456.48
4	Tadaroo	Le	58	144.47
5	Bandar	Le	61	509.9
	Total	Le	453	1798.41

Source: Department of Agriculture and Land Management Statistics (Kawa Township)

But after shifting to other location, 70 percent of households sold their cows and buffalos because they needed money to move and rebuild their house and other difficulties related to livestock raising.

Before shifting to other location, the numbers of duck raising households was six and each household had about 100 to 800 ducks. After moving to the relocated area, these duck were sold off to get money needed. The new area is not favorable for duck raising.

Fishing Industry

According to questionnaire's result, the major economy of 15 households or 62.5% of total households operate fishing industry. But two households depend solely on fishing and other 13 households not only on fishing but also on agriculture. After moving to new Mamauk village, fishermen from new village go on foot to main Mamauk, which is about 3.22 kilometer or two miles away. Therefore, fishermen sometime stay and catch fish for two or three days at main Mamauk because of rough linking road and they come back if they get fishes. Their income decreased due to the above mentioned problems. Average income of one fisherman per day is about 5000 kyats. But the income of fishermen is still large than farmer is income after moving to new Mamauk.

Conclusion and Suggestions

Severe bank erosion of Sittaung River mouth again took away the eastern part of Kawa Township from 2015 to the present time. Therefore, most of le land, pasture and settlement and other lands were destroyed due to severe mass erosion. The total loss of land area during seven-year period from 2010 until 2017 was about 163 square kilometers (16316.9 hectares). The villages along the Sittaung River in Kawa faced not only the destruction of the *le* land but also settlement area of village. Therefore, villagers witnessed the shifting of houses to new location, new school construction and other negative impact on social and economic factors. The total number of households destroyed by bank collapse was 754 with 3965 effected persons in 2017.

Villagers of study area were occupied with primary sectors especially farming and fishing, around the Sittaung river mouth and surrounding area before bank erosion. After bank erosion, occupations of the local inhabitants changed to general work, water transport related work (small boat owners and workers), sewing, sharecropping and so on.

Suggestions for development of land loss rural area in Kawa Township include both difficult and easy solutions. The following facts may solve problems of study area.

The settlement area is located over le land and it should be modified by landfilling the le land to become an area suitable for residing.

For sufficient availability of drinking water, pond should be dug and above mentioned information should be shared to attract donors and NGO by using Facebook and other social network.

The villagers want to have adequate teachers for effective teaching at schools and local authorized persons should consider and propose the department corned to appoint more teachers.

Weapatan canal is a major water transportation route for new location area and motor road should be constructed to connect Weapatan Village that has the hospital and high school for supporting education, health and other social needs.

Most villagers have no permanent job and income is low. Therefore, fish and prawn culture and duck breeding should be carried out by co-operative and companies supported by entrepreneur, local community and government.

Silviculture should be practised around the new villages and along the Weapatan canal for quality environment and firewood horticulture should be materialized within home compound to obtain some income and vegetable for dish.

Acknowledgement

We would like to thank specially Head and Staff from Town Administrative office and Land Record Department in Kawa Town. We also thank to Leaders from Mamauk village and villagers from Mamauk and Sarphyusu villages. We would like to express Zaw Win (MIMU) for providing Satellite Image (2010, 2015 and 2017) of the study area.

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BETEL LEAF AND BETEL QUID SHOP: ECONOMIC ACTIVITIES OF PANTANAW TOWNSHIP, AYEYARWADY REGION

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Abstract

This paper presents the geographical assessment of betel plant environment, particularly on the distribution pattern of betel leaf cultivation in Pantanaw Township. There are two species of betel leaf in Pantanaw Township such as Myaungmya species and Gwa species. Betel leaf is grown in wet and hot seasons as cash crop in the nearly all parts of Pantanaw Township. With the increasing population in the study area, more people are engaged in agriculture activities including betel leaf cultivation. Betel leave are commercial products, mainly used for chewing, besides having significant medicinal properties and ceremonial events. Although betel leaf cultivation can provide relatively sustainable income of local people in the Pantanaw Township, it can damage indirectly human health. The betel leaf cultivation and spatial distribution patterns of betel quid shops are analyzed by using ArcMap GIS 10 software and quantitative analysis.

Keywords: *Betel leaf cultivation, betel quid shop, distribution pattern, Pantanaw Township*

Introduction

Betel leaf cultivation is an important economic activity of Pantanaw Township.

Most betel leaf cultivated areas are found in Kazinngu, Bawaing, Shwekyaungmyauk, Tawchaung, Yaypawgyi and Katthawin villages.

Betel leaf has a deep green colour with heart-shape which is widely used in Myanmar. The scientific name of betel vine is *Piper betel linn*. It belongs to the family of *Piperaceae.*

There are two species of betel leaf in Pantanaw Township, as Myaungmya species and Gwa species. Betel leaf is grown in wet and hot seasons as cash crop in the nearly all parts of Pantanaw Township.

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Betel leaf is a mainly transported to Yangon and neighbouring townships such as Nyaungdon, Kyaunggon, Kyonpyaw, Danubyu, Maubin, Einme and Warkema,

Betel leaf is a commercial product, mainly used for chewing, besides having significant medicinal properties.

Betel quid made up of the betel leaf includes slices of betel nut, lime, tobacco, catechu, aniseed, liquorice, cardamom, clove, spicy materials and others.

Most betel quid consumers are automobile drivers, daily workers and other social classes. Therefore, the number of betel quid shops has increased near the main road and the streets in Pantanaw Township.

Betel quid chewing can affect staining the teeth of regular users. The red spit from chewing betel quid is prohibited in many places.

According to the released by WHO in 2014, more than half of the adults aged between 45 and 65 are being suffered with mouth cancer, essentially due to smoking and chewing betel quid, 34 persons for every 100 persons who have the habit of betel quid chewing, 22 persons who smoke and chew betel quid, 19 persons who smoke, but not chewing.

Educative talk on the danger of smoking and chewing tobacco was held at Insein General Hospital in 2014. Although 273 persons with bad habit of taking tobacco attended the forum only 33 persons could quit their bad habit. Tobacco includes various toxic materials that can cause cancer if used for a long time. Cavity cancer is most common among the males. In Southeast Asian countries 30 to 60 persons of males and 1.8 to 15.6 percent of female are either smoking or chewing betel quid with tobacco.

