Estimating Temperature-Pressure Conditions Based on Metamorphic Rocks Exposed Between Kyaukpya and Pinthabye Village, Mogok Township, Mandalay Region

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Abstract

The study area is situated between Kyaukpya and Pinthabye Village, Mogok Township, Mandalay Region. The research area falls in the Sino-Burma Ranges which belongs to the Shan-Tenesserim Block. There are four major types of metamorphic rocks can be observed as diopside quartzite, calc-silicate rock, marble, and gneiss and migmatite. According to mineral assemblages observed in calcareous rocks, the formation of diopside and forsterite which indicate the metamorphic grade takes places at relatively high temperature. In pelitic rocks, the occurrence of garnet, biotite, sillimanite in gneiss unit, that rock may have been formed in upper amphibolite facies. High-grade metamorphism is characterized by the isograd "K-feldspar + Al_2 SiO_5 (sillimanite). Paragenesis diagnostic of high grade pelitic gneiss are – K-feldspar, almandine, biotite, plagioclase and quartz which is formed at almandine-high grade metamorphism. The appearance of migmatite in gneiss units indicates the highest grade of metamorphic zone and represents the culmination of high grade metamorphism under hydrous condition that characterized the granulite facies.

Keywords: *gneiss, migmatite, forsterite, sillimanite, granulite facies*

INTRODUCTION

The study area is situated between Kyaukpya and Pinthabye Village, Mogok Township, Mandalay Region. It is bounded by latitude 22°42'00"N to 22°54'00"N and longitude 96°19'00"E to 96°27'00"E. The study area lies in one inch topographic map No. 93-B/5. The location map of the study area is shown in figure (1). The topography of the study area is highly mountainous and rugged in the northeastern part and gradually lowers to the western and southern parts. The drainage pattern of the study area is generally coarse dendritic pattern and some streams show rectangular pattern. Major streams are Laungzin Chaung, Nannga Chaung and Nampai Chaung and small streams are creeks of these main streams.

Purpose of Study

The study area has been investigated on the following objectives;

1. To estimate the metamorphic grade of metamorphic rocks of the research area
2. To examine the petrogenesis of rock units encountered in the research area
3. To discuss the metamorphic facies and zone of metamorphic rocks of the research area

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Methods of Study

Field works including systematic sampling of the representative samples from the rock units, measurement of geological structures and geological mapping have been carried out by using tape and compass traverse method and GPS. The detailed petrographic studies of various rock types were studied under transmitted light polarizing microscope.

