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Petrology of metamorphic rocks exposed in Mohauk area, Momeik Township, the boundary of Shan and Mandalay Region

Tin Zaw Oo[*], Nwe Ni Win[**]

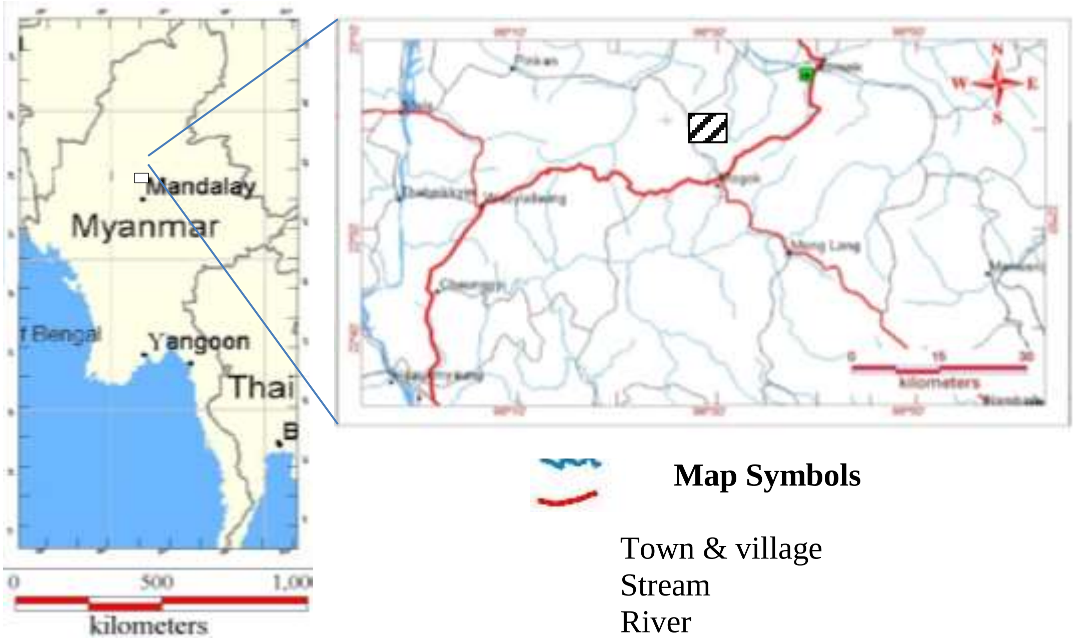
Abstract

The research area is situated about 7 miles from Momeik and 8 miles north west of Mogok in the boundary of Shan and Mandalay Region. Generally, the study area falls within the northern part of the Mogok Metamorphic Belt (MMB). It is bounded by King chaung in western part and the well-known left-lateral strike slip fault, Momeik Fault, in northern boundary of the study area. And thus, the main lithologies exposed are variety of Mogok Series, they are paragneiss and orthogneiss, many types of marbles and calc-silicates that host gem-quality rubies, sapphire and some quartzite. These rocks are intruded by peridotite, granites and various suite of syenites. According to mineralogical and textural evidences study area is affected regional metamorphism and, locally, contact metamorphism (metasomatism). On the basis of mineral assemblages, upper amphibolite to granulite facies has been recognized. The time of metamorphism of the study area can be assigned to Early Cretaceous to Early Eocene and peak- condition occurred in early Cretaceous to Oligocene and younger event would take later, probably in Early Miocene.

Key words: Mogok Metamorphic Belt, mineral assemblages, granulite facies

Introduction

The study area is situated about 8 miles north west of Mogok in Mandalay Region. The area is bounded by the latitude 23° 00' to 23° 07' N and the longitude 96° 22' 30" to 96° 30' 00" E and vertical grids 310 to 440 and horizontal grids 455 to 580 in UTM map **No 2396 08**. It covers about 175.5 square kilometers, with 13.5 kilometer in length and 13 kilometer in width.The location map and geological map of the study area is shown in figure (1) and (2).



Map Symbols

Town & village
Stream
River
Highway Road
Study area

Figure (1) Location map of the study area.