Research problem

Myanmar is agro-based country and most of the active workforces are engaged in agricultural activities. Although paddy is mostly grown in Pantanaw Township, betel leaf is also cultivated in some suitable lowland areas. Betel leaf cultivation can damage indirectly human health.

Since the days of Myanmar Kings, betel quid chewing has become traditional. In those days, the adverse effect of chewing betel quid was not known. People of the older generation, especially the males chewed betel quid with a little Myanmar tobacco. With the improvement of medical science, the people realized the deadly effect of tobacco.

In Myanmar, the proportion of people chewing betel quid has been rising and the percentage is highest among the Asian countries according newspaper's information. In order to reduce the bad habit of chewing betel quid, the government and health staff discourage the people by mean of raising awareness through television, radio, journals, newspapers and other medias.

However, such educative camping seen to be less effective and the number of betel quid chewers is still on the rise. To satisfy the current demand, the growers cultivate more acre of betel leaf in Pantanaw Township. Betel leaf growers can earn a moderate amount of profit for their livelihood.

Betel leaf cultivating is a traditional activity in the study area. On the other hand, it may indirectly cause health damage to the chewers. This is a great problem of this specific economic activity of the study area.

Research hypotheses

Hypothesis 1 – The development of betel leaf cultivation in Pantanaw Township depends largely on the existing physical geographic factors.

Hypothesis 2 – The existence of betel quid shops near the schools, offices and in densely populated area enhances the undesirable bad habit of chewing betel quid.

Aim

The main aim of this paper is to study the processes of betel leaf cultivation and development of betel quid shops in Pantanaw Township within Ayeyarwady Region.

Objectives

- To assess the physical factors that affects the betel leaf cultivation
- To analyze the spatial distribution pattern of betel leaf cultivation
- To examine the future prospect of betel quid shops

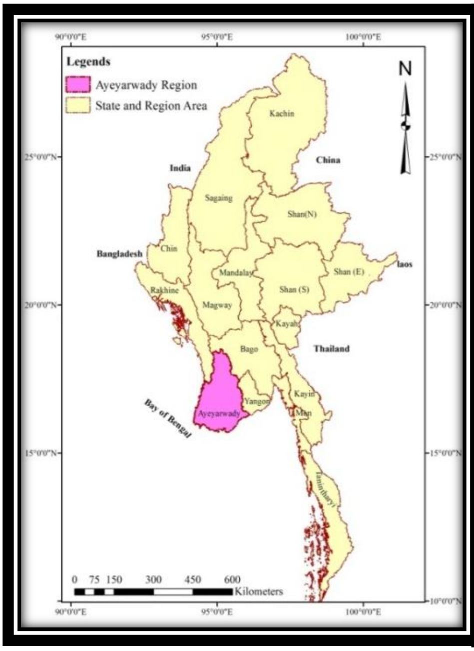
Data and Methods

In order to get the township boundary, ward, and village tract boundaries of the study area, it is digitized based on Google Earth Images (2017) and Land Sat TM Image (2013). Other facts and data are acquired from relevant offices.

The spatial distribution pattern of betel leaf cultivated land and aerial distribution of betel quid shops are analyzed by using ArcMap GIS 10 software and statistical methods.

The information data of cultivating process of betel leaf and number of betel quid shops are obtained from the field survey, interviews and discussion with consumers and shopkeepers of betel quid.

In order to know the perceptions of betel quid chewers, 100 people including teen-agers and above are randomly selected and given relevant structure interviews. The determination of sample size is not used a specific formulae, but it is determined purposively for the intended outcomes.



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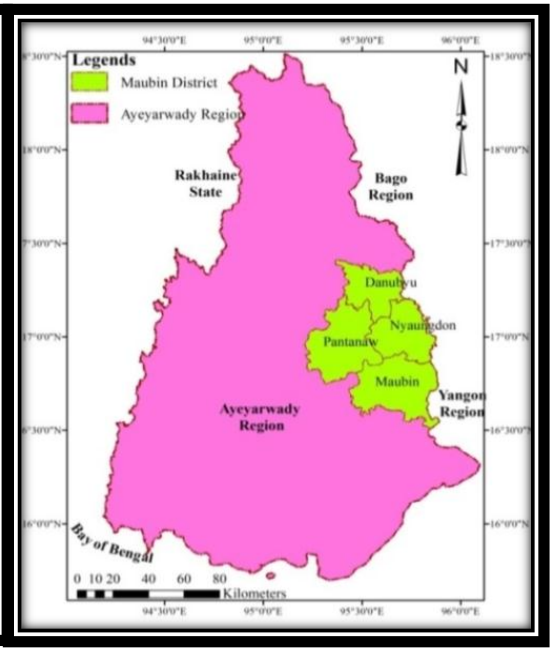

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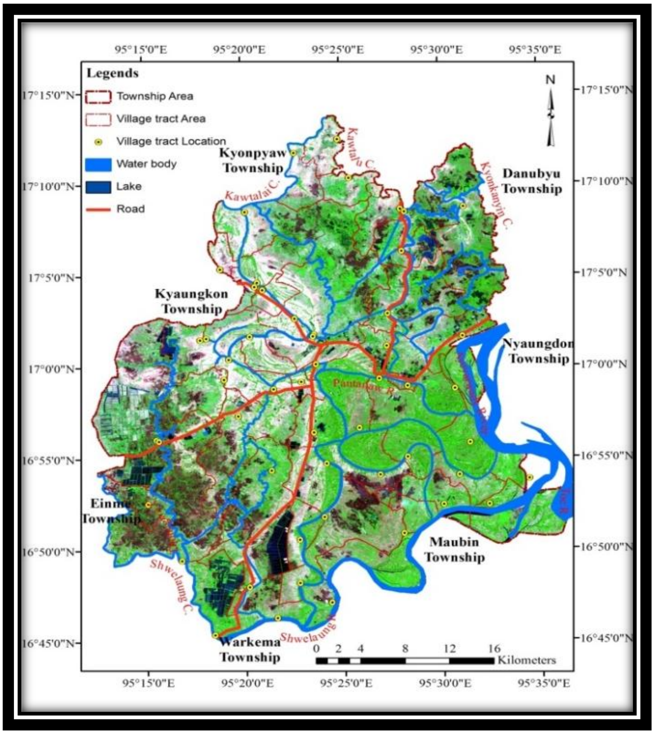


(c)

Figure 1: (a, b,c) Location of Pantanaw Township in Ayeyarwady Region within Myanmar

Source: Digitizing based on Google Earth (2017), Landsat TM (2013)

Geographical Background of the Study Area

Pantanaw Township is included in the Maubin District. It is one of the 26 townships of Ayeyarwady Region, located at the southern part of Myanmar. It lies between 16˚ 48′ and 17˚ 13′ N latitudes, and between 95˚ 16′ and 95˚ 34′ E longitudes. It has an area of 1291.17 square kilometer (498.52 square miles).