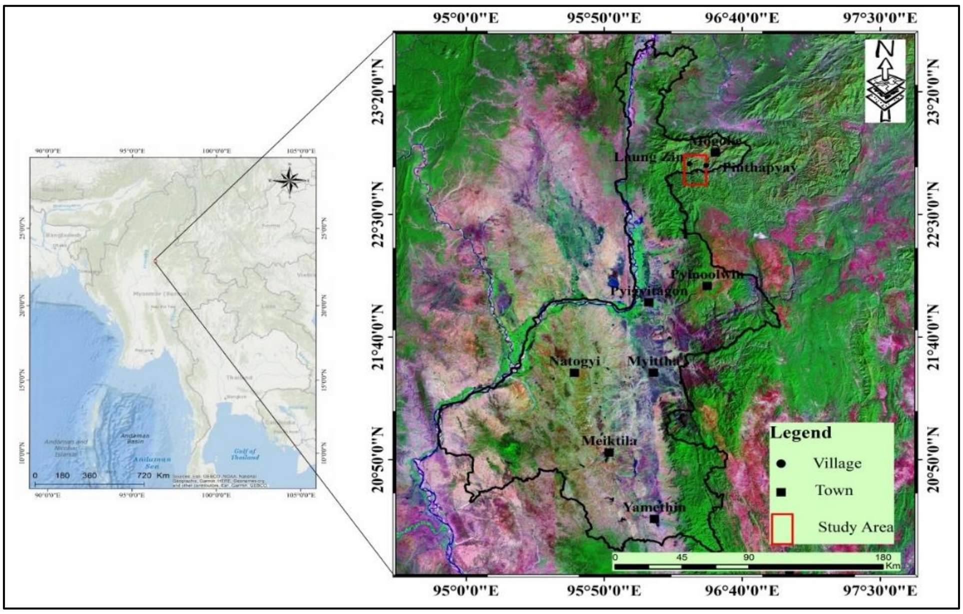


Figure (1) Location map of the study area

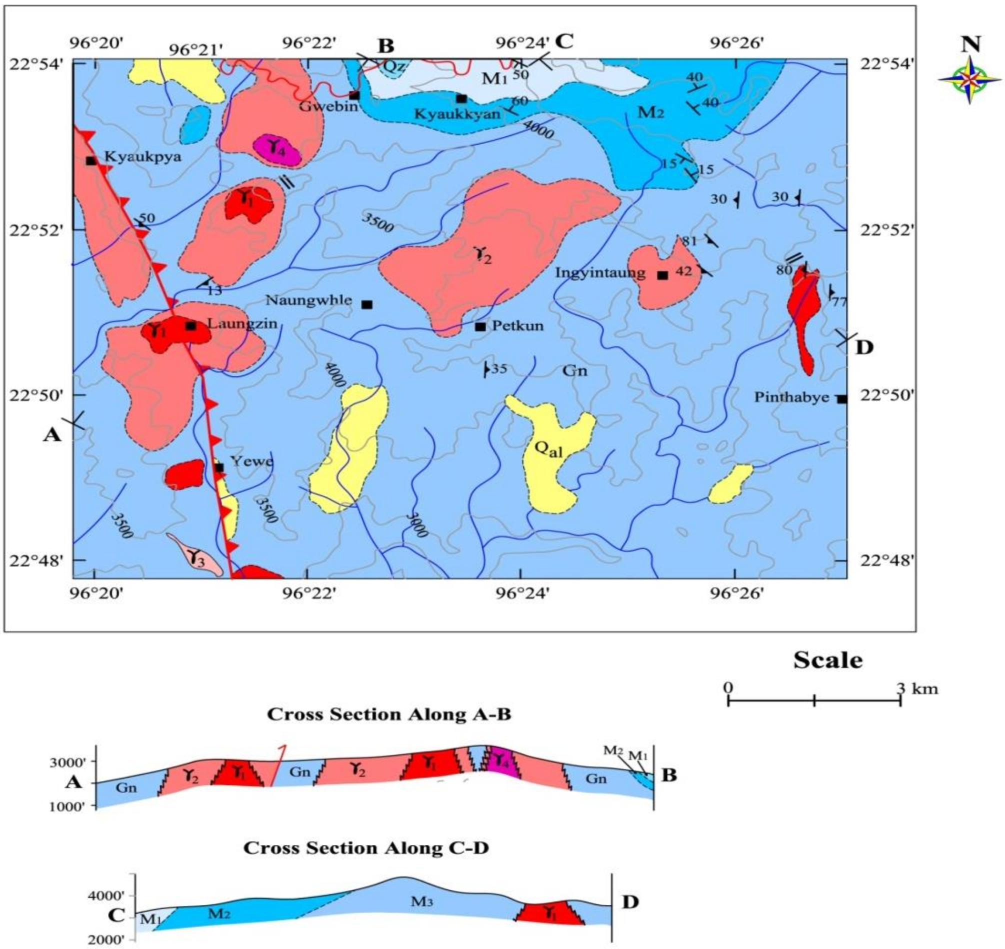
General Geology

Tectonically, Myanmar can be subdivided into four provinces, namely the Arakan Coastal Zone, Indo-Burma Ranges, Central Basin and Sino-Burma Ranges. The research area falls in the Sino-Burma Ranges which belongs to the Shan-Tenesserim Block, which is a part of SiBuMaSu (Sino-Burma-Malyasian-Sulawesi) terrain (Metcalfe, 1996). Mogok Metamorphic Belt is relatively narrow, elongated, sigmoidal shape belt which is generally oriented north-south, adjacent to the north-south trending Sagaing Fault in the west and Shan Scrap Fault in the east (Bertrand and Rangin, 2001). The Nam Pai Chaung bounds this belt in the north with the Momeik-Kunlong (Shweli) Fault. In the west, Irrawaddy Formation is running N-S and contacts with Mogok metamorphic units by Sagaing Fault.