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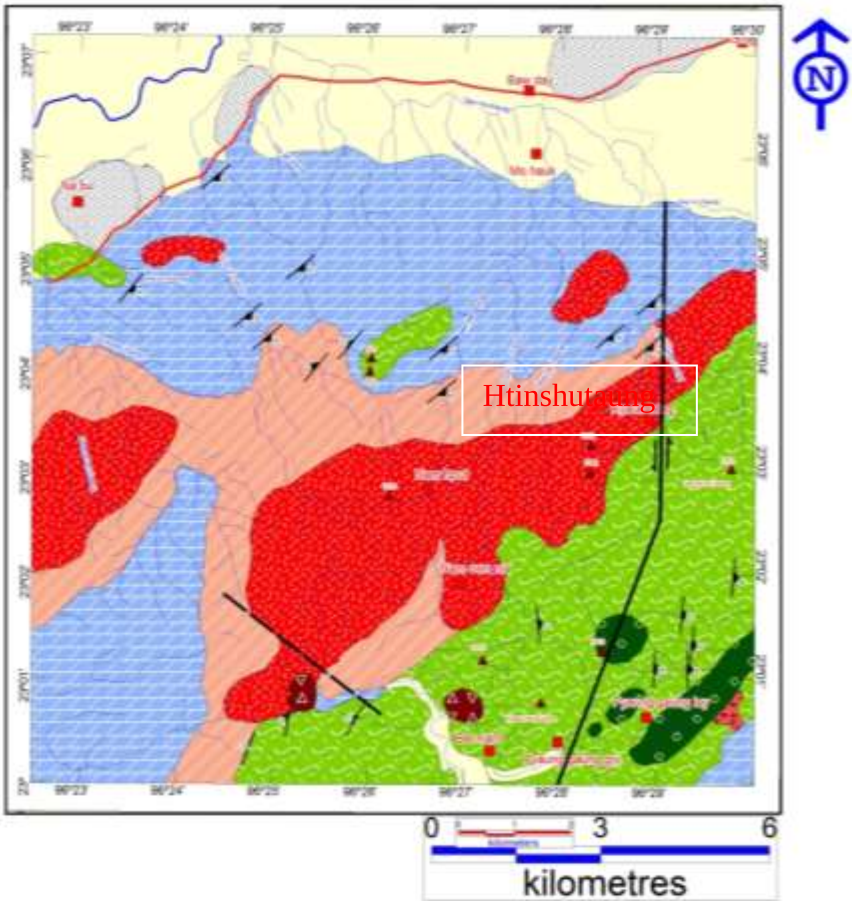
GEOLOGICAL MAP OF THE HTINSHUTAUNG AREA,
MOGOK TOWNSHIPS



STRATIGRAPHIC INDEXS

Alluvium

Late Miocene — Irrawaddy Formation

Igneous Rocks

Middle Oligocene to Middle Mi... — Biotite microgranite (Kabaing)

Syenite

Leucogranite

Jurassic — Mafic-ultramafic rocks

Metamorphic Rocks

Calcsilicate / Quartzite

Figure (2) Geological map of the Htinshutaung area, Mogok Township

Late Proterozoic — Biotite Gneiss/ Garnet biotite gneiss

STRUCTURAL SYMBOLS

Lithologic boundary

Stream / Chaung

Fault

Inferred Fault

Foliation

Peak

Car Road

Jungle way

Village

Map Index

93 A/4	93 A/8	93 A/12
93 B/1	93 B/5	93 B/9
93 B/2	93 B/6	93 B/10

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In the research area, the metamorphic rocks cover almost of all of the area with minor intrusion of different types of magmatic rocks. Generally, based on the observations of mineral assemblages, the metamorphic rocks of the study area fall in the amphibolite to granulite facies of medium to high temperature orogenic metamorphism during the Cretaceous to early Eocene time and metamorphic grade increases from north-west to south-east in the area.

Mineral Assemblages and Metamorphic Facies

Assemblages of coexisting minerals in the metamorphic rock units provide the principal evidence for the metamorphic condition under which they were formed. These mineral assemblages listed below are from the important and distinct rock units established. Certain mineral assemblages may vary considerably in amount because of diverse lithologies and different bulk compositions. Accessory minerals are not listed in the mineral assemblages of some rocks. The distinctive mineral assemblages of the petrographical images are shown in figure (3). For convenience and to emphasize bulk compositional controls on the assemblages of various rock units, they are divided into (7) typical mineral assemblages (table 1).

