Petrography of the Igneous and Metamorphic Rocks around Tetlet Area, Mohnyin Township, Kachin State

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Abstract

The study area is situated in the northwestern part of the Indawgyi Lake, Mohnyin Township in Kachin State of the northern Myanmar. It is bounded by North Latitudes 25º 20′ to 25º 24′ and East Longitudes 96º 16′ to 96º 22′ in one inch topographic map of 84 C-7. It is mainly composed of metamorphics and igneous rocks. The metamorphic rocks in the study area are subdivided into three informal units, namely Unit I, Unit II and Unit III. Unit I is chiefly composed of micaceous quartzite, biotite schist and garnet mica schist. Unit II mainly consists of graphite mica schist and muscovite schist. The uppermost Unit III is essentially composed of actinolite schist, epidote muscovite schist, chlorite schist and talc chlorite schist. The igneous rocks are mainly serpentinite, basalt and gabbro. More than 80 rock samples were cut from various representative rock samples, which were made thin sections and prepared for petrographic interpretation. Diagnostic mineral assemblages are used to identify the metamorphic facies of metapelites and metabasites. At least eight representative equilibrium mineral assemblages are defined of which seven belong to metapelites and the remaining one to metabasites. Greenschist facies is well documented by the mineral assemblages of chlorite-talc-muscovite-quartz, chlorite-muscovite-quartz, epidote-chlorite-muscovite-quartz, chlorite-graphite-muscovite-quartz and chlorite-muscovite-biotite-albite-quartz in metapelites and actinolite-epidote-albite-chlorite-quartz in metabasite. Mineral assemblages of biotite-muscovite-quartz and garnet-biotite-muscovite-chlorite-quartz in metapelite represent the epidote-amphibolite facies. Concerning metamorphic grade, it increases from east to west in the study area.

Key Words: Tetlet, Metapalites, Metabasites, Greenschist facies, Epidote – amphibolite facies

Introduction

Location, Arial Extent and Accessibility

The study area is situated close to the NW part of the Lake Indawgyi, located in Mohnyin Township in the Kachin State of the Northern Myanmar. The area is bounded by Latitude 25˚ 20´ N and 25˚ 24´ N and Longitude 96˚ 16´ E and 96˚ 22´ E in one inch to one mile scale topographic map of 84-C/7. It is 5 miles (N-S) long and 6 miles (E-W) wide, covering approximately 30 square miles.

It is accessible through the recently developed Nyaungbin-Saingdaung pass from Hopin on the Mandalay-Myitkyina railroad and Belumyo-Namma pass from Mohnyin on the Mandalay-Myitkyina railroad only during dry season. The location map of the study area is shown in Fig.(1).

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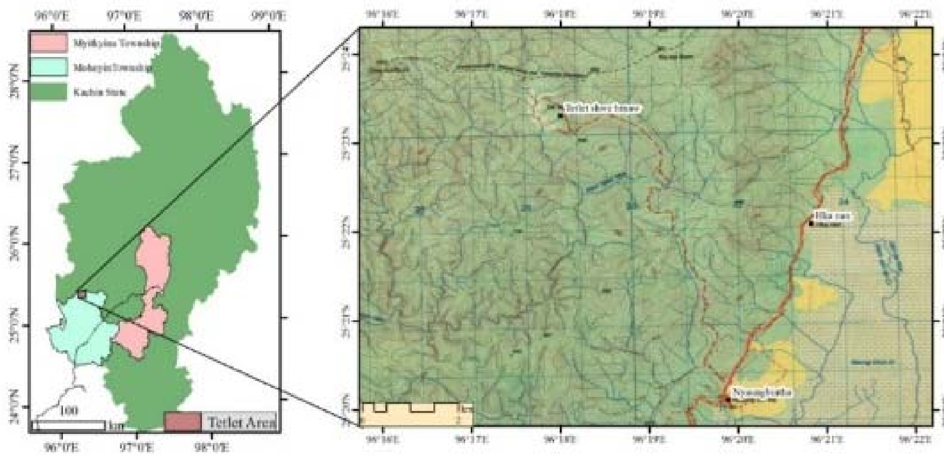


Figure (1). Location map of the study area.

Regional Geologic Setting

Mitchell (1981) divided the Myanmar region into four plates, viz., (1) Indian Plate lying west of the Indo-Burma Ranges; (2) The Eastern Burman Plate extending from the Indo-Burma Ranges to the Sagaing – Namyin Fault; (3) The Shillong Plate lying north of the Naga Hills; and (4) the Asian Plate lying east of the Sagaing-Namyin Fault. The regional tectonic setting and three dimensional view of the study area and its environs are also shown in Figs. (2 & 3).

The study area lies close to the western margin of the Indo-Burma Ranges (Kachin-Shan-Tenasserim Highlands or Eastern Highlands) (Bender, 1983). The study area falls within the eastern part of the Western Burma Plate and western part of Asian Plate, (Mitchell, 1981). Beyond the northern limit of the area, Hukawng Basin, Jade Mine Belt and Kumon Ridge, define the important tectonic features and the ancient volcanic peak of Taungthonlon (a part of central Volcanic Line) lies as the Upper Cenozoic volcano, about 80 km SW from the study area.

Generally, a large part of the Northern Myanmar is composed mainly of ultrabasic, basic igneous, sedimentary and metamorphic rocks, ranging in age from Precambrian to Quaternary with intrusions of granitic and gabbroic rocks of unknown age. This area is partly included in Kumon Range of Upper Ayeyarwaddy Province which consists of three belts; Tagaung – Myitkyina belt, Katha – Gangaw Range and Kumon Ranges (United Nation Team, 1978).

Tagaung – Myitkyina Belt, is a poorly mapped terrane characterized by basic and ultrabasic rocks of ophiolite suites mostly forming inliers within Late Tertiary sediments and alluvium. It extends from Tagaung Taung, east of the Ayeyarwaddy, northwards through Myitkyina to Sumprabum. Tagaung-Myitkyina Belt narrows northwards between Mogok belt and Kumon range (United Nation Team, 1978).

The Kumon Range, western part of the area, consisting of Upper Cretaceous to Tertiary sedimentary rocks including study area is structurally part of the western Trough. The range is bordered in the east and west by Oligocene and younger sediments and in the northeast bounded by the Miju Thrust (United Nation Team, 1978).

The northern part of the area, Jade Mine Belt (JMB) is well known, consisting of hornblende schist, glaucophane schist, chlorite schist, kyanite schist and graphite schist (Chibber, 1934b). The regional strike slip fault (Sagaing Fault) cuts Oligocene-Miocene sedimentary rocks, passing through Indawgyi Lake on the southeastern part of the area with a general trend north to south.