Four major rock types can be observed in the study area. Rock sequence of the study area is shown in Table (1). Geological map of the study area is described in figure (2).

Table (1) Rock Sequence of Metamorphic Rocks Exposed between Kyaukpya and Pinthabye Area, Mogok Township, Mandalay Region

	Rock Type		**Age**
	Alluvium		Quaternary
Metasedimentary Rocks			
	Diopside quartzite		Lower Paleozoic
	Calc-silicate rock		Lower Paleozoic
	Marble	White marble	Lower Paleozoic
		Diopside-phlogopite marble	
	Gneiss and Migmatite	Sillimanite-garnet-biotite gneiss	Lower Paleozoic
		Leucogneiss	
		Hornblende-biotite gneiss	
		Migmatite	



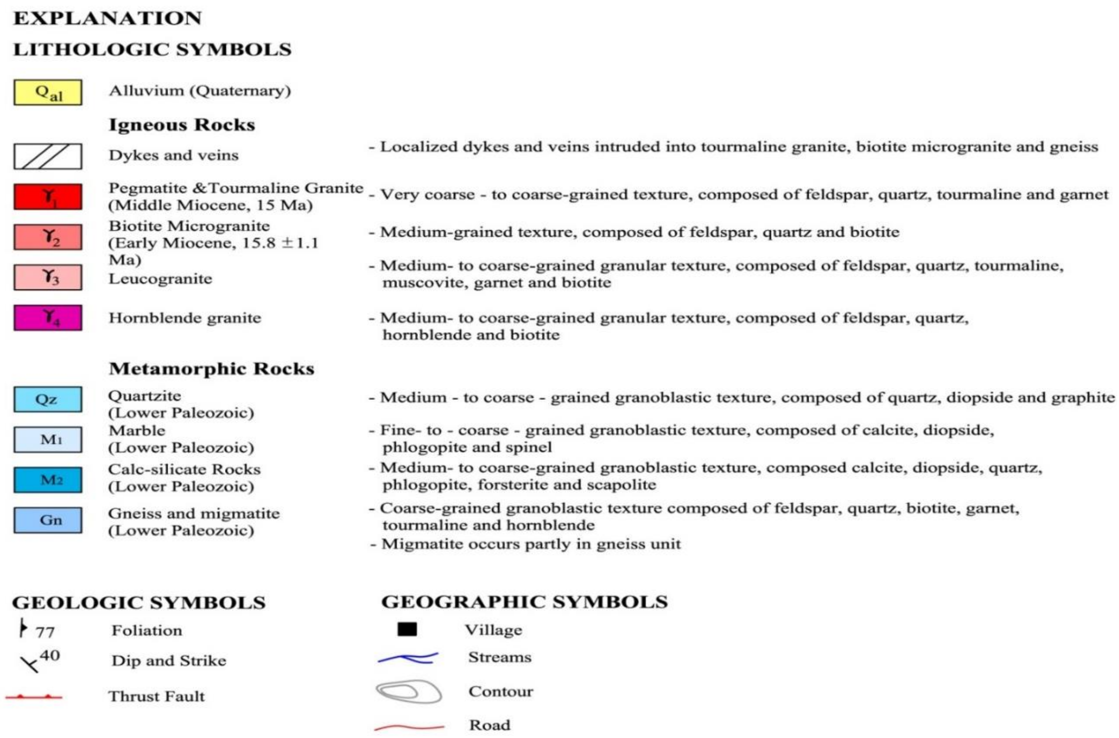


Figure (2) Geological Map of the Research area between Kyaukpya and Pinthabye Village, Mogok Township, Mandalay Region