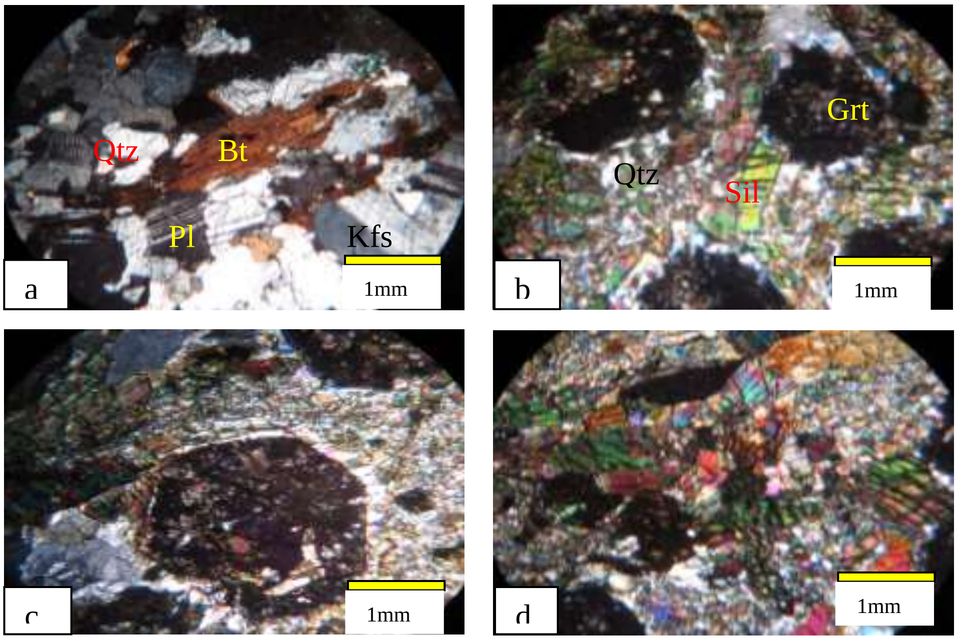

Figure (3). Photomicrophs of representative mineral assemblages and textural relationships in Grt,Bt,Sil,Crd gneiss of MMB. (a)Kfs+Bt+Qtz+Pl assemblages in Bt gneiss; (b) Grt+Sil+Qtz association in Grt gneiss; (c) Grt+Crd+Bt+Qtz with pressure shadow (d) Grt+Opx+Qtz assemblages in granulites.(XN. X 30)

Table (1). The prominent mineral assemblages and metamorphic facies in calcareous and pelitic rocks of the study area.

Index mineral, (pelitic)	**Pelitic rocks**	**Calcareous rocks**	**Facies**
Chlorite			Greenschist
Biotite	K-feldspar + quartz + plagioclase + biotite		
Garnet	chlorite + muscovite + quartz + garnet + biotite	calcite+diopside+ graphite +phlogopite±amphibole	Lower Amphibolite
Sillimanite	garnet+sillimanite+biotite + corderite	Calcite+spinel+diopside+ forsterite+phlogopite± graphite± corundum	Upper Amphibolite
Garnet, Pyroxene	garnet+sillimanite+quartz orthopyroxene +K-feldspar	Calcite+forsterite+diopside+spinel ±corundum	Granulite