The southern part of the area is covered by Pleistocene gravels, Irrawaddy Formation, Upper Pegu Group, (Myint Thein et al., 1983), Cenozoic volcanics and ultrabasic igneous rocks (serpentinite), Mayathein Complex. Katha Metamorphics, Ngapyawdaw Chaung Formation and Wabo Chaung Formation (Myint Thein et al., 1983).

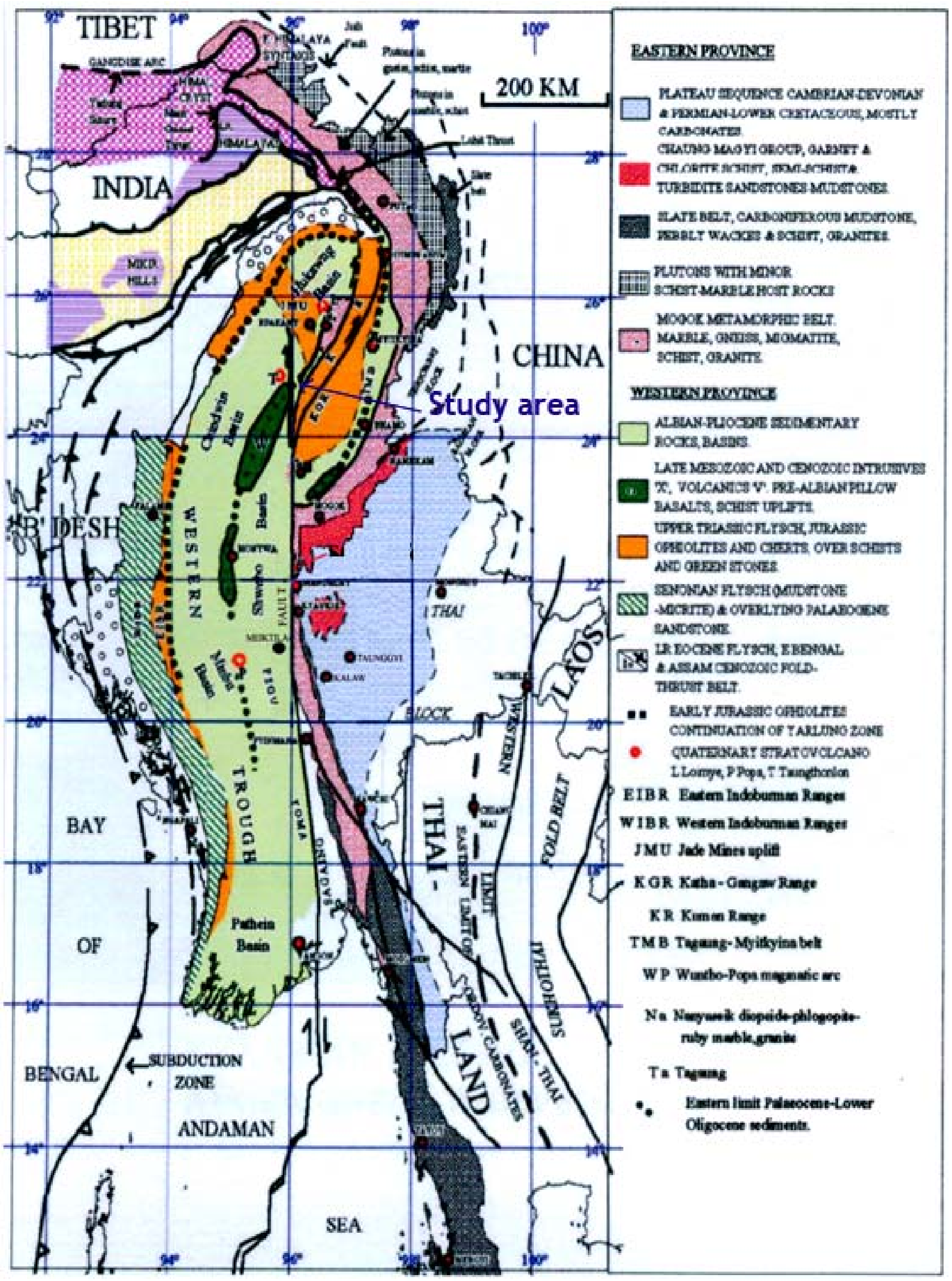


Figure (2). Structural units in northern, central Myanmar and adjacent areas. (from Ivanhoe Myanmar Holding, Ltd., Unpub. report , 2005 in Mitchell, 2007).

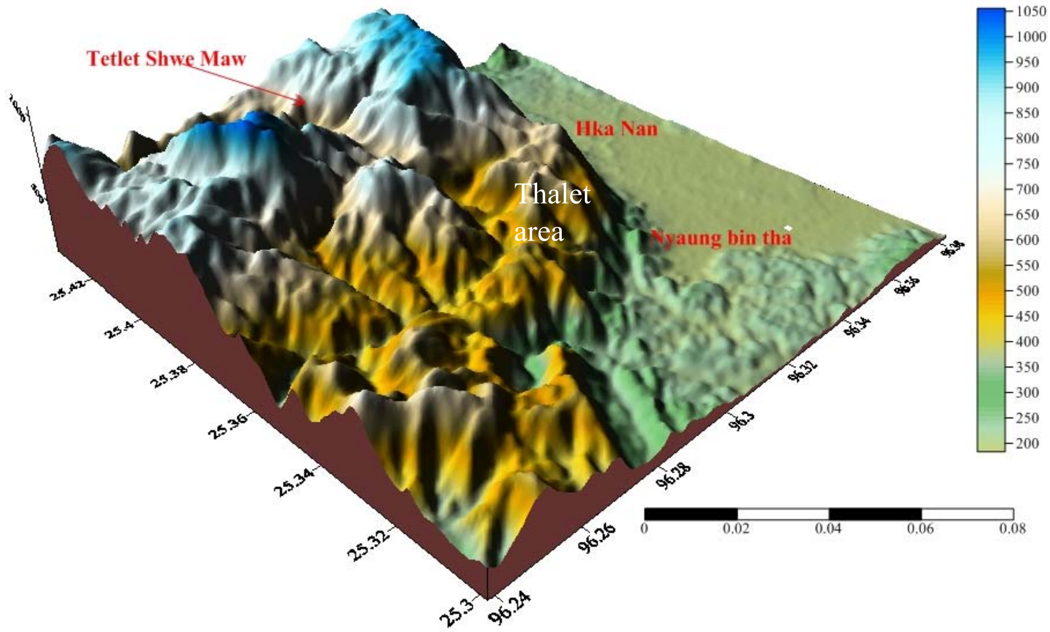


Figure (3). Three dimensional view of the study area.