Distribution of Metamorphic Rocks Exposed in the Research Area

Gneiss can be subdivided based on composition as sillimanite-garnet-biotite gneiss, leucogneiss and hornblende-biotite gneiss. Sillimanite-garnet-biotite gneiss exposed throughout the study area as it is the basement unit of the study area. Leucogneiss is mainly found at the northwestern part of Pinthebye Village. Small leucogneiss bodies are found about 3.2 km (2 miles) SE of Kyaukpya Village, Laungzin Village and Yewe Village (Shwedwingyi). Hornblende-biotite gneiss occurs very small extent at the east of Kyaukpya Village. Migmatites can be observed as an anatexis melting in garnet-biotite gneiss bodies in the vicinity of the intrusion of biotite microgranite, leucogranite and various compositions of pegmatites. They are mainly distributed around Pinthabye Village, Laungzin Village and Yewe Village.

Calc-silicate rocks occur abundantly near Yedwetgyi Village. They intercalated with diopside-phlogopite marble at Ingyin Taung. Ridge-and -furrow structure is recognized because of differential weathering. It is hard, compact and massive, and minor drag folds occur in this unit.

Marble unit can be subdivided into white marble and diopside-phlogopite marble. Marble units are exposed at the northern part of the study area near Kyaukkyan Village and Yedwetgyi Village. White marble and a few diopside-phlogopite marble are exposed at the east of Kyaukkyan Village. Diopside-phlogopite marbles are observed at Ingyin Taung and Yedwetgyi Village.

Diopside quartzite (Gwebin quartzite by Iyer, 1953) exposures are found at the south of the Mogok-Thabeikyin road between Gwebin and Kyaukkyan Village. It forms massive cliff in some places because it is highly jointed nature and breaks into thin slabs.

Mineralogical Assemblages and Metamorphic Facies

According to petrographical studies (Kerr, 1970 and Deer *et al*.,1992), the following mineral assemblages were recorded in the metamorphic rocks of the study area.

Mineral assemblages of quartzite:

1. Quartz+ Diopside+ Sericite+ Graphite
2. Quartz+ Diopside+ Sericite+ Calcite+ Graphite + Magnetite

Mineral assemblages in marble and calc-silicate rocks:

3. Calcite+ Graphite
4. Calcite+ Spinel+ Chondrodite+ Graphite
5. Calcite+ Spinel+ Chondrodite+ Orthoclase
6. Calcite+ Diopside+ Phlogopite+ Graphite
7. Calcite+ Diopside+ Phlogopite+ Forsterite+ Graphite
8. Diopside+ Scapolite+ Quartz+ Calcite+ Zircon
9. Diopside+ Scapolite+ Plagioclase+ Quartz+ Sphene
10. Diopside+ Scapolite+ Enstatite+ Quartz+ Calcite+ Plagioclase+ Zircon
11. Diopside+ Scapolite+ Calcite+ Quartz+ Sphene+ Zircon
12. Scapolite+ Diopside+ Quartz+ Plagioclase+ Orthoclase+ Calcite+ Sphene+ Zircon

Mineral assemblages of gneisses:

13. Orthoclase+ Quartz+ Plagioclase+ Biotite+ Apatite+ Graphite
14. Orthoclase+ Plagioclase+ Quartz+ Biotite+ Almandine+ Graphite
15. Quartz+ Orthoclase+ Biotite+ Plagioclase + Almandine + Zircon
16. Quartz+ Orthoclase+ Plagioclase+ Biotite+ Almandine+ Sillimanite+ Graphite
17. Orthoclase+ Plagioclase+ Quartz+ Biotite+ Almandine+ Sillimanite+ Zircon+ Graphite
18. Quartz+ Orthoclase+ Plagioclase+ Almandine+ Graphite
19. Orthoclase+ Quartz+ Plagioclase+ Tourmaline+ Muscovite+ Perthite+ Almandine+ Sillimanite+ Microcline+ Graphite
20. Orthoclase+ Quartz+ Plagioclase+ Almandine+ Tourmaline+ Biotite+ Sillimanite
21. Orthoclase+ Plagioclase+ Quartz+ Tourmaline+ Graphite
22. Plagioclase+ Orthoclase+ Quartz+ Hornblende+ Biotite+ Graphite
23. Orthoclase+ Quartz+ Plagioclase+ Hornblende+ Biotite+ Zircon

