Petrological Interpretation Based on Petrographical Analysis of Al_2SiO_5 Polymorphs Formation in the Shwe-U-Min Taung and Shantaung-U-Yinswe Range, Kyaukse Township

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Abstract

The research area is located approximately 8 km SSE of Kyaukse, Mandalay Region. It is situated in the middle segment of Mogok Metamorphic Belt. The rock units exposed in the study area are mainly metasedimentary rocks. The whole area is made up of calcareous group and pelitic-psammitic group of andalusite-bearing phyllite, andalusite marble, chiastolite-garnet-staurolite-mica schist, garnet-mica schist, garnet-staurolite-mica schist, biotite-sillimanite schist and kyanite-bearing quartzite. These rocks are widely distributed in Shwe-U-Min Taung and Shantaung-U-Yinswe range. The research area is indeed a mineralogist's paradise. It is noteworthy that almost all better known metamorphic minerals occur in an area. In order to study the salient mineralogical features and mineral assemblages of the metamorphic rocks in the study area, about 100 thin sections are prepared from representative samples. Many of these metamorphic minerals occur as porphyroblasts. The common minerals noted are andalusite, garnet, staurolite, chiastolite, sillimanite, kyanite and biotite. It is noticeable that polymorphs of Al_2SiO_5, namely andalusite, kyanite and sillimanite oc+cur altogether in such narrow area. Petrographic investigation on the rock assemblage of the study area reveals that the metamorphic grade of these rocks range from medium-grade of greenschist facies to higher grade of upper amphibolite facies. Petrogenetic interpretation on this mineral assemblage is attempted on the basis of petrographic criteria. Taking into account the various metamorphic conditions, distinct mineral assemblages form under different grades and pressure.

Key words; pelitic, psammitic, Polymorphs, greenschist facies, upper amphibolite facies

Introduction

The research area is located in Kyaukse Township, Mandalay Region. It is situated about 8km SSE of Kyaukse. It falls in one-inch topographic map no. 93C/2. (Fig. 1) show the location map of the research area. Metasedimentary rocks observed in the study area mainly consist of a various types of schist, marble and quartzite. The general trend of the most rock units is N-S with a few exception of localized area. Some rock sample locations are shown on topographic map of the study area (Fig. 2).

General Statement

The study area belong to the middle segment of Mogok Metamorphic Belt. This area is indeed a mineralogist's paradise in that almost all better-known metamorphic minerals occur in so small area (Maung Thein and Soe Win, 1969). Based on earlier literatures provided by various authors, there are many controversial arguments about the stratigraphic consideration on the protoliths, metamorphic processes, age of metamorphism, and

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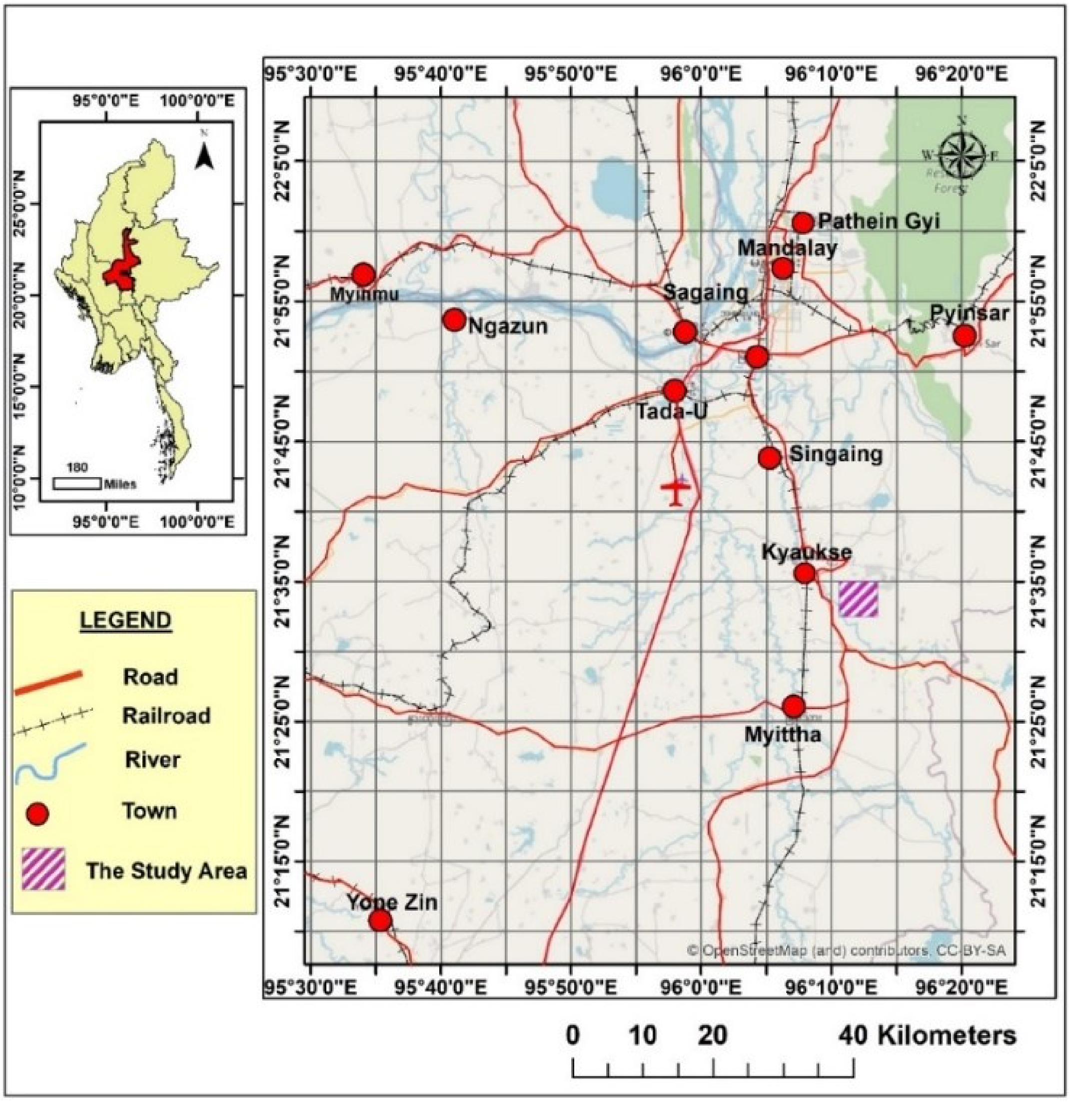
deformation mechanisms of the study area. The comprehensive interpretation on co-existence of Al_2SiO_5 polymorphs within such a small area is still lacking. Moreover, the nature of distribution of various rock units, the co-existence of polymorphs mineral, which seem to be indicatives of different metamorphic conditions, and distinct structural attitude of the area attract to explore this study area. It also necessitates to decipher the metamorphic evolution of the study area. In order to realize this, it will require a combined study of petrology, geochemistry, related tectonic mechanism and variable episodes of metamorphism. Regional tectonic situation and metamorphic processes, geochemical consideration on co-existence of polymorphic minerals in the narrow zone are one of the interesting problem of the study area. This study aims to infer the petrogenetic significance through a petrographic analysis of thin section.