Previous Works

The study area is remote and densely vegetated so that geological observations are difficult to be done. It is the immediate southern continuation of the Jade Mine area, works related to the aspects of the precious mineralogy have never been published. Some prominent work have been done on Jade mine area where jadeite deposits of economic sizes and their associated metamorphic and sedimentary rocks are exposed.

Chibber (1934) studied the Jade Mine area noted that associated rock types are crystalline schist, serpentinized peridotite, granite, gabbro and Tertiary sedimentary rocks. As his data collections were specially intended for the exploitation of jade, he mapped and described some geology in details of the northern part of the under investigation. Hutchison (1975) suggested the Jade Mines are to be in the bifurcation of the north trending Mandalay ophiolite line in the evidence of occurrence of ultramafic rocks in abundance and imbrications of the ophiolite suite were noted to be a plate contact in the geosuture between the India and Chinese massif.

Soe Thura Tun (1998) described the geology of Indawgyi area and the amphibolite and amphibole schist are characteristic metamorphic rocks. In 2006, Hla Htay assigned the Jade Mine and its surrounding areas into the Central Ophiolite Belt of Myanmar.Aung Win (2008) described the petrogenetic studies of metamorphic rocks in Mogaung area, northeastern part of the area and investigated that metamorphic rocks are essentially low to medium grade, regionally metamorphosed schist and quartzite with minor amounts of metabasite, eclogite rock and metagranite.

Nyan Win (2008) described the petrogenetic study of the metamorphic rocks in Mohnyin-Namma-Hopin area, southwestern part of the area. He proved the medium-grade garnet zone and high-grade kyanite zone.

Purposes of Study

The research work involves literature study, field and laboratory investigations with the following purposes in mind.

1. To describe the stratigraphy, petrology and mineralogy of the rocks.
2. To interpret the metamorphic facies of the area in terms of observed minerals assemblages.
3. To draw a geological map of the research area.

Methods of study

The one-inch topographic map 92 C-7 is used as base map. The map is enlarged to a scale of 4 Inches to a mile. GPS instrument and Brunton compass are used extensively in the field, for measuring specific locality, foliation, joints, trends, bearings, dip and strike, etc. With the use of landsat images major geological stuctures, lithologic contact and sstuctural trends were plotted on the map and these data were checked in the field, and necessary corrections were made. The rock samples collected in the field were cut, polished and ground to prepare thin sections. Then, 80 thin sections of various rocks were studied under a petrological microscope. Detailed studies under the petrographic microscope are used for petrographic analysis and then the results are used to interpret the petrogenetic consideration.

Stratigraphy

General Statement

The area under investigation is located between the Taung Chaung Fault and Sagaing-Namyin Fault. This area is chiefly composed of igneous and metamorphic rocks. The geological ages of these rocks are regarded as most probably late Jurassic to early Cretaceous for the metamorphics and Cretaceous to Eocene for igneous rocks respectively. Based on the field observation, the possible rock sequence is (in descending order) shown in Table (1).

Lithologic Unit	**Ages**
Alluvium	Quaternary
Igneous Rocks	~~~~~~~
Serpentinite	Cretaceous to Eocene
Basalt	
Gabbro	
Metamorphic Unit	
Talc chlorite schist	Late Jurassic to Early Cretaceous
Epidote muscovite schist	
Actinolite schist	
Muscovite schist	
Graphite mica schist	
Garnet mica schist	
Biotite schist	
Micaceous quartzite	

Distribution and lithology of Rock Units

Talc chlorite schist is exposed along the Tetlet - Waikhar cart-road (GPS: N25º 24′ 57.2″ E 96 º 17′ 39.8″). It is light green to dark green in color on fresh surface, fine-grained texture and soapy appearance on the surface (Fig.4).

Epidote muscovite schist is well exposed in the downstream of the Sa-gyin Chaung (GPS: N 25º 25′ 14.4″ E 96º 16 ′46.3″) (Fig.5). It is yellowish brown on weather surface and light grey in color on fresh surface, fine- to medium- grained and well bedded. Quartz veins are present in it. It dips about 35º towards N85ºE.

Figure (4). Dark green talc chlorite schist exposed along the Tetlet – Waikhar cart road.

Figure (5). Light grey, well bedded epidote muscovite schist exposed in the downstream of the Sa-gyin chaung.

The actinolite schists is found in the Pidaung Chaung, north of the Tetlet village (GPS: N 25º 24′ 57.2″ E 96º17′39.8″) and Taungsin chaung (GPS: N 25º 25′ 18.9″ E 96º 16′ 55.6″). It is fine to medium-grained, thin- to medium- bedded and light grey on fresh surface, quartz vein are intercalated in this schist (Fig.6).

Muscovite schist is thin to medium bedded, yellowish brown and variegated color fresh surface exposed in the western part of the Tetlet village, near Thawe Gem Company Limited compound (GPS: N 25º 23′ 19.5″- E96º 17′ 38.9″). In some places, it is thinly laminated. Gold bearing quartz veins are both concordant and discordant with muscovite schist. Quartz veins are numerous in it (Fig.7).

Figure (6). Light grey, thin to medium bedded actinolite schist exposed at Taungsin chaung.

Figure (7). Yellowish brown color well bedded muscovite schist exposed in western part of Tetlet village.

Graphite mica schist is cropping out locally west of Tetlet Village in the stream called the Taungsin chaung (Fig.8 A&B) (GPS: N 25º 23′ 09.3″– E 96º 16′ 55.4″). It is fine- to medium- grained, lead grey colored, soft and friable. It is well foliated and contains quartz, feldspar, graphite and other accessory minerals. Quartz veins are cutting across the graphite mica schist.

Figure (8). Lead grey color graphite mica schist cropping out west of Tetlet village (A) and in the Taungsin chaung (B).

Garnet mica schist is well exposed in the Taungsin chaung (GPS: N 25º 23′ 10.2″- E 96º 17′ 01.3″). It is generally light grey to dark grey on both weathered and fresh surface and is fine to medium-grained and thinly foliated. It is hard and compact. In some places, mullion structure is found in the garnet mica schist (Fig.9).

Biotite schist is exposed at the southern part of the Tetlet Village (Fig.10) (GPS: N 25º 22′ 49.3″ E 96 º 18′ 14.3″) in the stream of Nankan Kha (GPS: N 25 º 22′ 22.7″ E 96 º 18′ 14.7″). It is fine to medium grained and greenish grey in color and thinly foliated.

Micaceous quartzites are mainly exposed at the upstream of Sa-gyin chaung (GPS: N25º 25′ 01.5″ E 96º16′ 52.5″) west of the Tetlet Village and the Nakhan chaung (Fig.11) (GPS: N 25º 21′ 27.8″ E 96º 17′ 53.2″) southeast of the Tetlet Village. They are medium to fine grained, whitish to light grey and well-bedded. Generally these rocks are nearly vertical in some places. Quartz veins (>12 inches) are intercalated and some veins are folded concordantly with the host rock in the Sa-gyin Chaung.