The township is composed of rivers, creeks, inns, lakes, man-made embankments and low land. The average elevation of the land is less than 15 m (50 feet) above sea level.

The climate of the Pantanaw Township is controlled by the geographical location and the periodical shifting of monsoon winds. It enjoys the tropical monsoon climate (Am). This climate is favourable for growing betel leaf.

Soils in the study areas are formed from parent material of young and old alluvium deposited by rivers and creeks. Meadow swampy clayey soils and meadow alluvial medium loamy soils are predominant in the study area. These are widely found within the township which represents 86.36 percent of the study area. These soils are suitable for betel leaf cultivation.

In 2016-17, the total number of population in Pantanaw Township was 264562 persons, including 19150 urban people and 245412 rural people.

Processes of Betel Leaf Cultivation

Betel leaf cultivation varies from place to place in Pantanaw Township due to several factors like types of soil, types of betel leaf, current demand and supply in the market, types of season, etc.

Before the planting, betel species should be immersed in a fungicide mixture for about 30 minutes.

Betel Leaf Environment

Betel leaf environment is defined by soils, climate, making fence, growing periods, betel leaf size and picking up.

Soils

The soil preparation is the first step for betel leaf cultivation. Although betel leaf can be grown in various soils, the most suitable soil is meadow alluvial loamy soils.

Firstly, the betel farm land is chosen, usually by the flat level land, well drainage and good sun shine. Then, the soil should be prepared by tilling 15cm to 20cm depth. To cultivate the betel plants, the land should be raised by 10cm to 15cm height from the adjacent areas within the plot. Then, the betel beds (low ridge) are prepared having 30cm to 35cm wide.

After the soil preparation, for about two or three days, betel plants are cultivated on the betel beds.

Climate

Tropical climate is favorable for betel leaf cultivation. Good quality leaves come out the not too wet and not too hot season rather than in the dry season.

Making of fence

The fence is constructed with poles, bamboo stakes, palm leaves, kaing poles and other fencing materials. The number of poles needed in a betel farm depends on the betel fence size. For instant, around 6 square meters (60 square feet) of farm size need about 3000 poles with a length of 4 meters (14feet) each.

Growing periods

Betel leaf is cultivated in rainy and summer seasons. In order to get the best quality of betel leaf, it is mostly cultivated in the rainy season.

The rainy betel leaf is mostly cultivated from the beginning of June to the end of December. The summer betel leaf is cultivated from the early October to the end of May.

Betel farm should be covered with coconut fronds, kaing leaves and other shading material for about 4 weeks.

Plate 1. (75) days old betel leaf

Plate 2. Construction the betel farm

After the planting of betel leaves for 45 days, new leaves begin appearing usually about 7 to 8 leaves. After 75 days, mature leaves are suitable for plucking from the betel plants and it attains about 1 meter (3 feet) in high.

Betel leaf size

Betel leaf size depends on types of soil, relief, drainage, feeding chemical fertilizer and shading condition on the betel farm.

Large size is commercial size and commonly used in the betel quid shops.

Large size: there are 1000 leaves per viss

Medium size: it contains 1200 leaves per viss

Small size: it occupies 2000 leaves per viss

Plate 3,4 and 5. Large size (10 cm), medium size (9 cm) and small size (6 cm)

Picking up

Three months after the planting of betel leaf, mature betel leaves are picked up by hand along with a portion of petiole (the stalk of a leaf).

Mature betel leaf can be picked up 15-20 leaves once in 10 – 15 days. The yield depends on cultivation methods and types of betel leaf.

One packing basket contains 30 viss of betel leaves.

Types of betel leaf

There are two types of betel leaf. They are Myaungmya and Gwa species. These species are popular types in the whole township.

Myaungmya species

There are two types of Myaungmya betel species: red and green petiole. Myaungmya species fetches the highest price in market. Its flesh is more soft and delicate than other species. They can be grown easily in any soil.

Although the leaf is marketable leaf size and large bud, it sprouts a few buds. Each betel plant usually sprouts five or six buds in its lifespan.

The lifespan of this species averages five or six months. This type of betel plant is less resistant to weather conditions.It can be easily affected by pests that can destroy plants.

Gwa species

This species is small in buds and small in leaf size. It has also red and green petiole. It cannot be grown easily. After growing well, it can resist to pests. This species is more resistant to weather. The average lifespan is lasts up to ten or twelve months. It can also yield more betel leaves than Myaungmya species.

Another species can be grown in some villages in Pantanaw Township. This type is Ngaputaw species. It is similar to the Gwa species.

Plate 6 Myaungmya species

Plate 7 Gwa species

Spatial Distribution Pattern of Betel Leaf Cultivation

In Maubin District, the betel leaf total cultivated area was 998 hectares (2466 acres), comprising 393 hectares (971 acres) of Pantanaw Township in 2012 – 2013 which accounted for 39 per cent of the district betel leaf cultivated area. In 2016 – 2017, the total area under cultivation rose to 1032 hectares (2549 acres), comprising 416 hectares (1029 acres) of the study area which accounted for 40 per cent. The cultivated land of Pantanaw Township has slightly increased, the percentage is also slightly increased in the 5 year period from 2012 – 2013 to 2016 – 2017. (Table 1, Figure 2)

Table 1: Betel leaf Cultivated Area (Hectares) of Pantanaw Township in Maubin District (2012-2017)

Maubin District	2012-2013	%	2013-2014	%	2014-2015	%	2015-2016	%	2016-2017	%
Pantanaw	393	39	395	45	415	40	415	38	416	40
Maubin	212	21	212	24	212	21	314	29	314	30
Nyaungdon	328	33	207	24	333	32	294	27	223	22
Danubyu	65	7	65	7	67	7	69	6	79	8
Total	998	100	879	100	1027	100	2699	100	1032	100