Figure 1 Location map of the research area



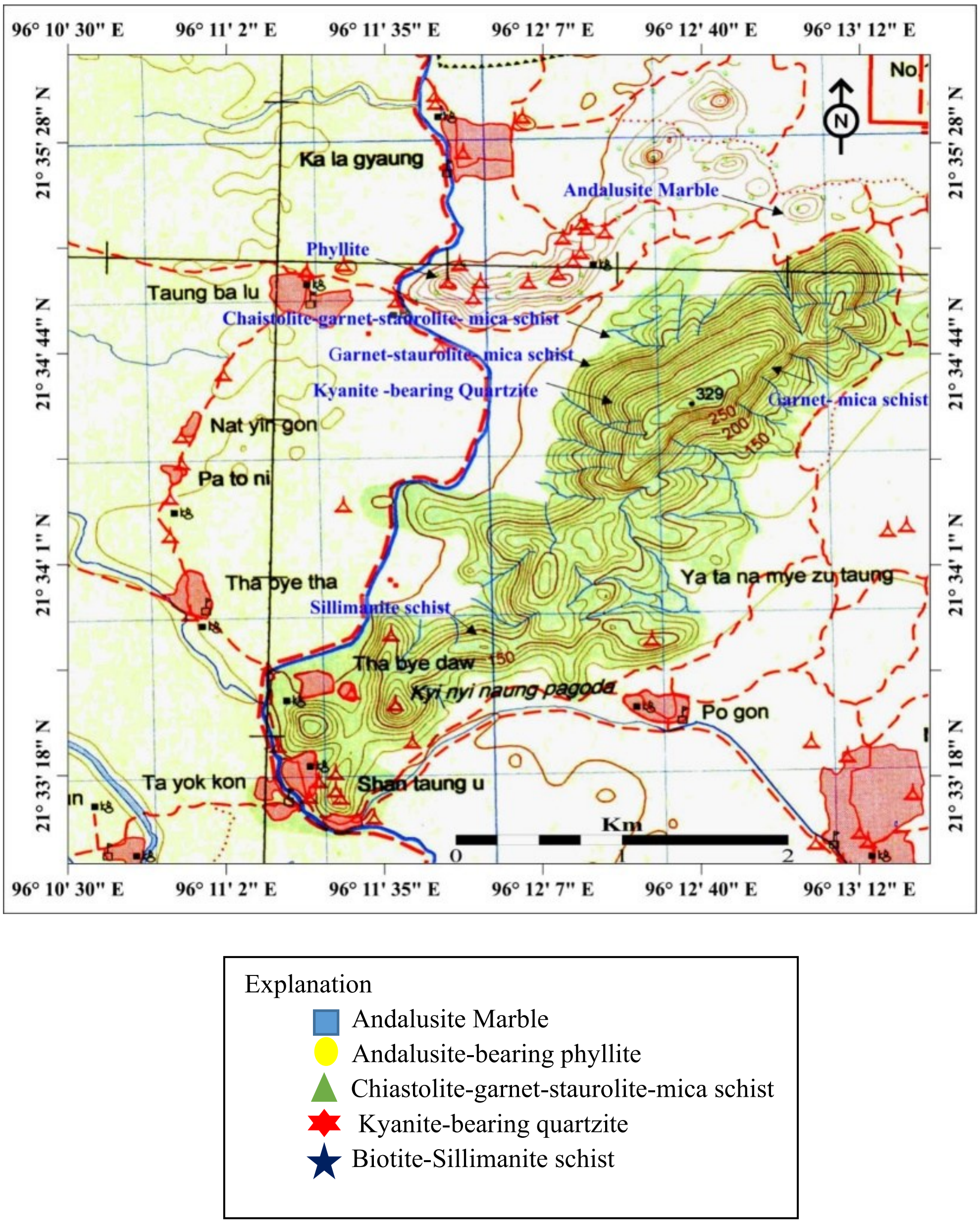


Figure 2 Some rock sample locations observed on topographic map of the study area

Method of study

This study mainly concerns with the mineral assemblage observed and salient textural features with respect to types and mechanism of metamorphisms. About more than 120 rock samples are collected systematically from the rocks of different compositions in the project area. More than 100 thin-sections are properly made for petrographic analysis. Highly equipped, advanced polarizing microscope in the Geological Lab of University of Mandalay greatly assist to identify and examine the petrography of the rocks collected from the study area.