Figure (9). Light grey color garnet mica schist exposed near the Taungsin chaung.

Figure (10). Greenish grey color biotite schist exposed in the southern part of the Tetlet village.

Figure (11). Micaceous quartzite unit exposed along the Nakhan chaung.

Age and correlation

Due to the lack of precise radiochronology of the present area, possible stratigrpahic position and age are determined based on the field observations, lateral continuity to other established lithostratigarphic units and lithologic correlations. The area to the south is the Phyu Taung Metamorphics (Triassic in age) of Banmauk area (UN Team, 1976). Metamorphic rocks exposed in the area are lithologically similar and laterally continuous to Katha-metamorphic rocks exposed in the Katha-Gangaw-Tigyaing (Myint Thein et al., 1983) are separated by Sagaing-Nanyin Fault.

Bender (1983) considered that the Paleozoic rocks of the West Kachin Highlands are linked with the Triassic Kanpetlet schist and rocks of Assam region. Mitchell (2007) described the lower grade metamorphics of Tagaung – Myitkyina belt are locally overlain by upper Triassic turbidites, serpentinized harzburgites, basalt and cherts preserved in synclines and overlain unconformity by mid-Cretaceous Limestone (Clegg, 1941). He also regarded that mica schist in the eastern part of Indo-Burma ranges is probably the southwestward continuations of the Katha-Gangaw range. The schists are overlain structurally by upper Triassic turbidites first described by Theobold (1871) and associated harzburgites, hornblende pegmatite with Jurassic (UN, 1978), pillow basalt and amphibolites.

The jade mine uplift of northwestern Myanmar consists of garnet schists and gneisses with local glucophane within sinuous serpentinite bodies, dikes or veins of jadeite and albite. Jadeite clasts occur in lower Miocene conglomerate. Isolated bodies of middle Permian limestone with fauna similar to those of the Thisipin Limestone of Shan Plateau occur in Jadeite Mine area (Mitchell, 2007).

In Jade Mine Belt, phyllite, kyanite amphibolite schists, garnet mica schsits intruded by gabbro and by sill-like bodies of serpentnite, peridotite and chromite bearing dunite have been described by Noetling, 1893; Chhibber, 1934; Clegg, 1941; Brunnschweiler, 1966. Limestones commonly crystalline but in places, with corals and foraminifera of Albian-Cenomian age are widely distributed associated with serpentinites (Clegg, 1941).

Myint Thein et al., (1983) suggested that the occurrences of Katha Metamorphics may be derived from the psammitic, carbonate rocks as well as pelitic rocks of Ngapyawdaw Chaung Formation of middle to upper Triassic age.

Aung Kyaw Thin (2006) considered that the metamorphic rocks of calc-chlorite schist, chlorite schist, and biotite schist can be put into the Ngapyawdaw Chaung Formation of late Jurassic to Early Cretaceous age. The microfossil, radiolarian-bearing chert of Ngapyawdaw Chaung Formation at Taugaung area might be considered of Middle Jurassic to Early Cretaceous in age (Personal communication with Dr Maung Maung).

Hla Htay (2006) suggested that the metamorphic rocks of Myitson area, associated with ophiolite rocks and Cretaceous Limestone are equivalent of Ngapyawdaw Chaung Formation.

Aung Win (2008) noted that the metamorphic rocks in the Mogaung area, east of the present area, were primarily derived from the pelitic and psammitic rocks with metabasite rocks of Ngapyawdaw Chaung Formation of late Jurassic to early Cretaceous age.

Nyan Win (2008) described that the metamorphic rocks of Mohnyin-Namma-Hopin area, south of the present area, are middle Jurassic to early Cretaceous in age.

Therefore, the metamorphic rocks of the present area may be concluded to Late Jurassic to early Cretaceous.

Undifferentiated Igneous Units

In the present area, only three igneous rock units viz., serpnetinite basalt and gabbro are exposed. Serpentinite body is well cropped out east of the Tetlet village and gabbro is well exposed in the stream of Taungsin chaung near Tetlet village. Bannert and Helmcke (1981) suggested the occurrence of igneous rocks in the northern Myanmar as an older (? Jurassic) subduction zone between the Eurasian plate and the old Tethys Ocean can be connected with the ophiolites and mélanges of the Indus-Tsangpo Suture. Bender (1983) stated that the emplacement of the serpentinite was probably considered of Cretaceous to Eocene.

Soe Thura Tun (1998) stated that the igneous rocks of the Indawgyi area, southeastern continuation of the present area was as young as the Cretaceous.

Serpentinite

Generally, they are well exposed in the eastern part of Tetlet village (Fig.12) (GPS: N 25º 23′ 26.9″ – E 96º 18′ 13.0″). They are generally massive, hard and compact and olive green in color. But they show dark green color on the weathered surface. Slickensides (Fig.14) are commonly found in this unit.

Basalt

The outcrop of the basalt occupies in the eastern part of the study area especially along the Nan-Hkam Chaung (GPS: N 25º 22′ 30.4″ and E 96º 19′ 26.2″). The rock is dark gray color on the weathered surface and dark green color on fresh surface. It is fine grained, hard and compact and massive (Fig.13). The basalt shows pale green in color due to alteration (GPS: N 25º 24′ 08.3″ E 96º 17′ 51.0″).

Gabbro

Gabbro is well exposed at the downstream of the Taungsin chaung (GPS: N 25º 23′ 07.6″ – E 96º 16′ 51.5″). It is dark brown to dark color and has granular texture. It is medium to coarse grained, hard, compact and massive. It is also found as boulders (Fig.14).

Figure (12). Serpentinite body exposed in the eastern part of Tetlet village.

Figure (13). Good exposures of gabbro at the downstream of the Taungsin chaung.

Figure (14). An outcrop of basalt in the upstream of Nankhan Chaung.