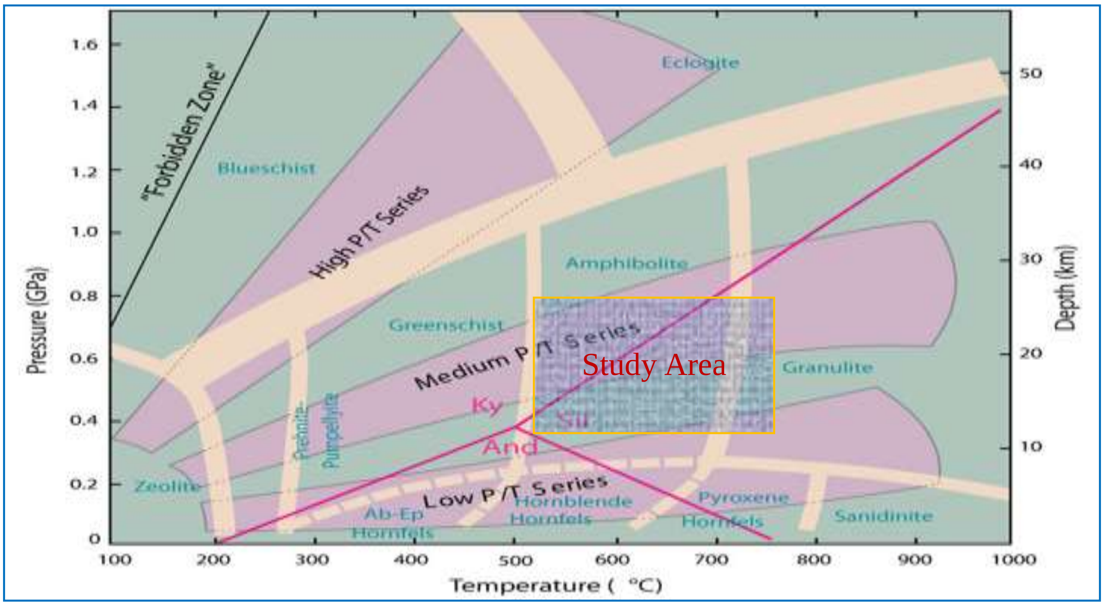

Figure (4). Temperature-pressure diagram showing two major types of metamorphic facies series proposed by Miyashiro (1973, 1994) (in Winter, 2010). The shade rectangle represents the condition of present area.

Types of Metamorphism

The dominant metamorphism of the study area is regional metamorphism which prevailed in metasedimentary rocks of prominent calcareous and peletic compositions. The regional metamorphism in the area is characterized by foliations, lineations, recrystallization, neomineralization, crenulation, minor folding and contorted foliations.

The metamorphic rocks are relatively folded and brecciated throughout the study area, and they show a range in grade of metamorphism from amphibolite facies to granulite facies. The patterns of mineral zones have been disrupted to some degree by intrusions, faulting or other deformation and polymetamorphism.

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Mineral Zone

The mineral paragenesis recognized in study area may be delineated to be indicative of the amphibolite facies to granulite facies in pelitic rocks. On the basis of mineral paragenesis, metapelitic rocks of the study are divided into biotite, garnet, and sillimanite zone, in order of increasing metamorphic grade. These zones are defined by the index minerals and appearance and disappearance of these minerals in pelitic rocks. Simplified zonal pattern of metapelitic rocks is shown in figure (5).

The overall progression of mineralogical changes in the area is biotite-garnet-sillimanite. Characteristic mineral assemblages of the pelitic zones are as follows;

Biotite zone - K-feldspar + quartz + biotite + plagioclase

Garnet zone - garnet + biotite + quartz + chlorite

Sillimanite zone / upper sillimanite zone - garnet + sillimanite + biotite + orthopyroxene

Cordierite-garnet-K-feldspar zone - garnet + sillimanite + biotite + cordierite + K-feldspar

The distinct zonal pattern, biotite zone, garnet zone and sillimanite zone, and mineral paragenesis in the present area is somewhat similar to that of Abukuma-type Facies series of Japan and Buchan-type series, and believed to be rather higher grade of Barrovian series of Scotland. The occurrence of migmatite gneiss with the leucosome intercalation (stromatic migmatite, Yardley, 1989) implies the higher temperature metamorphism. However these migmatites are often of much more restricted extent, closely associated with the intrusion of deeper-derived hot magmatic rocks.

Garnet zone is defined by the first appearance of pyralspite garnet and by the absence of biotite, and chlorite change in composition in rock which is garnet-in isograd (Winkler, 1979). It is easily to trace in the field because garnet appears in a wide range of rock composition as well as in pelites. Frequently it forms conspicuous porphyroblasts and aids to distinguish almandine rich garnets typical of garnet zone from spessartine garnets which may develop at lower grades in Mn-rich sediments, but are usually fine-grained (Yardley, 1998). A mineral assemblage in garnet zone of the present area is generally almandine-rich garnet-chlorite-biotite-muscovite-quartz.