Petrographic Interpretation

Andalusite-bearing Phyllite

This unit well exposes in the Shwe U Min Taung. It is mainly composed of fine grained of quartz, feldspar, sericite, andalusite, chlorite, small amounts of calcite and opaque minerals. Phyllitic texture is well marked by not only subparallel arrangement of quartz, feldspar, chlorite and sericite but also preferred orientation of chlorite and mica flakes. Black opaque minerals (magnetite) are also found in this rock. In some section andalusite porphyroblast contains several inclusions giving helicitic texture. The alignment of these inclusion is parallel and continue with the orientation of matrix (Fig. 3 A). Longitudinal section of andalusite is also observed in this rock (Fig 3.B).

Andalusite marble

Andalusite marble occurs in the eastern flank of Shwe U Min Taung. It is chiefly composed of calcite with minor constituents of quartz, andalusite, phlogopite and other trace minerals. The most of constituent minerals are fine to medium grained. This rock is mainly composed of a mosaic of unequal grains of calcite giving granoblastic texture. Most calcite is hypidioblastic grains. Andalusite occurs generally as porphyroblastic grain. The presence of helicitic inclusions andalusite shows the incipient growth of porphyroblasts. Andalusite porphyroblast and cluster of calcite minerals as observed in this rock. Andalusite and calcite are well-developed in this rock (Fig. 3.C). Suture grain boundaries developed between these grains are conspicuous and it suggest the low grade of metamorphism. Quartz occurs as equidimensional xenoblastic grains and juxtaposed with calcite grains.

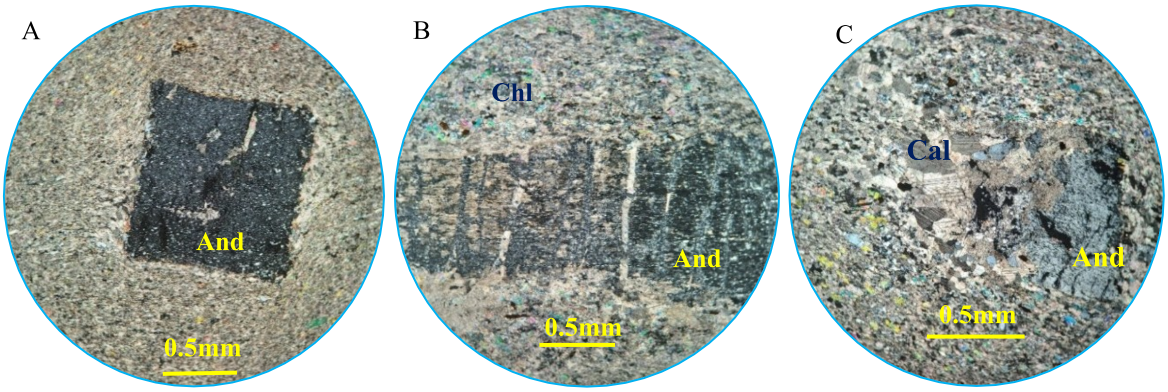


Figure 3.A, Andalusite porphyroblast with helicitic texture observed in andalusite-bearing phyllite, B Longitudinal section of andalusite observed in andalusite-bearing phyllite, C. Mineral assemblage of andalusite and calcite observed in andalusite marble (between XN).(Chl=chlorite, Cal=calcite, And=andalusite)

Chiastolite-Garnet-staurolite-mica Schist

This unit is predominantly exposed on the southeastern crest of Yinswe Range. The rock essentially consists of staurolite, garnet, biotite, chiastolite and quartz. Staurolites usually occur as porphyroblasts. Chiastolite occurs as 4-sided crystal typically containing carbon inclusion arranged in a cross pattern (Fig 4.A). Chiastolite schist showing the swerving of the schistosity is formed by muscovite and quartz around porphyroblast garnet. Most prismatic grains of staurolite are subparallel to the foliation of the rock. Slightly rotated nature of staurolite grains can be observed in some specimens (Fig 4.B). Garnet inclusions are observed within chiastolite, indicating that garnet crystals formed earlier and are incorporated as inclusions during the growth of chiastolite (Fig.4.C).Slightly flattened quartz grains also mark the schistosity of the rock.

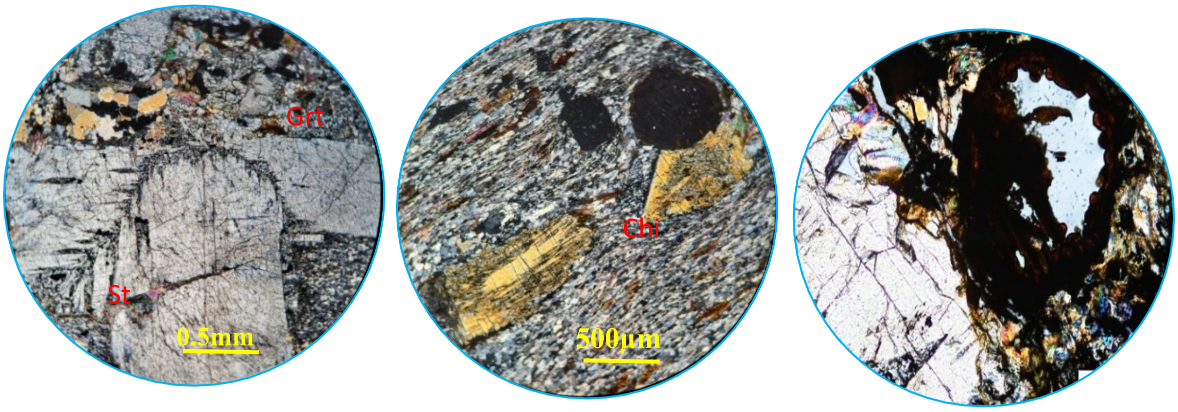


Figure 4.A Large chiastolite with carbon inclusion developed along the cleavage trace in chiastolite-garnet-staurolite-mica schist, B. Slightly rotated nature of staurolite grains observed in chiastolite-garnet-staurolite-mica schist, C.Garnet inclusions observed within chiastolite.(between XN).(Chi=chiastolite, St=staurolite, Grt=garnet, Bt=biotite)