GEOLOGICAL MAP OF THE TETLET AREA, MOHNYIN TOWNSHIP, KACHIN STATE

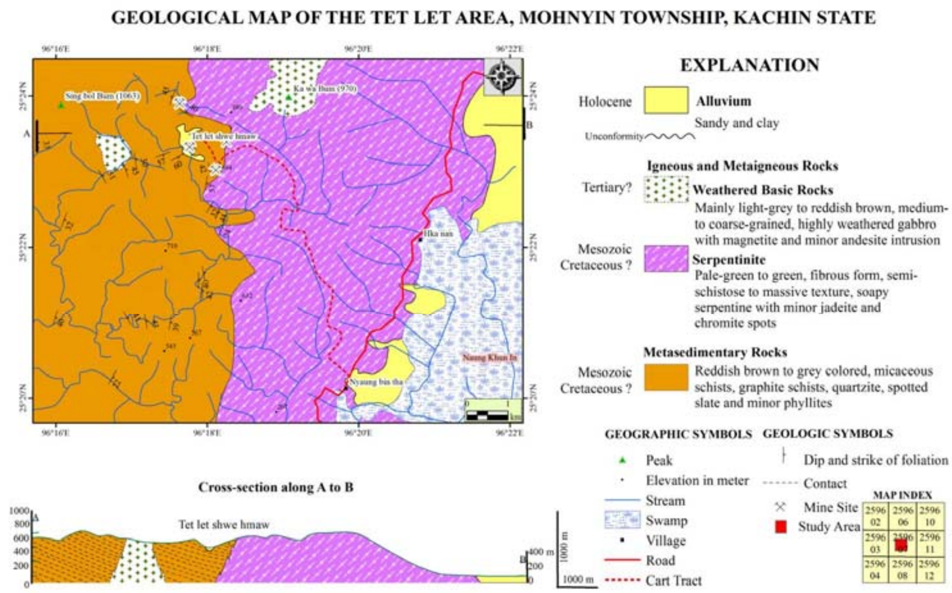


Figure (15). Geological map of the study area.

Petrography

General Statement

The study area is chiefly composed of metamorphic rocks. The metamorphic rocks in the study area are subdivided into three informal units namely Unit I, Unit II and Unit III. Unit I is chiefly composed of biotite schist and garnet mica schist. Unit II mainly consists of graphite mica schist and muscovite schist. The uppermost unit III is essentially composed of epidote muscovite schist, chlorite schist and talc chlorite schist.

Representative samples were collected from distinctive lithologic units covering the whole area. More than 80 rock samples were cut from various representative rock samples, which were made thin sections and prepared for petrographic interpretation.

The works of Kerr (1959), William, Turner and Gilbert (1953), Yardley, Mac Kenize and Guilford (1990) and Ron. H. Vernon (2004) are used to make detailed microscopic studies. Common lithologic units are determined after detailed microscopic studies combined with field works. Modal composition of some coarse-grained rocks was estimated visually.

Talc Chlorite Schist

Under microscope, this rock is mainly composed of talc (15%), chlorite (30%), muscovite (12%), quartz (40%), and other minerals (8%).

Talc shows brightly second order interference colour. It cannot easily be distinguished from muscovite in thin sections. Muscovite can be found as reddish brown, fine-grained flakes. Chlorite occurs as the dominant greenish mineral and often shows crenulation or bending. Talcoccurs as flaky crystals, fine-grained and shows perfect basal cleavage. Quartz is fine-grained and mostly oriented parallel to the foliation plane (Fig.17).Well-defined schistosity is formed by the parallel arrangement of talc, chlorite, muscovite flakes and minute aggregate layers of quartz and feldspar grains (See also Fig.16).

Epidote - Muscovite Schist

Under microscope, this rock consists mainly of epidote (10%), muscovite (35%), chlorite (20%) and lesser amount of plagioclase (10%) and quartz (25%). Epidote is colourless in under PPL and shows paleochroism. Under cross polarized light, interference colours are usually gray to white but anomalous blue and brown colours are frequently present. This epidote mineral is parallel in the direction of schistosity (Fig.17). Flakes of muscovite are often associated with epidote defining the weak foliation (also see Fig.17). Anhedral quartz grains are also present in the matrix.

Actinolite Schist

Microscopically, it consists mainly of actinolite (20%), feldspar porphyroblast (20%), epidote (15%) with minor chlorite (10%) and quartz (35%). Feldspar occurs as a mosaic of xenoblastic grains or large idioblastic prophyroblasts enclosing parallel strings of epidote and actinolite needles (Fig.18). Some porphyroblasts tend to be untwined but simple twinning also develops in other porphyroblasts. Actinolite shows the form of slender prisms and is imperfectly terminated. The epidote minerals occur as strings elongated in the direction of the schistosity. The dark, schistose regions are primarily composed of actinolite, chlorite and epidote. The light areas are mainly made up of porphyroblastic feldspar with some quartz.

Muscovite Schist

Microscopically, it comprises muscovite (30%), quartz (35%), biotite (20%) and graphite (10%) and other minerals (5%). Muscovites are flaky form terminated with attenuation edge. Biotite is reddish brown and shows pleochroism. It is subhedral to anhedral and exhibits flaky or bladed form. Anhedral to subhedral quartz grains 0.3 to 0.5 mm in size, are aggregates bounded by micas and graphite. Boundaries between quartz grains are mostly sutured and show undulatory extinction. The foliation is strongly crenulated, folded and can be seen in thin section. Biotite is folded and is surrounded by muscovite (Fig. 19). Moreover, the rock is segregated into mica rich and quartz, rich domains.

Graphite Schist

Under microscope, this rock is primarily composed of graphite, quartz, feldspar, muscovite with minor amounts of opaque minerals. By volume percent, it contains graphite (40%), quartz (30%), feldspar (5%), muscovite (20%) and opaque minerals (5%).

Graphite occurs as discrete crenulation cleavage (Fig.20). Xenoblastic quartz grains developed in fine-grained schist are lens like aggregates that are bounded by graphite and muscovite. Most of the quartz grains are elongated or flattened aligned parallel to the schistosity (See also Fig.20). The boundaries between quartz grains are mostly sutured and the grains show undulatory extinction. Feldspar is anhedral and turbid. Some show albite twin. It is mainly identified by its mode of occurrences as trains or strings of dark grains following the foliation.

Muscovite in this rock is concentrated in aggregate with lesser amounts occurring as groundmass oriented parallel to the foliation. Rectangular opaque mineral is mostly magnetite.

The whole rock shows well-defined schistosity. The main schistosity is formed by the parallelism of muscovite and graphite which are intensely crenulated to tightly folded.

Garnet Mica Schist

Microscopically, this rock mainly contains biotite, muscovite, quartz, garnet prophyroblast, plagioclase and chlorite. By percentage, it has quartz (35%), biotite (30%), gamet porphyroblast (15%), muscovite (15%), and plagioclase, chlorite and other minerals (5%).

Biotite commonly occurs as lepidoblastic, brown colour and fine- to medium- grained mineral. Muscovite is concentrated as groundmass which is oriented parallel to the foliation. Fine-grained muscovite flakes are parallel and aligned with schistosity and wrap around the porphyroblast (Fig.21). Plagioclase forms as small grains in the matrix and coarse-grained. Sometime it is warped by the muscovite and biotite.

Quartz crystals show as grain matrix. Anhedral to subhedral forms mostly occur under the microscope. Most of quartz grains are angular in outline. Under the microscope, the quartz microstructure is also characterized by deformation features such as pressure solution, sub-grain formation along grain boundaries and undulose extinction.