Source: Department of Agricultural Land Management and Statistics (Maubin)

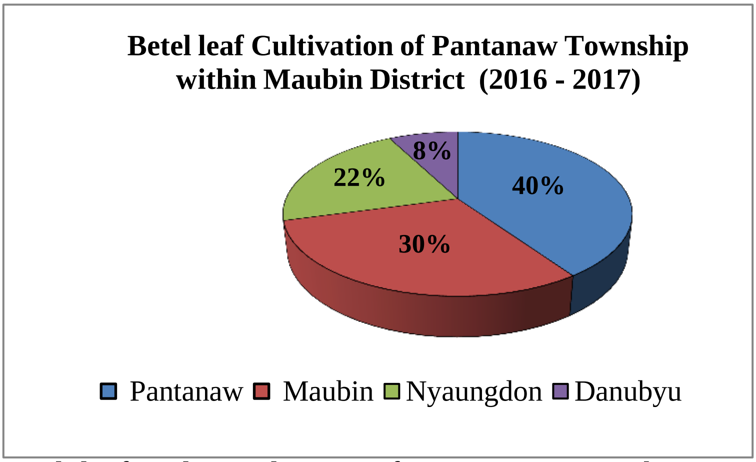


Figure 2: Betel leaf Cultivated Area of Pantanaw Township in District (2016– 2017)

Source: Based on Table 1

In the study area, only 4 wards out of 56 (Wards + Village tracts) had no betel leaf cultivated land in 2016 – 2017. These wards are Eastern Ward, Middle Ward, Western Ward and Extension Ward. The betel leaf cultivated lands are found widely in the whole township. The cultivated land mostly occupies the eastern portion of the township, that is, western part of Ayeyarwady River and Kazinngu, Bawaing, Shwekyaungmyauk, Tawchaung, Yaypawgyi and Khayakan villages. (Table 2, Figure 3)

There is one village tract, Kazinngu, cultivates above 24 (32 hectares).

In 2017, the township had 50526 households. Among them, 2424 household are practicing betel leaf cultivating activity. The number of household is greatest in Kazinngu Village Tracts with 176. Owing to increasing demand from market, the number of cultivated acres has increased, and this economic activity is traditional activity of Kazinngu Village Tracts. (Table 3, Figure 4)

Table 2: Number of Village Tracts in Betel leaf Cultivated Area (Hectare)

Class of Cultivated Area	Number of Wards and Village Tracts
Above 24	1
19 - 24	3
13 - 18	7
7 -12	11
1 - 6	30
0	4
Total	**56**

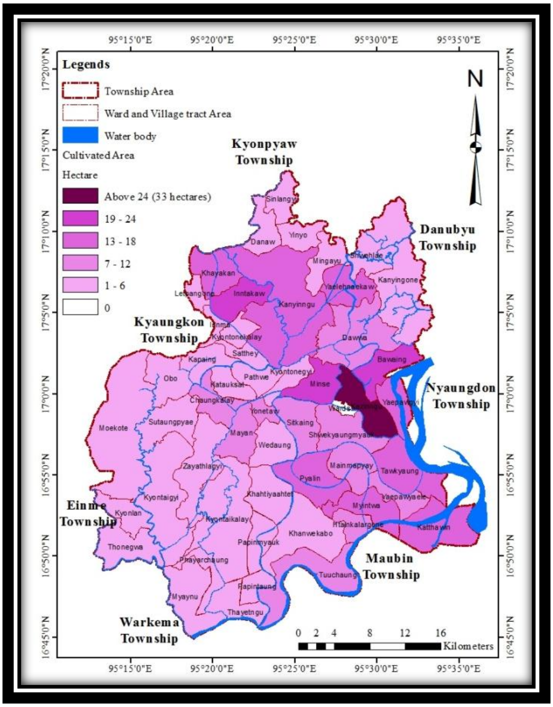


Figure 3: Distribution Pattern of Betel leaf Cultivated Area in Pantanaw Township (2016-2017)

Table 3: Number of Households that involve in Betel leaf Cultivation Activity

Class of Household Number	Number of Ward and Village Tracts
0	4
1 – 40	31
41 – 80	14
81 – 120	3
121 – 160	3
Above 160	1
Total	56

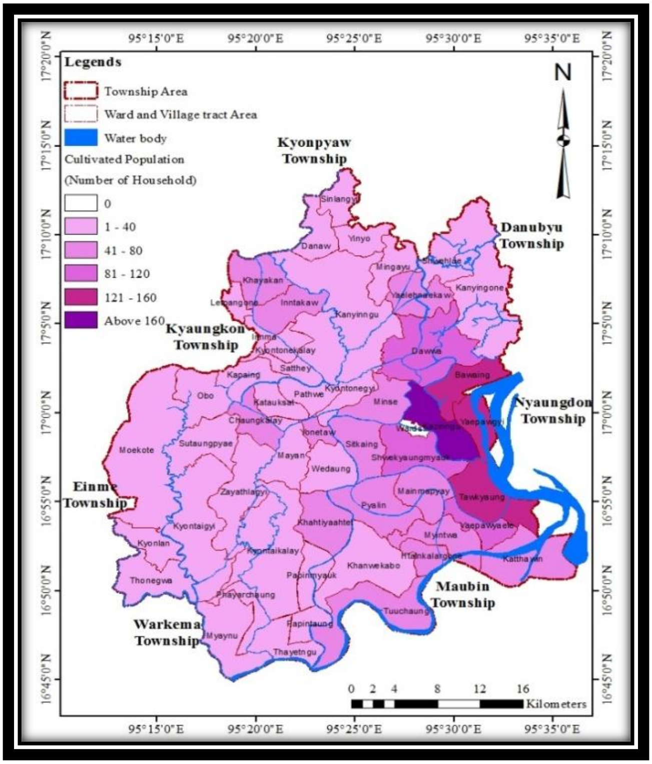


Figure 4: Distribution Pattern of the number of Household in Betel leaf Cultivation (2016-2017)

Source: Department of Agricultural Land Management and Statistics (Pantanaw)

Cost and Benefit Analysis of Betel Leaf Cultivation

Cost and benefit of betel leaf cultivation depends on the input cost and labor, using the fertilizer, disease problem, commodity flows and human health.