Garnet-mica Schist

Garnet-mica schist occupies the eastern flank of Yinswe range. Garnet mica schist is mainly composed of garnet, biotite, quartz, muscovite and chlorite. Schistose texture is produced by the parallelism of small biotite flake and quartz grains. Biotite commonly occurs as lepidoblastic and flaky form. Curved biotite flakes observed around garnet grains seem to be caused by the development of garnet porphyroblasts. Slightly rotated garnet porphyroblasts are prominent with development of pressure shadow (Fig 5.A). Garnet crystals align along the schistosity plane. The internal cracks of the garnet porphyroblast is perpenticular to the external schistosity developed in some section (Fig 5B). Inclusions of quartz grains occur in garnet. Xenoblastic grains of quartz are usually minute and slightly flattened. Some quartz grains exhibit sutured boundaries and display strained extinction, indicating a low grade of metamorphism.

Garnet-staurolite-mica Schist

This rock unit is well developed on the southeastern flank of Yinswe ridge. Garnet-staurolite-mica schist is mainly composed of garnet, staurolite, biotite, quartz, muscovite and chlorite. It is coarsely crystalline and well-foliation. Staurolites usually occur as porphyroblasts and also occur as typically twinned crystal in foliated plane. Growth of garnet and staurolite porphyroblasts disturbs the foliation of matrix (Fig 5.C). Staurolite shows apparently grew primarily by replacement in the foliated medium so that helicitic inclusions of quartz inside the crystal are continuous with the schistosity outside**.** The features in garnet are nearly right angles to the enclosing schistosity (Fig.6.A). Such a feature may be interpreted by Billings as "garnet that rotated after it grew". Most garnet grain occurs as zoned crystals. This fact indicates that garnet reacts with matrix phase to form staurolite.

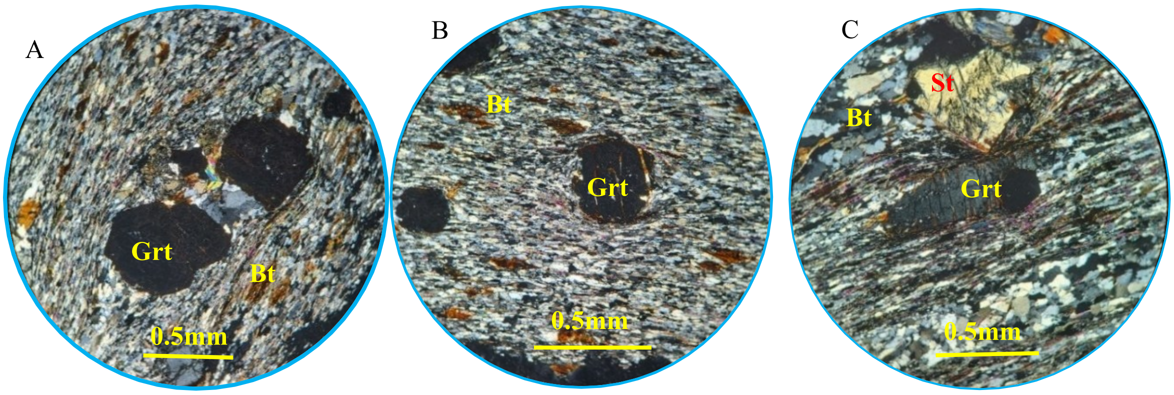


Figure 5.A Slightly rotated garnet porphyroblast prominent with pressure shadow observed in garnet-mica schist, B. Internal cracks of the garnet porphyroblast perpendicular to the external schistosity developed in garnet-mica schist, C Growth of garnet and staurolite porphyroblasts disturbs the foliation of matrix observed in garnet-staurolite-mica schist (between XN). (St=staurolite, Grt=garnet, Bt=biotite)

The mica flakes are oriented parallel to the foliation of the rock. The trails of muscovite grains from matrix are continuous with that of inclusion in staurolite (Fig.6.B). Garnet and staurolite minerals are well-developed in this rock, indicating significant metamorphic conditions conducive to their growth (Fig.6.C). It seems that staurolite-producing reaction involve muscovite mineral.