According to mineral assemblages observed in calcareous rocks, the formations of index minerals which indicate the metamorphic grade are as follows:

The formation of diopside in diopside-phlogopite marble may be produced by the following reaction

1tremolite + 3calcite + 2quartz = 5diopside + $3CO_2$ + $1H_2O$ (after Winkler, 1979)

This reaction is believed to be of the great importance in the first formation of diopside.

In some section, diopside and forsterite contain in the same slide. By the occurrence of forsterite in diopside-phogopite marble, forsterite was formed by the following reaction 3tremolite + 5calcite = 11diopside + 2forsterite + 5CO_2 + 3H_2O (after Winkler, 1979)

The first formation of forsterite in metamorphosed siliceous dolomite takes places at relatively high temperature according to the following reaction

1tremolite+ 11dolomite = 8forsterite+ 13calcite+ 9CO_2+ 1H_2O (after Winkler, 1979)

Diopside and forsterite are stable together in the mineral paragenesis by the following reaction:

1diopside + 3dolomite = 2forsterite + 4calcite + 2CO_2 (after Winkler, 1979)

The result mineral paragenesis becomes forsterite-diopside-dolomite-calcite.

In the reaction of impure magnesium limestone with potash feldspar, phlogopite was produced by the following reaction

3dolomite + 1K-feldspar + H_2O =1phlogopite + 3calcite + 3CO_2 (after Winkler, 1979)

In pelitic rocks, the occurrence of garnet, biotite, sillimanite in gneiss unit, that rock may have been formed in upper amphibolite facies (Butcher and Frey, 1994). The breakdown of muscovite in the presence of quartz and plagioclase defines the change from medium-grade to high-grade metamorphism. The following mineral parageneses are found by the breakdown of muscovite.

1. K-feldspar + Al_2SiO_5 (sillimanite)
2. K-feldspar + Almandine garnet

High-grade metamorphism is characterized by the isograd “K-feldspar + Al_2 SiO_5 (sillimanite). The formation of sillimanite indicates that these gneisses had experienced a high grade metamorphism of amphibolite facies and the reaction is:

Muscovite + quartz = liquid +K-feldspar + sillimanite

This reaction can take place from temperature 730°C at 6 kb and above.

The presence of almandine garnet in gneiss indicates the pressure of that rock is between which is 5 to 8 kb (Winkler, 1979). Almandine garnet may have been found by the following equation:

2muscovite + 2biotite + 1quartz = 4K-feldspar + 1almandine + 4Al_2SiO_5 + 4H_2O

Paragenesis diagnostic of high grade pelitic gneiss are – K-feldspar, almandine, biotite, plagioclase and quartz which is formed at almandine-high grade metamorphism.

The highest grade of progressive regional metamorphism of the Barrovian Type is marked by the appearance of sillimanite in pelitic rocks. Again mats of sillimanite prisms are commonly seen partially replaced by micas presumably with K-feldspar as a complementary product. The association of hornblende and plagioclase is also stable in the sillimanite zone and this clearly places the sillimanite-almandine subfacies in the almandine-amphibolite facies (Fyfe *et al.,* 1958 and Bucher *et al.,* 1994). The ACF and AKF diagram for sillimanite-almandine subfacies of the almandine-amphibolite facies of the study area is described in figure (3). The ideal assemblages of this subfacies are described in Table 2.