Garnet commonly occurs as porphyroblast, showing subhedral to euhedral. Porphyroblast garnets are size range from 1.5 mm to 4 mm in diameter. Almost all of the garnet crystals invariably show parting and minor fracture that indicate probably due to deformation during and after the crystal growth. Some biotites and iron ores are found along the cracks. So, it is no wonder that the colour of garnet is reddish brown. Inclusions of quartz grains occur in and around the garnet. This is why the garnet developing reaction produces the quartz as by product. In some garnets, fracture and marginal parts are altered to chlorite.

The musocovite, elongated quartz and biotite define the dominant schistosity of the rock. The foliation is lightly crenulated and muscovite and biotite show noticeable parallelism. In addition, the rock is segregated into mica rich and quartz rich domains parallel to the foliation. The foliations tend to wrap around the garnet porphyrobalsts due to deformation after they grew.

Biotite Schist

Under microscope, the rock essentially consists of biotite (40%), quartz (30%), muscovite (10%) and with minor amounts of graphite and feldspar (20%).

Biotite is reddish brown in colour and shows pleochroism. It is subhedral to anhedral and exhibits flaky or bladed form. The schistosity of this rock is dominated by biotite, muscovite and elongated quartz (Fig.22). The cleavage can clearly be seen in thin section. Graphite is randomly oriented in matrix. In addition, the rock is segregated into mica rich and quartz rich domains parallel to the foliation.

Petrography of Igneous Rocks

Serpentinite

Under microscope, this rock is almost entirely made up of the serpentine (90%) together with iron-ore opaque minerals and some dark patches which are possibly magnetite (about 10%). The characteristic feature of serpentinite showing mesh texture in which very low birefringence, fine-grained serpentine is divided into small blocks by numerous thin veinlets of serpentine with slightly higher birefringence. In some specimens, it is found that partially altered grains (a few clinopyroxene to antigorite) are embedded in serpentine matrix. Under the microscopic study, serpentines are recognized into two types mainly based on their elongation directions namely, alpha (α) serpentine which is length-fast and hence has negative elongation and gamma (γ) serpentine which is length-slow and positive elongation according to Coats (1968). Diagonal measurements of each mesh are not the same. Some short and others are long. Some are of complete square shapes and some are sub-square to triangle in form. In some sections, light green to yellowish green needle shaped antigorite grains are randomly oriented. In mesh texture, two portions may be considered separately, the mesh rim and mesh centre. Most of the mesh rims are composed of (α) serpentine. Mesh centres are usually isotropic serpentine (Wick and Whiltaker,1977). Sometimes, mesh textures are not clearly developed. They are closely packed showing parallel to sub-parallel pattern texture. Frequently, relict olivine is found as mesh centre (Fig.23).

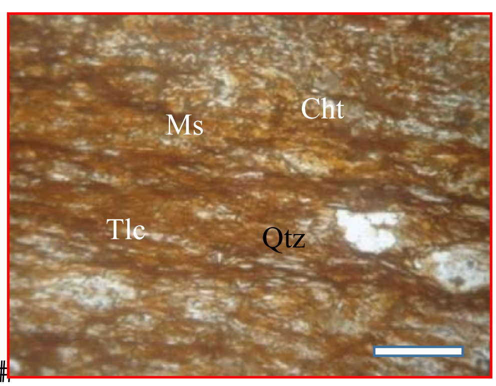
Basalt

Basalt consists predominantly of feldspar (60%), olivine (15%), augite (20%), iron and other accessory minerals (5%). The plagioclase minerals are usually lath-shaped. They occur as long prismatic laths which range in length from 0.2 mm to 0.5 mm and are so altered that their composition cannot be determined. Phenocrysts of subhedral olivine and plagioclase are found (Fig.24). The laths are more altered near phenocrysts. Olivine occurs as euhedral crystals that have more or less corroded borders. Augite is granule with average size of about 0.3 mm, occupying mostly interstitial spaces.

The opaque iron oxides (mainly magnetite and hematite) occur as scattered grains and on the borders of the other minerals.

Gabbro

Microscopically, it is mainly composed of plagioclase feldspar (55%), orthopyroxene (10%), clinopyroxene (augite) (20%) with magnetite (15%). Hypidiomorphic granular texture is observed possibly because of slight metamorphism. Uniform orientation of mineral grains is not distinctly seen in thin section. Most plagioclases are in labradorite range. They are sub-hedral to anhedral in shape and their sizes vary between 1 mm to 5 mm. Twinning occurs as albite twins. Olivine usually occurs in subhedral to anhedral and its fractures and cracks are common and along which serpentinization has taken place (Fig.25). Pyroxene minerals are anhedral in shape and they are also altered to serpentine minerals. Chloritizations are found along the crystal boundaries. Most of mineral constituents observed in this specimen display wavy extinction indicating that the rock had suffered strain effect.

####### 

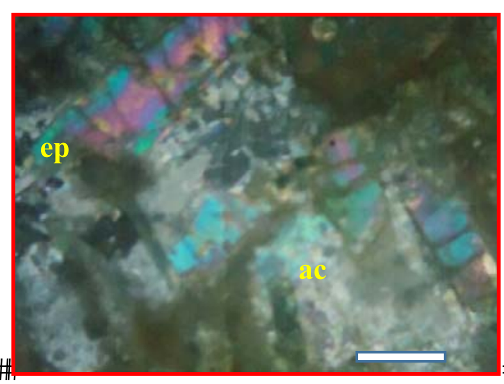


Figure (16). Microscopic view of talc chlorite schist containing parallel arrangement of Minerals. Scale bar is 1 mm. (Under PPL)

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Figure (17). Needle-shaped actinolites together with epidote in actinolite schist. Scale bars are 1mm. (Under XN)

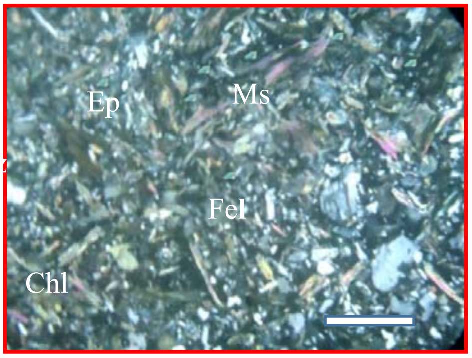

Figure (18). Microscopic view of epidote muscovite containing flakes of minerals. Scale bar is 1 mm. Under XN.

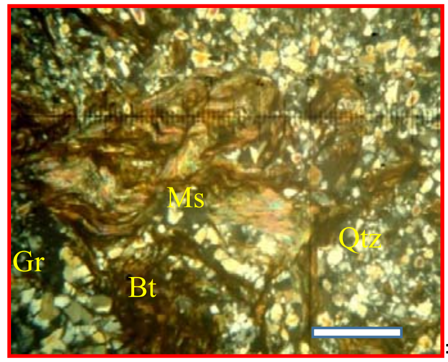

Figure (19). Microscopic view of muscovite schist in which muscovite is strongly curved. Scale bar is 1 mm. Under XN.