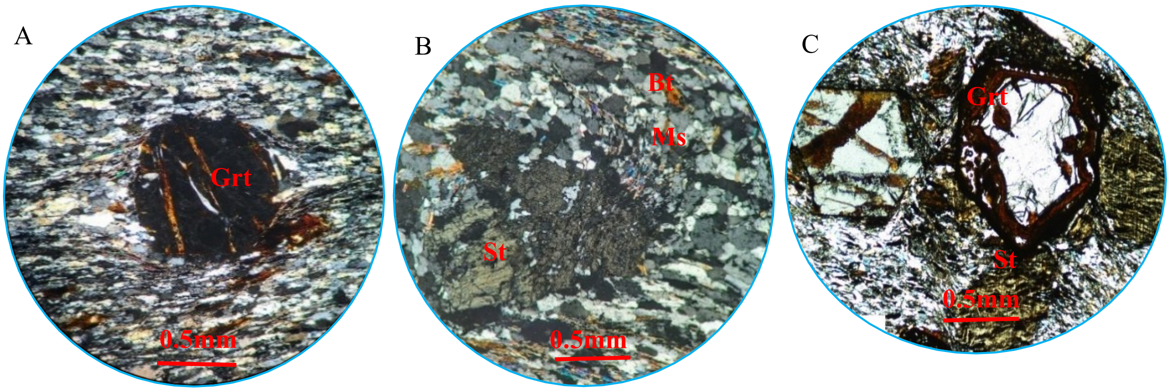


Figure 6.Distinctive texture observed in garnet-staurolite-mica schist. A. Internal schistosity of the garnet porphyroblast developed perpendicular to the external schistosity of the matrix, B. Continuity trails of muscovite grains from matrix with that of inclusion in staurolite, C. Mineral assemblage of garnet, biotite and staurolite minerals (between XN). (St=staurolite, Grt=garnet, Bt=biotite)

Biotite-Sillimanite Schist

Biotite-sillimanite schist occurs as good exposure in the northeastern flank of Shantaung-U range. In hand specimen, sillimanite appears as silky, scaly aggregates on schistosity surface. Sillimanite schist is chiefly composed of quartz, biotite, sillimanite, plagioclase, muscovite and minor amount of sphene. Sillimanite, biotite and muscovite are well-developed in this rock (Fig.7A). Muscovite decomposed to fine, sillimanite aggregate is abundantly in this rock (Fig 7.B). Most constituent minerals are hypidioblastic to xenoblastic grains and this rock shows porphyroblastic texture. Quartz in this rock is mostly found as equidimensional euhedral grains. These quartz grains give the granoblastic polygonal texture which is characteristic of high grade metamorphism (Fig 7.C). Biotite grains usually occur as fine and curved crystals as well as in matrix phase and their distinctive cleavage can be easily recognized some grains. Long sillimanite aggregate with distinct parting parallel to the foliation of matrix is observed in most section.

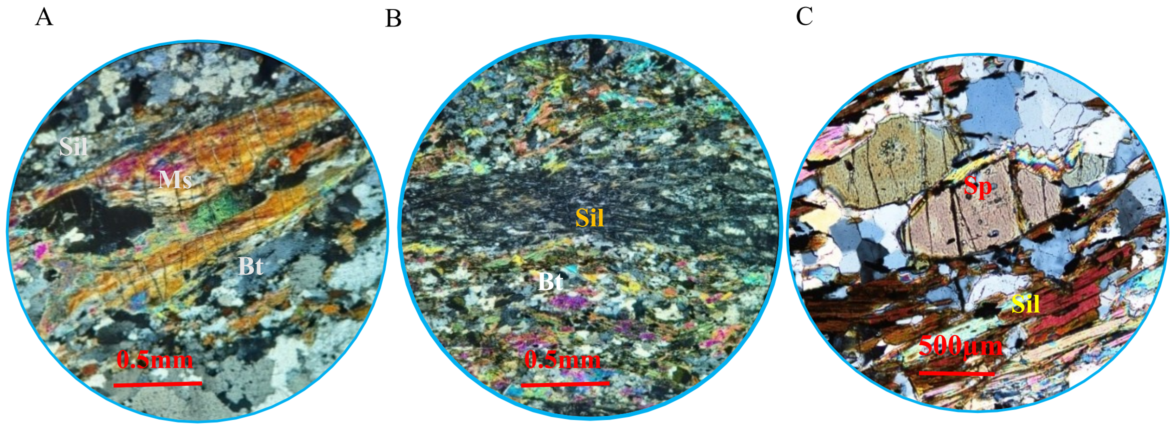


Figure 7.A Mineral assemblage of biotite, sillimanite and muscovite observed in biotite-sillimanite schist, B. Muscovite decomposed to fine fibrous sillimanite found in biotite-sillimanite schist, C. Granoblastic polygonal texture formed by equidimensional euhedral quartz grains in the biotite-sillimanite schist (between XN). (Sil=sillimanite, Bt=biotite, Mus=muscovite)

Kyanite-bearing Quartzite

The quartzite is mainly exposed on the northwestern flank of Yinswe range. Kyanite-bearing quartzite are observed at the northern base of the Yinswe ridge. This rock unit is mainly composed of quartz, kyanite, muscovite, feldspar and other opaque minerals. It essentially consisted of fine- to medium-grained granoblastic mosaic of quartz grains. A few mica and opaque mineral occurs as accessory constituents along the quartz grain boundaries. Planner contact is observed along the most quartz grains boundaries in quartzite. Kyanite crystals occur as bladed form with diagonal segments with good cleavages. In some locality kyanite occur as vein in quartzite. Some kyanite crystals show bent and break feature which are surrounded by flaky muscovites. K-feldspars are cemented between the quartz crystals and magnetites and ilmenite are found as inclusions in quartz. Deformed kyanite crystal developed as a result of brittle deformation is observed in quartzite (Fig 8.A). Muscovite occurs as hypidioblastic prismatic crystals. It occupy the margin of kyanite grains. Muscovite grains show sub-parallel orientation along faint foliation. A considerable amount of magnetite is observed in this rock. No schistosity show in kyanite quartzite. Long prismatic kyanite mineral is observed in quartzite (Fig 8.B). Kyanite surrounded by muscovite crystals is exhibited in kyanite-bearing quartzite (Fig 8.C).