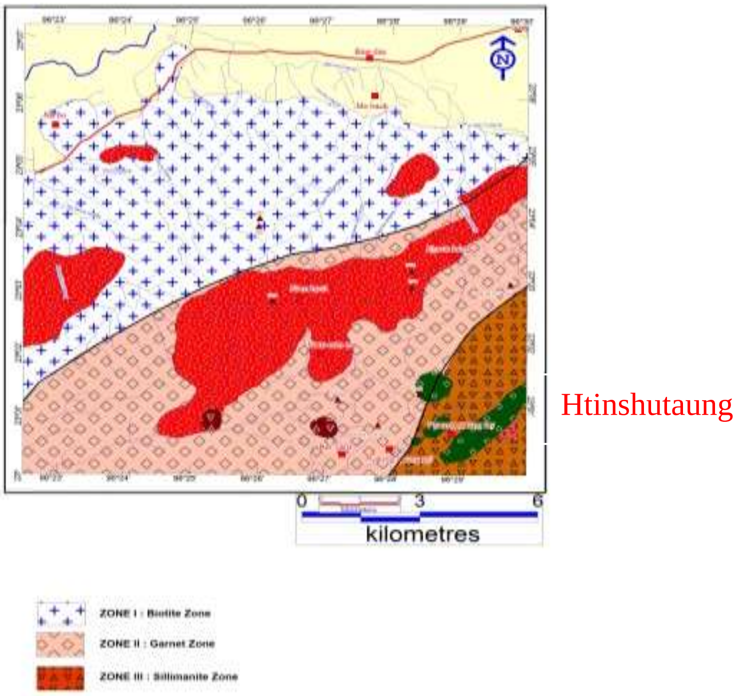

Figure.(5). Schematic metamorphic zone map of the present area (Nouthern part of Mogok), showing distribution of zonal pattern and location of magmatic rocks. The location of granulite sample is marked by star

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In sillimanite and upper sillimanite zone, the sillimanite occurs in the form of very fine needles which is matted together with biotite and quartz. There is no andalusite and staurolite. According to (Yardley, 1998) the upper sillimanite zone is characterized by the coexistence of sillimanite and K-feldspar, rather than by only one mineral and there is no longer muscovite in sillimanite zone. Muscovite breakdown may involve a melt phase and is close to the first developed second sillimanite isograd (Yardley, 1998). The mineral assemblage in the sillimanite/ upper sillimanite zone is garnet-sillimanite-biotite-quartz.

At still higher grades, pelitic rocks develop assemblages with cordierite, garnet, K-feldspar and sillimanite in the cordierite-garnet-K-feldspar zone. Cordierite and garnet develop depending on the pressure condition. Cordierite is favoured by low pressure and garnet by higher pressure. In the cordierite-garnet-K-feldspar zone, garnet- sillimanite-biotite-cordierite and K-feldspar are recognized. The garnet-corderite-K-feldspar assemblage is typical of high grade pelitic migmatite, and is often taken to mark the beginning of the granulite facies, which represents the highest grade zone of the present area.

Winkler (1979) also noted that the transformation of low grade to medium grade is marked by the "almandine-in" in pelitic rocks and "hornblende-in" in mafic rocks. It is taking into account that biotite zone and lower part of the garnet zone belong to lower part of amphibolite facies.

Mineral assemblages in pelitic rocks are garnet-K-feldspar-orthopyroxene-muscovite and garnet-sillimanite-cordierite, which represent the highest grade zone of the present area.

The beginning of the amphibolite facies or the beginning of medium grade metamorphism is constrained by the break between albite and oligoclase or at somewhat higher temperature by the first appearence of staurolite and/or cordierite (Eskola, 1939; Turner and Verhhogen, 1960; Wenk and keller, 1969; in Winkler, 1979).

Staurolite is absent the mineral that develops in a range of Al-rich, Ca-poor pelitic rocks but does not form in other lithologies. Many garnet-biotite gneisses are detrimental to staurolite formation (Yardley, 1989).

From the above mentioned facts, biotite zone in pelitic rocks of present area belongs to the lower-amphibolite facies. The upper sillimanite zone and cordierite-garnet-K-feldspar zone suggest granulite facies which is the highest grade zone of the present area.

Origin of metamorphic rocks

The prominent major rock types of the study area include a variety of marbles, calc-silicates, quartzite, biotite gneiss and garnet gneiss. The exposures of biotite gneiss and garnet gneiss are widespread in the area and the exposures of marbles and calc-silicates are overlain the biotite gneiss and garnet gneiss units. On the basis of mineral paragenesis and textural criteria, the metamorphic rocks of the study area belong to two types of sedimentary protoliths: calcareous and pelitic.

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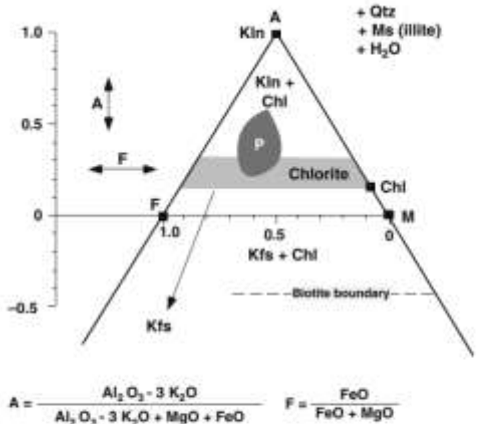