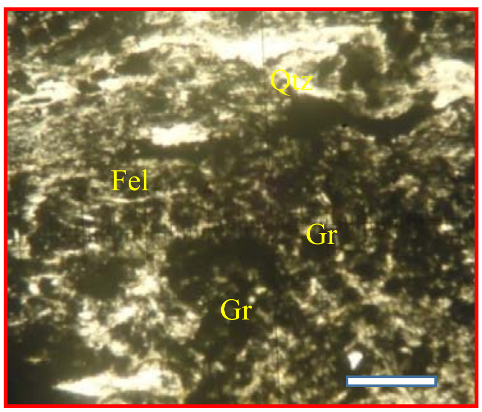

Figure (20). (A) Microscopic view of graphite schist. Scale bar is 1mm. Under PPL

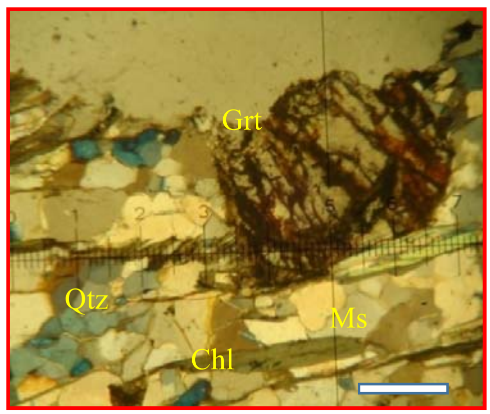

Figure (21). Microscopic view of Garnet mica schist and chlorite (cl), and garnet (gr)

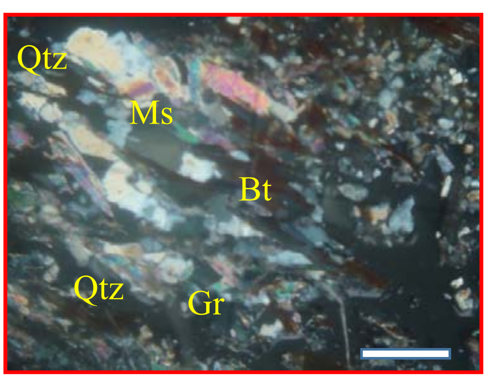

Figure (22). Microscopic view of Biotite schist containing Parallel alignment of minerals. Scale bars are 1mm. (Under PPL and XN)

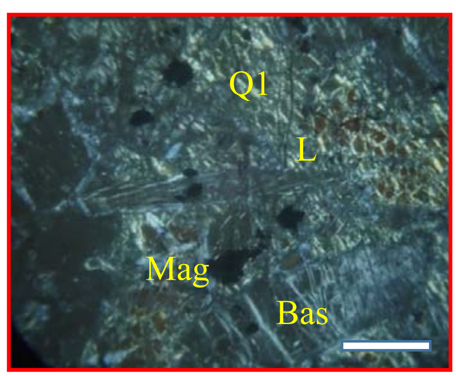

Figure (23). Microscopic view of serpentinite containing lizardite forms as mesh texture. Scale bars are 1 mm. Under XN

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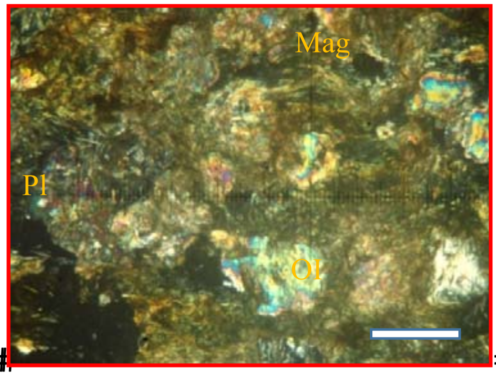

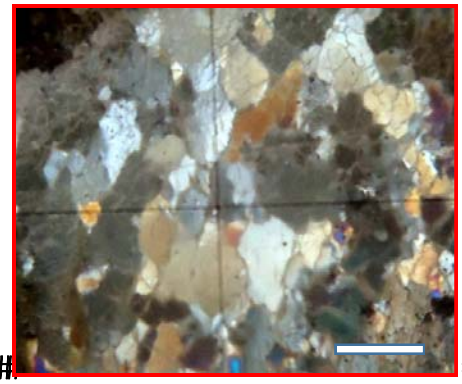

#Figure (24). Microscopic view of basalt containing showing plagioclase laths. Scale bar is 1mm. Under XN

Figure (25). Microscopic view of gabbro containing plagioclase, olivine and magnetite. Scale bar is 1 mm. Under XN.

Types of Metamorphism and Metamorphic Facies

General Statement

The study area is underlain by the rocks of the Katha Metamorphics. The dominant rock types are pelitic to psammatic schists and metabasites as mentioned earlier.

The present work attempts to describe the types of metamorphism, pressure and temperature conditions, and petrographic studies of minerals and rocks. To meet these purposes, the equilibrium mineral assemblages comprised in the rocks as well as the textural arrangement of these minerals are investigated under the petrographic microscope.

Based on the mineral assemblages, lithology, mineral chemistry, field relationships and correlation to those of other areas, it is found that the metamorphic rocks of the study area fall in the greenschist to epidote-amphibolite facies. Moreover, metamorphic grade increases from east to west of the study area and so the sequence of metamorphism is normal.

Types of Metamorphism

The field occurrence, mineralogy, and textural evidences of the metamorphic rocks of the area indicate that they were formed by regional metamorphism and locally by dynamic metamorphism.

Regional metamorphism of the study area is characterized by the occurrence of definite foliation, lineation, and recrystallization, neomineralization such as garnet, actinolite, etc. Under microscopic examination, the presence of strong preferred orientation of mica flakes suggests the regionally metamorphosed condition.

Deformational features that favor the dynamic metamorphism are grain granulation, sutured grain boundary, undulose extinction, intensely fractured grains, contortion or crenulation of mica flakes and rotation of garnet porphyroblasts. All these facts suggest that dynamic metamorphism might have been taken place due to the tectonism. Therefore, mineral parageneses and sequence of zonal patterns differ from those of the contact metamorphism.

Mineral Assemblages and Metamorphic Facies

It is found that the assemblages of coexisting minerals in the metamorphic rock units provide the clear evidence for the metamorphic condition of these mineral were formed. In contrast, some mineral assemblages have attained a long range of stability and occur invariably in several metamorphic facies: but other assemblages have only a restricted stability range (short range of stability field) and are found as one facies only. In addition, some rock types do not show diagnostic assemblages at some particular metamorphic grade.