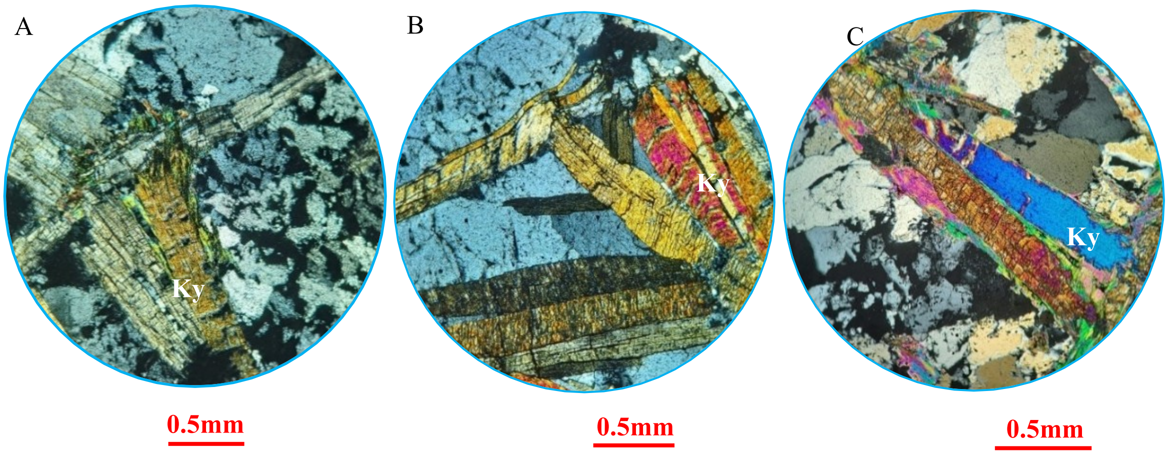


Figure 8.A Deformed kyanite crystals observed in quartzite, B. long prismatic kyanite crystals observed in quartzite, C.kyanite surrounded by muscovite crystals found in quartzite (between XN).

Mineral Assemblages and Metamorphic Facies

According to the petrographic study, the following distinctive mineral assemblages are recognize in some metamorphic rocks occurred in the study area.

(1) Muscovite-chlorite-quartz-sericite
(2) Garnet-biotite-andalusite
(3) Garnet-biotite-muscovite
(4) Garnet-biotite-staurolite
(5) Quartz-biotite-sillimanite-plagioclase-muscovite

Mus-Qtz-Chl-Ser mineral assemblage developing in phyllite indicates the upper greenschist or transition to amphibolite facies.

Grt-bt-and mineral assemblage occurs in chaistolite-garnet-staurolite-mica schist. These mineral assemblages fall within the upper greenschist or transition to amphibolite facies.

Grt-bt-ms mineral assemblage occurs in garnet-mica schist. Garnet-mica schist are stable from the upper greenschist or transition to amphibolite facies.

The assemblage grt-bt-st develops in garnet-staurolite-mica schist. These are characteristic for the lower amphibolite facies.

The indicator assemblages such as quartz-biotite-sillimanite-orthoclase-muscovite indicate the greater part of the lower amphibolite facies.

Andalusite-bearing Phyllite

Bucher and Frey (1994) have suggested it for the petrographic observation. Prograde metamorphism, for example along the Ky-geotherm, will replace kaolinite by pyrophyllite at about 300ºC. The stable mineral on the A apex of an AKF diagram become pyrophyllite (Fig.10). At about 400ºC in pure H_2O fluid, pyrophyllite reaches its upper thermal stability and decomposed to aluminosilicate+quartz (andalusite along low pressure geotherm). Andalusite is not stable at pressures greater than 4kbar, sillimanite is not stable below about 500ºC. Along a sillimanite type geotherm, pyrophyllite decomposes to andalusite+quartz at about 380ºC. Mus-Qtz-Chl-Ser mineral assemblage is observed in andalusite-bearing phyllite. (Fig.9) show that pyrophyllite breaks down to produce andalusite via;

Prl = And + Qtz + H_2O

Pyrophyllite =Andalusite+Quartz+water

Equilibrium is difficult to attain in experiments at these low temperature so that P-T conditions are not certain but they are believed to be in the 350ºC to 450ºC range (Winter, 2001). On the basis of this consideration, the chlorite zone is placed below the biotite isograd in P-T space.

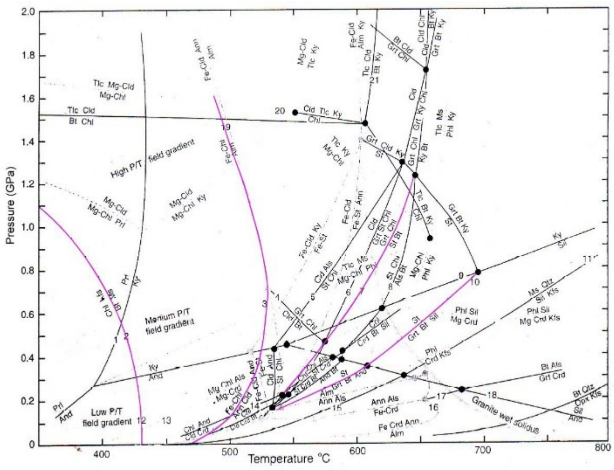


Figure .9 Petrogenetic grids showing the location of selected reaction isograds appropriate for the study area. After Spear and Cheney (1989) and Spear (1999).