Input Cost and labour

Input costs include bamboo poles, betel species, wages of labor, fertilizer and pesticides, bamboo baskets and transportation.

In a farm which is 6 square meters (60 square feet) wide, to cultivate 2000 betel plants, 3000 bamboo poles are necessary. Bamboo poles are usually bought from Kyaunggone and Pathein townships. Each bunch of bamboo pole with girth one and half inches costs 1250 kyats. One bunch usually consists of 25 bamboo poles.

Betel species are available from Myaungmya, Gwa and Ngapudaw townships. Each betel species price is 50 or 55 kyats. The price of betel species can vary depending on the price of betel leaf.

For the construction of a betel farm, labor is essential. Most of the betel farmers have to hire laborers to erect bamboo columns, which cost 35000 or 40000 kyats for 1000 columns. The wages are different from place to place in the Pantanaw Township. The labor is also hired to pluck betel leaves which cost 2500 kyats a day per head. But for some, they have to pay 3500 kyats for ten viss.

In soil preparation, a bag (25 Kilograms) of fertilizer is necessary for 2000 betel plants. The price of one fertilizer bag is 10000 kyats. After planting of betel leaves, chemical fertilizer is applied to the betel plants, and the price of 10 kilograms of fertilizer is 4000 kyats.

Pesticides are essential for betel leaves cultivation. Cost of pesticides is 10000 kyats for every month in the cultivated period. But, some of betel farms are more costly for using pesticides.

Bamboo baskets are used to transport betel leaves. The price of per bamboo basket is about 1000 kyats.

The transport of one basket costs 2500 kyats from Pantanaw to Yangon by truck. These baskets are transported by motor boats from the villages to Pantanaw Town. Each basket costs 500 kyats for transport fee.

To cultivate 2000 betel plants, the average expense is about 350000 kyats in cultivated period.

Fertilizer and Disease Problems (Pesticides)

Regular feeding and watering will keep the betel leaf plants growing very lush. Application of chemical fertilizer is essential for higher yield and better growth. Chemical fertilizer is fed once in every 10 - 12 days.

Benefit effects of betel leaf

About three months later after being cultivated, they are ready to sell on market. Each betel plant yields average 30 betel leaves in a month and so about 60000 betel leaves are available from 2000 betel plants. There are 1000 betel leaves (10 cm length and 13 cm in width) in a viss and so from 2000 betel plants, about 60 viss of betel leaves are available. There can also be the fall or the rise of price of betel leaf on market. They sell betel leave at the price of 10000 kyats a viss when the price is high and 2500 kyats when the price in low. The normal price is 5500 Kyats.

From the beginning of plucking betel leave, about 330000 kyats (60 viss x 5500 kyats) are received per month.

The average benefit from 2000 betel plants is about 1,630,000 kyats (1980000 kyats – 350000 kyats) as a net profit in the plucked period (6 months).

Medicinal values of betel leaf

Betel leaves contain many health benefits, curative and healing properties. It is also a good source of calcium.

Betel leaf contains 85.4% of moisture, 6.1% of carbon hydrates, 3.1% of protein, 0.8% fat, 2.3% fiber per 100 grams. Therefore, it is used for the treatment of inflammations, applied for chest relief, cough and breathing difficulty in children and it relieves sore throat, relieves ear aches by dropping the juice of betel leaf, help in treating diabetes by reducing the level of sugar in blood, and treatment of acne and black spots on the face.

Commodity flows

Owing to demand from market, betel bamboo baskets are transported to other township's market especially to Yangon by car. Transportation systems include truck, motor boats and motor cycle from Pantanaw town to the market place such as Einme, Nyaungdon, Kyaungkon, Kyonpyaw, Danubyu, Maubin and Wakema townships.

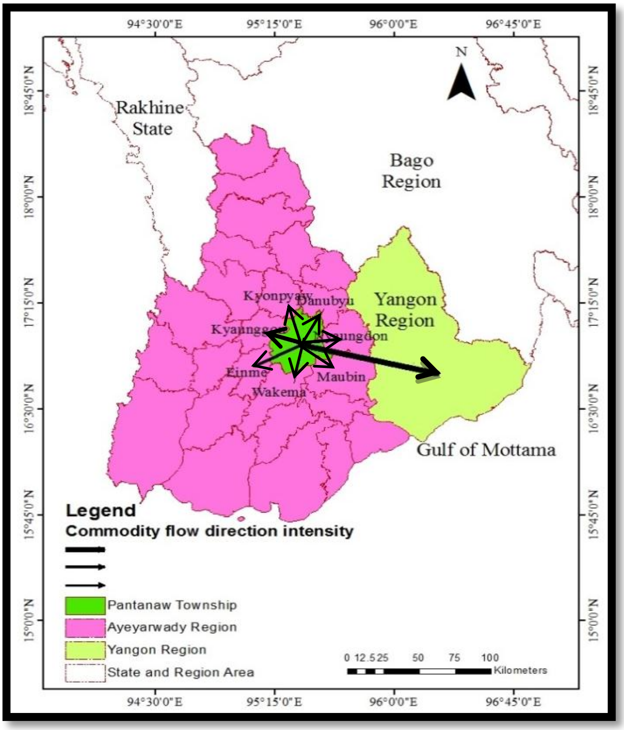


Figure 5: Commodity flow direction intensity

Studying the Betel Quid Shop in Pantanaw

Betel quid made up of the betel leaf is not a type of food. It includes slices of betel nut, lime, tobacco, catechu, aniseed, liquorice, cardamom, clove, spicy materials and others. These ingredients are wrapped together in a fresh green betel leaf. After chewing, the red colour of betel juice and betel pulp is spited.

According to the field survey, there are eight different types of betel quid in many betel quid shops in Pantanaw. These are named Regular (tobacco free), Myanmar tobacco (black), Myanmar tobacco (yellow), Queen (Parijat), Signal, Hundred, 92 and Bar Bar.