More than 80 thin sections cut from various representative rock types were studied for the mineral assemblages and their implications. Diagnostic mineral assemblages are used to identify the metamorphic facies of metapelites and metabasites. On the basis of petrographic analysis, at least (8) representative equilibrium mineral assemblages are defined of which seven assemblages represent metapelites and the remaining one belongs to metabasites. They are as follows;

Mineral assemblages in metapelites

(1) Chlorite- talc-muscovite-quartz
(2) Chlorite- muscovite-quartz
(3) Epidote-chlorite- muscovite-quartz
(4) Chlorite- graphite-muscovite-quartz
(5) Chlorite-muscovite-biotite-albite-quartz
(6) Biotite-muscovite-quartz
(7) Garnet-biotite-muscovite-chlorite-quartz

Mineral assemblage in metabasites

(1) Actinolite-epidote-albite-chlorite-quartz

The mineral parageneses recognized in the study area may be delineated to be indicative of the greenschist facies to epidote-amphibolite facies in metapelites; and only greenschist facies in metabasites. The facies classification, nomenclature and defining mineral assemblages used in this work were mainly based on Turner (1968), Hyndman (1985), Yardley (1989), Spear (1995) and Best (1986). Generalized metamorphic facies of the study area is shown in Fig. (27). Mineral assemblages and metamorphic facies of the study area are shown in Table (2).

Greenschist Facies

Greenschist facies is well documented by the mineral assemblages of chlorite- talc-muscovite-quartz, chlorite- muscovite-quartz, epidote-chlorite- muscovite-quartz, chlorite-graphite-muscovite-quartz and chlorite-muscovite-biotite-albite-quartz in metapelites and actinolite-epidote-albite-chlorite-quartz in metabasite. It is noteworthy that the diagnostic minerals of this facies are chlorite, actinolite and epidote.

Epidote-Amphibolite Facies (Greenschist-Amphibolite Transition)

This facies falls in metapelitic rocks only. Mineral assemblages of biotite-muscovite-quartz and garnet-biotite-muscovite-chlorite-quartz in metapelite represent the epidote-amphibolite facies. Almandine garnet is one of the diagnostic minerals present in this facies.

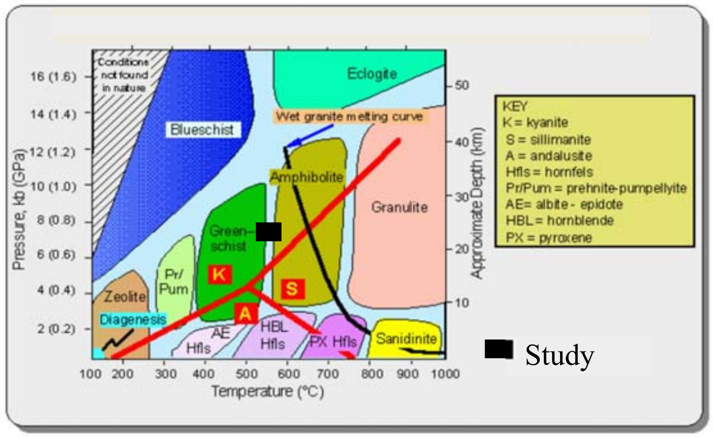

Figure (26). Generalized metamorphic facies boundary (after Yardley 1989).The study area falls within the field of Greenschist to epidote-amphibolite facies.

Table. (2) Mineral assemblages and metamorphic facies of the study area.

Type of Metamorphism	Rock Group	Representative Rock	Mineral Assemblages	Metamorphic Facies
Regional Metamorphism	Metapelite	Talc-chlorite schist	Chlorite-talc-muscovite- quartz	Greenschist Facies
		Chlorite schist	Chlorite-muscovite- quartz	
		Epidote muscovite schist	Epidote-chlorite-muscovite-quartz	
		Graphite mica schist	Chlorite- graphite-muscovite-quartz	
		Muscovite schist	Chlorite-muscovite-biotite-albite-quartz	
	Metabasite	Actinolite schist	Actinolite-epidote-albite-chlorite-quartz	
	Metapelite	Biotite schist	Biotite-muscovite-quartz	Epidote-Amphibolite Facies
		Garnet-biotite	Garnet-biotite-	

		schist	muscovite-chlorite-quartz	

Summary and Conclusion

The study area is situated immediate northwest of the Indawgyi Lake, Mohnyin Township in Kachin State of the northern Myanmar. It is bounded by North Latitudes 25º 20′ to 25º 24′ and East Longitudes 96º 16′ to 96º 22′ in one inch topographic map of 84 C-7. It is mainly composed of metamorphics and igneous rocks.

The metamorphic rocks in the study area are subdivided into three informal units namely Unit I, Unit II and Unit III. Unit I is chiefly composed of micaceous quartzite, biotite schist and garnet mica schist. Unit II mainly contains graphite mica schist and muscovite schist. The uppermost Unit III is essentially composed of actinolite schist, epidote muscovite schist and talc chlorite schist. Gold bearing quartz veins are injected along the bedding planes and crossed cut them.

The igneous are mainly serpentinite, basalt and gabbro. In some localities, the margins of serpentinite bodies are partly or completely altered to chlorite or talc bearing assemblages.

Regional metamorphism of the study area is characterized by the occurrence of foliation, lineation, and recrystallization, neomineralization such as garnet, actinolite, etc. Deformational features that favor the dynamic metamorphism are grain granulation, sutured grain boundary, undulose extinction, intensely fractured grains, contortion or crenulation of mica flakes and rotation of garnet porphyroblasts. All thesefacts suggest that dynamic metamorphism might have been taken place due to the tectonism.

More than 80 rock samples were cut from various representative rock samples, which were made thin sections and prepared for petrographic interpretation. Diagnostic mineral assemblages are used to identify the metamorphic facies of metapelites and metabasites.

On the basis of petrographic analysis, at least (8) representative equilibrium mineral assemblages are defined of which seven assemblages represent in metapelites and the remaining one in metabasites occur. The mineral parageneses recognized in the study area may be delineated to be indicative of the greenschistfacies to epidote-amphibolite facies for metapelites; and only greenschist facies for metabasites. Greenschistfacies is well documented by the mineral assemblages of chlorite-talc-muscovite-quartz, chlorite-muscovite-quartz, epidote-chlorite-muscovite-quartz, chlorite-graphite-muscovite-quartz and chlorite-muscovite-biotite-albite-quartzin metapelites and actinolite-epidote-albite-chlorite-quartzin metabasite.Mineral assemblages of biotite-muscovite-quartz and garnet-biotite-muscovite-chlorite-quartz in metapeliterepresent the epidote-amphibolite facies. Moreover, metamorphic grade increases from east to west of the study area.

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