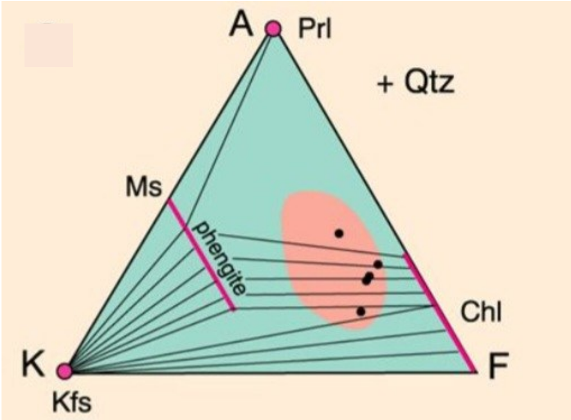


Figure 10 AKF diagram showing the mineral assemblage occurred in the andalusite-bearing phyllite

Chaistolite-garnet-staurolite-mica Schist

The Grt-bt-chi assemblage are observed in the chiastolite-garnet-staurolite mica schist. The assemblage falls within the andalusite-staurolite zone of amphibolite facies of Buchan Facies Series. The andalusite forming reaction can be expressed by the following reaction:

Chlorite + Chloritoid (+ MS) → Biotite + Andalusite (+ Qtz + H_2O)

Chl + Cld (+ MS) → Bt + And (+ Qtz + H_2O)

The mineral assemblages are graphically represent by means of AFM diagram (Fig 11).

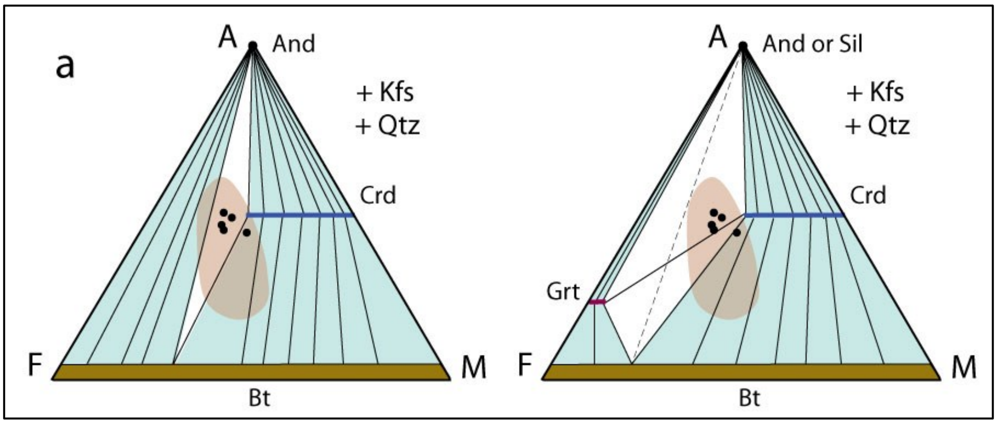


Figure 11 AFM compatibility diagrams (projected from Kfs) in the lowermost pyroxene hornfels facies, (a) the compositional range of cordierite is reduced as the Crd-And-Bt sub-triangle migrates toward more Mg-rich compositions. Andalusite may introduced into Al-rich pelites, (b) Garnet introduced to many Al-rich pelites via reaction .

Garnet-mica Schist

The assemblage Grt-bt-ms is observed in garnet mica schist. The assemblage is the characteristic of garnet zone of upper greenschist or transitional to amphibolite facies. Garnet isograd reaction is represented by the following chlorite-broken down reaction.

3 Chlorite + 1 Muscovite + 3 Quartz → 4 Garnet + 1 Biotite + 12 H_2O

3 Chl + 1 Ms + 3 Qtz → 4 Grt + 1 Bt + 12 H_2O

Thompson and Norton (1968) suggested this reaction, which is common in more typical pelites (in Winkler, 1979). The mineral assemblages are graphically represented by means of AFM diagram as shown in (Fig 12).

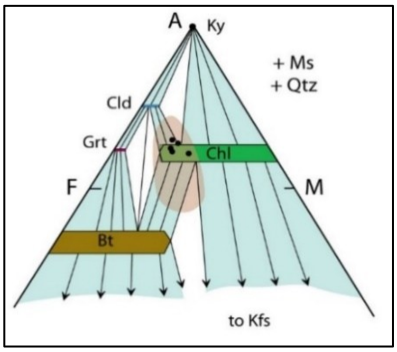


Figure 12 AFM diagram showing the mineral assemblage occurred in the garnet-mica schist

Garnet-staurolite-mica Schist

The assemblage is chiefly composed of garnet, biotite and staurolite. This assemblage is typically developed in this rock of staurolite zone and the rock including it is belonged to the lower amphibolite facies. The staurolite forming reaction can be expressed as:

Garnet + Chlorite →Staurolite + Biotite

Grt + Chl →St + Bt

Bucher and Frey (1994) have suggested it for the petrographic observation. The first staurolite + biotite appears at temperature slightly above 600 °C and marks the beginning of middle amphibolite facies. The discontinuous nature of reaction makes it well suited for isograd mapping. In metamorphic terrains, the chlorite + garnet zone are separated from the staurolite + biotite zone by a sharp isograd. The temperature at the boundary is about 600 °C and it is rather insensitive on pressure (Bucher & Frey, 1994). The observed mineral assemblage for this reaction can show in the AFM diagram (Fig 13). However, the P-T condition for this garnet-isograd reaction can be observed in (Fig. 9).

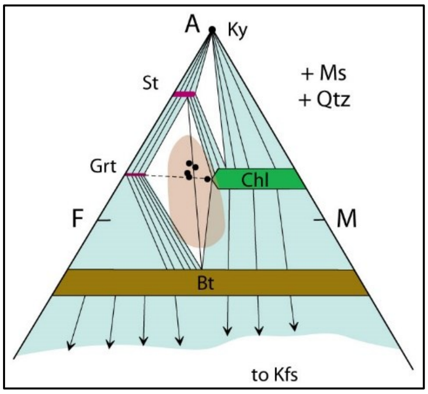


Figure 13 AFM diagram showing the mineral assemblage of garnet-staurolite-mica schist

Biotite-Sillimanite Schist

The assemblage is mainly composed of quartz, biotite, sillimanite, plagioclase and muscovite. Mineral assemblage developed in this rock may be considered to be indicative of the lower amphibolite facies. The Qtz-Bt-Sil-Kfs is typical of sillimanite zone. Increasing temperature leads to decomposition of muscovite in pelitic rocks and this takes place within the stability field of sillimanite. The formation of sillimanite from muscovite in sillimanite schist can be represented by the following reaction.