Figure (6). AFM diagram for average compositions of pelitic rocks fall into the dark shaded area and is represented by P. AFM coordinates of minerals and rocks can be calculated from equations given below the figure (molar basis). (source: Bucher and Grape, 2011)

Metapelites are mainly composed of Al_2O_3, FeO + Fe_2O_3,H_2O, MgO, K_2O, Na_2O, TiO_2 and CaO. In the chemographic representation metapelite compositions are often approximated by the six-component KFMASH system, that include the six most abundant oxides above and representing total iron as FeO. The average compositions of pelitic rocks can be graphically represented by the dark shaded area, represented by P in AFM diagram (Fig. 7). Sodium is mainly stored in feldspar (Ab) and paragonite. The low amount of CaO in clays is, in metapelitic rocks, present in garnet (Grs component) and plagioclase (An component).

Lack of chloritoid, typical of low grade metamorphic rocks of pelite, in the study area indicates that the primary chemical composition of pelite is low in Fe/Mg ratio and implies relatively small Al content and simultaneously high contents of K, Na, and Ca (Winkler, 1979). The particular bulk rock chemistry leads to the absence of chloritoid from assemblages including biotite, albite and/or K-feldspar.

Biotite gneisses and garnet-biotite gneiss are typical metamorphic product of low Al shale/siltstone. They are often referred to as semipelitic shale (Bucher & Frey, 1994).The original rock sequence of the metasedimentary rocks from the study area shows bedded sequence of peletic rocks, dolomitic limestone, calcareous limestone and siliceous limestone.

Searle and Ba Than Haq (1964) mentioned that the Mogok Series is equivalent to the stratigraphic units of Shan Plateau ranging from Precambrian to Upper Paleozoic in age.

The presence of siliceous nodules in the marble east of Wabyutaung (Maung Thein, 1979), east of Kyetsaungtaung (Maung Maung, 1986) and northeast of Chaunggyi (Myint Naing, 1987) implies that these marbles are metamorphosed Plateau limestone.

Based on the lithologic similarity, Myint Lwin Thein et al., (1990) suggest gneisses, marbles and related rocks of the Mogok metamorphic belt are metamorphosed equivalent of the Lower Paleozoic carbonate rocks of southern and northern Shan States.

As previously described, the study area form part of northern continuation of the Mogok Belt and is mainly made up of medium to thick bedded of marbles and calc-silicate rocks. They closely resemble those of the Ordovician Limestone group but the chert nodule is not occurred in marble of the study area. Furthermore, very thick, high temperature pelitic gneisses(Mogok gneiss) is stratigraphically overlained by the marble and calc-silicates .Thus, based on stratigraphic position the pelitic rocks of biotite gneiss and garnet biotite gneiss (Mogok gneiss) are chronologically older than the marble and calcsilicates and therefore the protolith age of the pelitic gneisses (Mogok gneiss) may be upper Proterozoic. And then the lithologic similarities lateral continuity, and regional framework, the age of marble and calcsilicate rocks of the study area is thought to be Lower Paleozoic age.

Time of metamorphism

The study area form the northern striation of the Mogok metamorphic belt (MMB), where the belt sharply bends east-ward in a sickle shape and to the north, it reaches the eastern part of the Kachin State. The metamorphic events along the MMB have been the source of numerous discussions: many authors have considered the metamorphism along the MMB as Precambrian to Paleozoic (La Touche, 1913; Iyer, 1953; Bender, 1983; Wolfort et al., 1984), some authors have suggested the metamorphic rocks equivalent of younger series such as the Silurian Mawchi Series (Clegg, 1954; in Searle & Haq, 1964) and the Cretaceous Orbitolina bearing limestone of Mogok (Clegg, 1941).

Searle and Ba Than Haq (1964) mentioned that the age of metamorphism of MMB must have been Post Paleozoic and almost certainly related to the Himalayan Orogeny.

Maung Thein and Ba Than Haq (1969) documented that the radiometric date of 40 Ma for the phlogopite from the marble of Mogok suggests the age of regional metamorphism in the Mogok area to the Late Eocene.

Myint Thein et al, (1982) studied the Mogok belt and stated that the majority of Mogok rocks in the area, west of Ayeyarwady river, were inliers forming a basement for Tertiary sediments and that the Mogok metamorphism took place before Tertiary.

Recently, the radiochronological analyses have been conducted on metamorphic samples from the MMB. Radiometric dating by GIAC (1999) indicates that the latest regional metamorphism in the Mogok area occurred during Late Oligocene to Early Miocene.