Plate 8. Myanmar tobacco (black)

Plate 9. Myanmar yellow tobacco

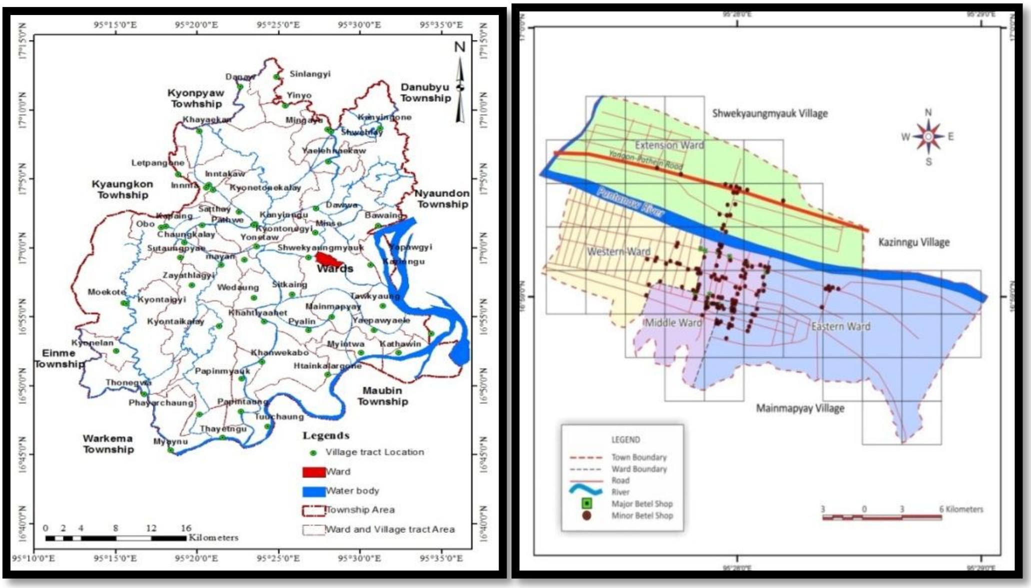
Plate 10. Foreign betel quid tobacco

The price of betel quid can change depending on the kind of ingredient. Generally the price is 100 kyats for four betel quid.

The betel quid shops in Pantanaw mostly get betel leaves from Kazinngu and Tawkyaung villages because it is located nearby the Pantanaw and betel plants are cultivated commercially. The main ingredient such as betel nut and other accessories are acquired from the Yangon Region.

The Study Area

There are very few betel quid shops in the rural area. The chewers make the quid by themselves at home. Most betel chewers of residents in town and daily workers buy it from the shops. Therefore, only betel quid shops in the four wards of the town area (3.34 square kilometers) are included as case study area. (Figure 6 a & b)



(a) (b)

Figure 6: (a & b). Location of Ward within Pantanaw Township
Source: Department of Agricultural Land Management and Statistics (Pantanaw)

Types of betel quid shop

According to the field survey, betel quid shop can be classified into two types: **1**. the shop which sell above 10 viss of betel leaves per day; it is defined as the major shop. There are 10 major shops in Pantanaw. **2**. the shops that sell below 10 viss of betel leaves per day, it is called minor shop. Minor shops are combined with other items such as cheroots, cigarettes, sweets and miscellaneous snacks. There are 113 minor shops in the study area.

Although most of the shops are those which sell the betel quid at a fixed place, some selling style can be seen on a three-wheeled motorcycle drive to designated place.

Plate 11. Major shop which sell out 25 viss of betel leaf per day

Plate 12. Three-wheeled mobile shop

Plate 13. Minor shops combined with cigarette

Spatial Distribution Analysis of Betel Quid Shop

Buffer analysis (Proximity)

Buffer involves the creation of a circular region around a point. The radius of the circle is determined by the analyst.

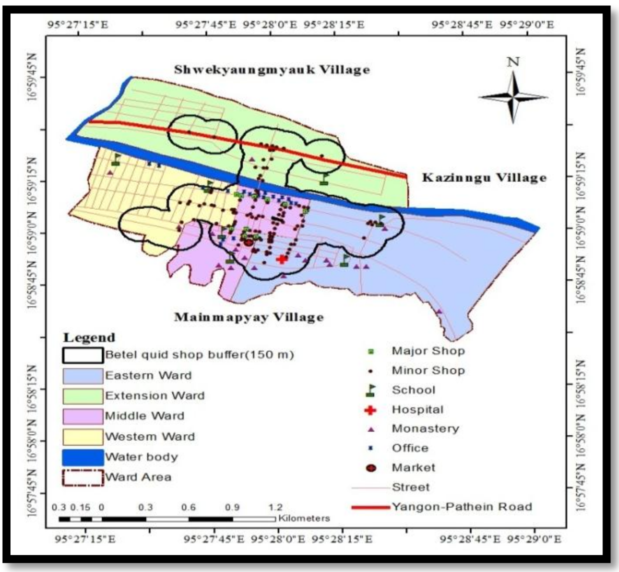


Figure 7: Spatial Distribution of Betel Quid Shops in Pantanaw by 150 meters Distance of Buffer Analysis (2017)

Source: Based on Author's observation

In this study, point is served as a betel quid shop. Distance buffer zone is created for buying distance from betel quid shop of 150 meters and the customers or consumers within 150 meters use for the attractive the shops.

According to the field survey, there are 123 betel quid shops in Pantanaw in which 10 shops are major shops. These are mostly located along Bogyoke Aung San, Bayintnaung, Anawyahta, Thiha and Yuzana streets within Middle Ward. Other minor shops are clustered along the Tapinshwehti, U Aung Zayya and other streets in Western Ward and Middle Ward, Eastern Ward.

Buffer analysis of ArcMap GIS reveals that there are several betel quid shops within 150 meters distance from 16 governmental offices, 1 hospital, 1 market, 1 monastic school, 1 basic education high school (BEHS) and 2 basic education primary schools (BEPS). (Figure 7)

The closeness of betel quid shops to schools can result in the acquiring of betel quid chewing habit by the school children at their early age. Some school children may get interested in earning income by selling betel quid at the bus stops and drop out of the school.

A number of betel quid shops are located close to the hospital, market and government offices, leading to all-time chewing of betel quid by the staff, degrading the environmental quality with red spits and negatively affecting their health.

Development of Betel Quid Shops

The habit of chewing betel quid is popular among the Myanmar people and most of the local people of Pantanaw consume betel quid regardless of age and gender.