Muscovite + Quartz = K feldspar +Sillimanite + Water

Ms + Qtz = Kfs + Sil + H_2O

This reaction has been used (Winter, 2001) for the formation of sillimanite in pelites. The mineral assemblages observed for this reaction can be shown in the AFM diagram (Fig.

14). This reaction took place at temperature a little above 700 °C and is only slightly pressure dependent. The metamorphic condition appropriate for this reaction is shown in (Fig. 9).

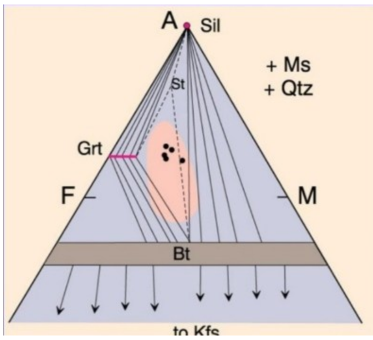


Figure 14 AFM diagram showing mineral assemblage of sillimanite schist

Significant factors for Al_2SiO_5 Polymorphs of study area

Andalusite, sillimanite and kyanite, all polymorphs of Al_2SiO_5 are observed in a small study area. The following factors are considered to emphasize the formation of these polymorphs.

1. The metamorphic grade for metapelitic rocks gradually increase from biotite schist through garnet-mica schist, to garnet-staurolite-mica schist, progressed from upper greenschist facies conditions to lower amphibolite facies condition.
2. The peak metamorphic assemblage is garnet-staurolite-biotite-muscovite observed in garnet-staurolite-mica schist.
3. Andalusite occurs in phyllite and andalusite marble. The mineral assemblage Muscovite-Chlorite-Quartz-Sericite of phyllite clearly indicates the upper greenschist or transition to amphibolite facies.
4. Chiastolite (Andalusite), garnet, staurolite, biotite, assemblage is developed in chiastolite-garnet-staurolite-mica schist.
5. The Qtz-Bt-Sil-Kfs assemblage is developed in biotite-sillimanite schist. Based on occurrence of this assemblage and spatial, distribution of other rock units co-existing in this area, it can safely be said that the metamorphic condition under which this rock developed has reached up to amphibolite facies and the bulk rock composition for this rock is likely different from protoliths of other metapelitic rocks in the study area.
6. Kyanite-bearing quartzite is observed as metapsammitic rocks in the study area. Kyanite is not present in most quartzite units and occurs only in certain localities within the host quartzite. It usually occurs in quartz vein which seems to fill in fractures of quartzite.

Discussion

This research enlightend the petrogenesis of metapelitic rocks and metapsammitic rocks in the study area. The study area is occupied by metapelite, metapsammite, metacarbonate and a small portion of igneous rocks. This study specifically concentrates on petrographic examination of metamorphic rocks, metamorphic conditions under which these rocks developed and the metamorphic evolution of the study area. The garnet-staurolite-biotite-muscovite mineral assemblage observed in garnet-staurolite mica schist represents the peak metamorphic conditions of the study area. Although most metapelitic schist, including biotite schist, garnet-mica schist and garnet-staurolite-mica schist are formed by continuous metamorphic conditions, the occurrence of rotated garnet grains along the foliation plane, internal schistosity within garnet grains perpendicular to the external schistosity of the matrix, quartz grain pressure shadows around garnet, and undulose extinction in quartz. Sillimanite schist is formed by a specific discontinuous reaction. This is suggested by the mineral assemblage observed in sillimanite schist. It may be concluded that the bulk rock composition of this rock differs from the other metapelitic rocks. Andalusite minerals in phyllite and marble exhibit a helicitic texture, suggesting they are relatively immature. Chiastolite in schist appears to have developed from the breakdown of garnet and staurolite in a decompressional tectonic environment. Additionally, the formation of andalusite in phyllite and marble differs from that of chiastolite (andalusite) in schist. Kyanite is not present in all quartzite units and usually occurs as a fracture-filling mineral in quartz veins within quartzite. It appears to have formed through the addition of hydrothermal fluids from an external or magmatic source.

Conclusion

This research provides significant insights into the petrogenesis and metamorphic evolution of the rocks in the Shwe-U-Min Taung and Shantaung-U-Yinswe range, Kyaukse Township. The petrographic analysis reveals distinct mineral assemblages, ranging from greenschist to amphibolite facies, indicating a progressive metamorphic history. The formation of Al_2SiO_5 polymorphs (andalusite, sillimanite, and kyanite) within a confined area is attributed to varying metamorphic conditions and tectonic processes. Andalusite observed in phyllite and marble is associated with low-pressure conditions, while chiastolite in schist suggests decompression during tectonic evolution. Sillimanite schist reflects high-temperature metamorphic conditions. Kyanite formation is linked to hydrothermal processes in specific quartzite veins. Garnet-staurolite-mica schist represents the peak metamorphic conditions in the area, with distinct texture indicating a complex metamorphic and tectonic history. The findings emphasize the role of regional tectonic settings, variable P-T conditions, and protolith compositions in influencing the mineralogical and textural characteristics of contributes to understanding the metamorphic processes and offers a framework for further geological investigations in similar terrains.

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