Bertrand et al, (1999) analyzed the metamorphic rocks from the MMB ranging from Oligocene to Middle Miocene. Moreover, they stated a slight diachronism with ages decreasing from the south to the north within the belt. Bertrand et al., (2001) also analyzed several types of micas (biotite, muscovite and phlogopite) from the MMB to confirm the above ages ranging from Oligocene to Middle Miocene. They proved the age range from 25.9 to 26.9 Ma for the southern Shan Scarp (Thaton area), from 18.4 to 22.7 Ma for the northern continuation of Shan Scrap and Mogok range, respectively. They also stated that the NNW-SSE trending ductile extensional deformation in Mogok area was intruded by the Kabaing granite and that yielded the age of 15.28 ± 1.1 Ma on biotites.

Myo Min (2007) studied the temporal relationship between India-Eurasia collision and the episode responsible for the exhumation history and peak metamorphism along the MMB in Central Myanmar. Based on new Ar/Ar, apatite and titanite fission-track thermochronology and apatite (U-Th), he described that Mogok-Twinnge area has an Ar/Ar muscovite age of 15.8 Ma, an Ar/Ar biotite age of 19.5 Ma and an AFT (Apatite Fission- Track) age of 7.4 Ma. Based on these ages he interpreted that the Mogok – Twinnge area had rapid cooling rate in the MMB from south to north significantly from 50°- 22°C/Ma.

The granulite-facies rocks near Mogok may be Precambrian (Garsin,1992) while schists and marbles with a Permian fauna near Kyaukse indicate Mesozoic or younger regional metamorphism(Maung Thein and Soe Win, 1970).

Searle et al., (2014) proposed the three metamorphic events with the magmatic events in MMB with dating.

(1). Late Cretaceous – Palaeocene metamorphism >71-59 Ma cut by 59 Ma intrusion of Bt granite dykes (Belin).This metamorphism occurred before theintrusion of 210-170 Ma orthogneiss protoliths and ~170-120 Ma granitic orthogneisses.

(2). High grade metamorphism – 47-43 Ma SHRIMP ages of zircon overgrowths- 46.33 Ma leucogranite (Kyaushe) - Age of ruby crystallisation in Mogok.

(3). High-grade metamorphism - 37-29 Ma 29.4 ± 0.15 Ma Metamorphism or ? retrograde resorption of garnet & replacement of andalusite, (Kyaukse). Finally intruded the 24.5 Ma S-type tur/grt leucogranite melts (Kyanigan) and 22 Ma (Rb Sr) – Sedogranites.

Based on the above mentioned points, the time of metamorphism of the study area can be tentatively assigned to Early Cretaceous to Early Eocene and peak- condition occurred in early Cretaceous to Oligocene and younger event would take later, probably in Early Miocene.

Discussion and Result

Temperature-pressure conditions of metamorphic rocks in the present area are depicted in figure (7) with their respective facies and zones. P-T conditions to decipher the metamorphic evolution of the rocks have been estimated by three methods: (1) considering the P-T ranges of critical metamorphic assemblages known as metamorphic facies and formation on the minimum conditions for recrystallization of particular minerals, (2) using the empirically and experimentally determined geotherometers such as the garnet- clinpyroxene thermometer of Ghent (1979), and conducted thermodynamic calculations of numerous mineral equilibria relevant to the assemblages observed here.

Metasedimentary rocks of the study area are classified into three distinct zonal patterns based on the appearance and disappearance of index minerals; biotite, garnet and sillimanite/upper sillimanite zones. Reaction isograd and petrogenetic grids are estimated from the equilibrium mineral assemblages of the rocks. Near 400° C, the first biotite appeared in Al-poor metapelites. Biotite formed at the expense of Kfs and Chl. The reaction gives equilibrium conditions of 420° C at about 350 MPa along the Ky-type path in the pure KFASH system. Prograde metamorphism along a Ky-type geotherm produced Bt at about 520° C,the first Grt at 540° C and finally St at 560° C. The three-phase assemblage Grt–Bt–St is characteristic for much of the amphibolite facies. Fe-rich chlorite was replaced by garnet –biotite between 500° C and 520° C. The new assemblage Grt + Bt remains stable to very high grades, and Fe–Mg partitioning between the two minerals is a common of geothermometer. The new diagnostic assemblage is garnet + biotite + sillimanite and marks the beginning of the upper amphibolite facies. This boundary also coincides with the production of the first melt in rocks of suitable composition at H_2O-saturated conditions.