With the construction and upgrading of bridges and roads for travelling in Ayeyarwady Region, Yangon-Pathein Road that crosses Pantanaw is mostly used by travelers from place to place. Bus drivers and conductors are the major consumers of betel quid. Thus street side small shops selling betel quid have increased in Pantanaw year by year.

For the reason mentioned above, the number of betel quid shops increased from 29 shops in 2012-2013 to 123 shops in 2016-2017. (Table 5 and Figure 8)

Among 123 shops in Pantanaw, Eastern Ward is occupied by 52 shops which account for 42 percent of the total shops in 2017. The reason of the increase in the number of shops is that Eastern Ward is always crowded with daily routine workers especially along the Bogyoke Aung San Street. Other concentrated areas in Eastern Ward are along the U Aung Zayya Street near the market.

Table 5:Temporal changes of betel quid shops in Pantanaw (2012 - 2017)

Wards	2012-13	2013-14	2014-15	2015-16	2016-17
Eastern Ward	6	8	11	32	35
Middle Ward	18	22	23	50	52
Western Ward	2	3	6	16	18
Extension Ward	3	4	4	15	18
Total	**29**	**37**	**44**	**113**	**123**

Source: Department of Township Development Committee (Pantanaw)

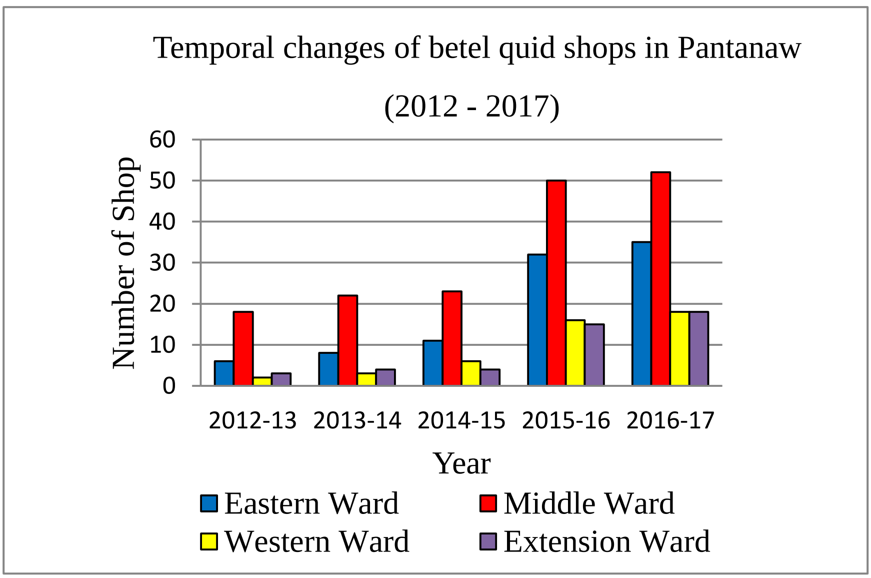


Figure 8. Temporal changes of betel quid shops in Pantanaw (2012 - 2017)
Source: Based on Table 5

Findings

The Pantanaw Township economy is heavily based on the agriculture sector. Betel leaf cultivation is also one of the important economic activities in the township.

The study area is mostly lowland formed by rivers and creeks. Much of the betel leaf cultivated lands especially Kazinngu, Tawkyaung, Pyalin, Shwekyaungmyauk, Yaypawgyi, Minse, Kanyingu, Mainmapyay and Khayakan villages are covered with meadow swampy clayey soil and meadow alluvial medium loamy soil. Cultivation of betel leave is a major livelihood of rural population of the study area.

Socio-economic role of betel leaf cultivation

. In Maubin District, the ‘betel leaf total cultivated area was 1031.55 hectare (2549 acres), of which 416.42 hectare (1029 acres) were in Pantanaw Township in 2016– 2017 which accounted for 40 per cent of the district betel leaf cultivated area. (Table 1)

As in other townships, people are mostly concentrated in Pantanaw Town (Town population 19150 persons) with 14844 persons per square kilometer and the whole township with 205 persons per square kilometer. In 2016, the total number of population in Pantanaw Township was 264562 persons with 50526 total households. Majority of households, 38394 (76.15%) are engaged in farming. Betel leaf cultivators (2424 households) represented (4.8%) of total households.

120 households are betel quid shopkeepers occupying 0.24% of the total households.

Impact

There are two types of impacts: positive and negative impact.

Positive impact refers to the local people’s socioeconomic positive impact.

Betel leaf cultivation within the study area not only provides jobs to the local inhabitants, but also enhances the economic development of the township. Betel leaf cultivation is maintained by traditional economic activity of the study area and it is used for some traditional medicines.

Negative impact is the adverse effects resulting from the cultivation of betel leaf. Human health is damaged by the effects of the pesticides. By touching the skin of people with the pesticides, the skin can cause allergy. If the people breathe the pesticides, they will cause dizziness.

Another indirect effect of betel leaf cultivation are chewing betel quid. The habit of chewing betel quid (including betel leaf, betel nut shred, Myanmar tobacco black and yellow, foreign tobacco and lime) can threaten consumer's health gradually leading to tooth decay, mouth cancer (C.A Larynx or Oral Sepmucous Fibrosis (OSMF)), tongue cancer (C.A Tongue), premature ageing and even to death.

Among these diseases, Oral Sepmucous Fibrosis (OSMF) disease is mostly common in Pantanaw. In 2013, local people suffered OSME disease was 3 persons and it increased to 5 persons in 2015. In 2017, 11 persons suffered this disease and among them 8 persons died. (The data are acquired from the Hospital of Pantanaw)

Discussion

According to the senior doctor of Pantanaw Township, buccal cavity cancer (Cheek cancer) is essentially caused by foreign tobacco put in betel quid in different forms and also by the repeated abrasion of lime. Such cancer is more common in people who keep the betel quid in mouth for a long time without chewing.

Because of spitting sputum repeatedly, it leads to indigestion. Nicotine included in tobacco may cause constriction of heart-vessel (Coronary artery or thrombosis) and hence hypertension and eventually stroke.

Toxic material is removed by liver and heavy intake of nicotine can damage the normal function of liver. In men, it can also lead to impotency.

Both smoking and chewing the quid can damage the people. In fact, the content of nicotine included in the tobacco wrapped in a betel quid is much higher than in a cigarette. In cigarette smoking much of the nicotine is burnt out.

Although the number of those who suffer from mouth cancer (OSMF) has been increasing in Pantanaw Township, a greater proportion of betel quid chewers have no problem. According to the structured interview responses of

100 betel quid shopkeepers, nearly all the betel quid chewers take only that include Myanmar black tobacco prepared with tamarind liquid, instead of with that prepared foreign tobacco imported from India.

Mouth cancer (OSMF) is most common in these who take betel quid with prepared foreign tobacco and those who keep the quid in the mouth for a long time. The shopkeeper of "U Soe Lay" betel quid shop started to prepare the Myanmar black tobacco with tamarind and others follow suit. To expel the hazardous chemical the betel nuts are boiled 5 times before making betel quid. Likewise, lime used in betel quid is treated 8 times with water to remove toxic chemicals. Everyday, he can sell out about 25 viss of betel leave with the betel quid.

To know the health conditions of betel quid chewers, 100 chewers are randomly selected and asked relevant questions. Among them, a greater proportion (61 %) are heavy chewers with 25- year experience of chewing and 77 chewers take more than 30 quid per day. They all look quite healthy.

These conditions suggest that the number of betel quid chewers is less likely to decrease in the foreseeable future and betel leaf cultivators and betel quid shops will remain unchanged in number, if not increasing in the study area.

Conclusions

Being part of the Ayeyarwady deltaic region, Pantanaw Township has a wide stretch of low flatland. As the township lies within the tropic temperatures are high throughout the year.

Betel leaf plants thrive on fairly high temperature. Under the monsoon climatic regime the alternate wet and dry seasons are the main characteristics. Betel leave plants depend on the rain water in the rainy season. In the dry season, the betel plants need to be irrigated. The irrigated water is available by sinking tube well or lake.

The existing soils, particularly meadow swampy clayed soil and meadow alluvium soils with loamy texture are best suited for growing betel leaf plants. The areas with such soils condition occupy a large proportion of the township. Therefore, as shown in **Table 1**, Pantanaw Township has the largest betel leaf cultivated area among the 4 townships of Maubin District.

As such **Hypothesis 1** “the development of betel leaf cultivation in Pantanaw Township depends largely on the existing physical geographic factors” is accepted.

The betel quid shops are located elsewhere in Pantanaw Township, particularly where people are more concentrated such as schools, offices, markets, etc.

The elder school children start chewing betel quid and the younger students imitates it, increasing the number of chewers.

In the beginning, the chewer usually start chewing the betel quid without tobacco, and then with little tobacco. The amount of tobacco gradually increases and the chewer become addicted with nicotine included in the tobacco.

According to structure interview result, 98 out of 100 chewers answered that betel quid chewing can damage the human health and 91 people know this information of the adverse effect of nicotine from different sources of media such as newspapers and television.

Among them, 78 people want to quit the bad betel quid chewing habit, but bad habit die-hard and it is difficult for them to quit. Whenever the level of nicotine falls in the blood of chewer, his brain commands him to take another betel quid.

As the betel quid shops are located close to the offices and markets, these working at these workplaces can easily get betel quid, thus increasing the number of heavy chewers.

Therefore **Hypothesis 2** “the existence of betel quid shops near the schools, offices, markets and in densely populated areas enhances the undesirable bad habit of chewing betel quid” can be accepted.

Table 6: SWOT analysis of betel leaf cultivation and betel quid shop

Items	Strengths	Weaknesses	Opportunities	Threats
Betel leaf cultivation	**1**. sustainable soil **2**. sustainable traditional work **3.** get profit within three months after planting	**1**. lose by disease and pesticide **2.** lose by climatic change	**1**. get more jobs	**1**. by touching to the skin of people with the pesticides, the skin can cause by an allergy. **2**. If the people breathe the pesticides, they will cause dizzy.
Betel quid shop	**1.** get the regular income	**1.** daily cost of about 500kyats **2.** dirty the surrounding by spit **3.** spitting sputum repeatedly leads to indigestion **4.** early aging **5.** leading to black teeth	**1.** get job	**1.** tobacco may cause constriction of heart-vessel and hence hypertension and eventually stroke **2.** damage the normal function of liver **3.** the seller's hands may have bruises due to the reaction of lime **4.** consumer's health gradually leading to tooth decay, mouth cancer, tongue cancer, premature ageing and even to death.

Suggestions

Although betel leaf cultivation and betel quid business are beneficial for the cultivators and betel quid shopkeepers, it can harm the consumer's health and pollute the surrounding due to the spit of betel juice.

Therefore, strict rules and regulations concerning with betel pulp juice spitting should be imposed on the consumers not only in Pantanaw but also at public places such as universities, offices, hospitals, on the road and bus stops.

Although betel quid chewing habit is discouraged due to health damage, the number of betel quid chewers is less likely to decrease and the economic activity of betel leaf cultivation and betel quid shopping may continue to survive in Pantanaw Township in the foreseeable future.

Acknowledgement

I would like to express my sincere and profound gratitude to all my teachers who assisted me in preparing this research paper. I owe special thanks to the staffs of offices and local people of Pantanaw for aiding me in the collection of data concerned and their help in my field work.

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ရဲရင့်မင်းခန့်(မြစ်မခ)၊ "မြန်မာနိုင်ငံမှကွမ်းစားသူအယောက်၁၀၀၌ ၃၄ ဦးနှုန်း ခံတွင်းကင်ဆာ ဖြစ်ပွားနေ"၊ နေ့သစ်သတင်း ဂျာနယ်၊ ၄.၆.၂၀၁၄ ။

ပန်းတနော်မြို့နယ်ပထဝီဝင်အနေအထား၊ ပန်းတနော်မြို့နယ်အုပ်ချုပ်ရေးမှူးရုံး။

ရာသီဥတုနှင့်ကောက်ပဲသီးနှံအစီရင်ခံစာများ၊လယ်ယာမြေစီမံခန့်ခွဲရေးနှင့်စာရင်းအင်းဦးစီးဌာန(ပန်းတနော်မြို့)

ရာသီဥတုနှင့်ကောက်ပဲသီးနှံအစီရင်ခံစာများ၊လယ်ယာမြေစီမံခန့်ခွဲရေးနှင့်စာရင်းအင်းဦးစီးဌာန(မအူပင်ခရိုင်)။