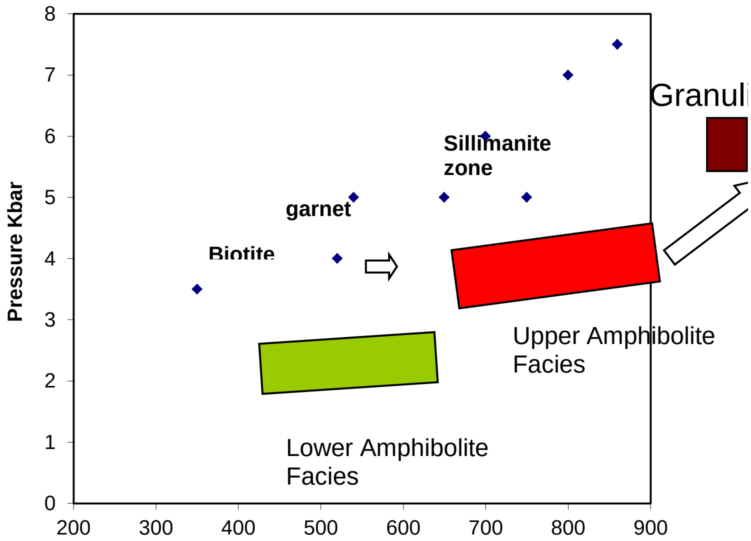

Figure (7). P-T trajectory estimation for each zone of metapelitic rocks and granulite in present area.

Crd–Grt–Kfs–Bt gneisses are transitional between upper amphibolite and granulite facies conditions and the assemblage often indicates equilibration under conditions of reduced PH2O. The representative assemblage in such rocks is Crd-Grt-Sil-Bt. It forms at P–T conditions similar to the Kfs-bearing Crd-gneisses. They are most typically found in terrains that have been metamorphosed at 300–500 MPa and 650–750̊ C. The pair Opx + Sil is restricted to P>600 MPa at 700̊ C and toP > 750 MPa at 860̊ C.

Mineral assemblages, mineral paragenesis, zonal pattern and metamorphic facies series are roughly similar to the medium pressure type Barrovian metamorphic style such as biotite, garnet and sillimanite zone. But the study area is relatively higher the Burrow's zone because of the occurrences of garnet, sillimanite minerals that suggest the second sillimanite isograd. Therefore the study are is more similar to Buchan types. Yardley (1989) pointed out that garnet is pressure sensitive and biotite relies on temperature. Biotite is rare or absent in high pressure metamorphic terranes. Also, plagioclase feldspar is entirely absent at very high pressures (Miyashiro, 1961; there in Enami, 1983), and garnet is indicative to medium to high pressure and is absent from metabasites metamorphosed under low pressure conditions, as in most contact aureoles.

Formation of staurolite in biotite zone is controlled by the bulk composition as well as metamorphic conditions. It can be generally stated that the common ferromagnesian minerals contained in pelitic rocks are controlled by the Fe/Mg and Al/Si ratio of parent rocks (Spear, 1993; Zaw Win Ko, 2005). Thus the Al and Fe rich bulk rock composition of the pelitic sediments is suitable for the occurrence of staurolite. However, pelitic rocks in present area are mainly rich in biotite, subordinate in albite, and rare in alkali rich minerals so that staurolite cannot be formed in biotite zone of the present area.

Based on the above criteria, metamorphism and metamorphic conditions of the present area are fairly similar to those of the Barrovian metamorphic terranes in Scotland. Again, the rocks are true pelites for epidote group minerals and hornblendes are rare.

In addition, the first major deformational episode in the present area produced the predominant foliations and lineation in all rock types accompanied by progressive high P-T metamorphism. The event is characterized by a penetrative flattening foliation and in most gneisses by megascopic scale inclined to recumbent isoclinal folding of the primary layering. In general, the style and intensity of folding vary depending upon the lithology, pre-existing anisotropy and the competency of the rock types. Microscopic post-crystalline strain are common in most gneisses, as evidenced by minor rotation and fracturing of porphyroblaststic garnet, bent micas and strained grains. This post-crystalline strain was followed by a low P high T metamorphism, as evidenced by static overgrowths of cordierite and sillimanite. Both this post crystalline strain and the post kinematic low-P high T metamorphism are interpreted as related to syn-magmatic metamorphic event and later deformation episode.

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