Table (2) The ideal mineral assemblages of the almandine-amphibolite facies

	Ideal Mineral Assemblage	Rock type
1	Quartz - microcline - sillimanite - almandine ± plagioclase ± biotite	Pelitic rock
2	Anorthite - diopside - hornblende - quartz	Calcareous rock
3	Calcite - diopside - tremolite	
4	Hornblende - plagioclase - diopside - quartz	Mafic rock
5	Hornblende- plagioclase - almandine - quartz	

The observation of anatexis in gneiss unit defines the beginning of high grade metamorphism if P_{H2O} is above 3.5 kb. At higher pressure, muscovite does not disappear because of the common additional presence of plagioclase, so that, muscovite accompanied by quartz, plagioclase ± biotite ± K-feldspar, is completely dissolved in a melt formed by the anatexis of gneiss. This takes place at minimal temperature of 660°C at 3.5 kb and 615°C at 10 kb. During the process of anatexis, muscovite furnished sillimanite and K-feldapar together with previously crystalline quartz and plagioclase constitute the anatectic melt.

According to Winkler(1979), the process of anatexis in gneiss gives the following mineral assemblage as muscovite + quartz + plagioclase + H2O = anatectic melt consisting of the component of K-feldspar + Ab-richer plagioclase + quartz, plus An-richer plagioclase or quartz depending on their amounts previously present in the gneiss, plus Al_2SiO_5 + H_2O dissolved in the melt, biotite also participates in anatectic melting.

The appearance of migmatite in gneiss units indicates the highest grade of metamorphic zone and represents the culmination of high grade metamorphism under hydrous condition that characterized the granulite facies.

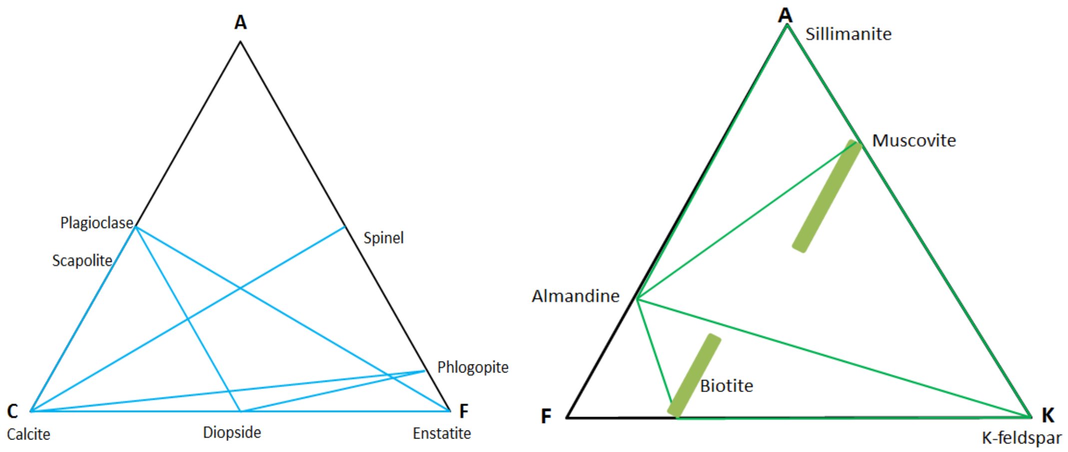


Figure (3) The ACF and AKF diagrams for sillimanite-almandine subfacies of upper amphibolite facies

Possible Temperature-Pressure Condition of Metamorphism

The temperature-pressure estimation of metamorphic rocks of the study area can be determined as follows:

In calcareous mineral assemblages, forsterite formed at the temperature about 690°C and diopside formed at 600°C.The formation of sillimanite in gneiss indicates a high grade metamorphism of amphibolite facies at the temperature 730°C at 6 kb and above. The presence of almandine garnet in gneiss indicates the pressure of that rock formed which is 5 to 8 kb (Winkler, 1979).

The association of hornblende and plagioclase in hornblende-biotite gneiss indicates the sillimanite zone, the sillimanite-almandine subfacies in the almandine-amphibolite facies (Fyfe *et al.*,1958 and Turner *et al.*, 1951). Almandine-amphibolite facies at the temperature range about 550°C- 680°C and pressure about 4 kb- 8 kb.

There is an evidence of anatexis in gneiss in the study area which defines minimal temperature of 660°C at 3.5 kb and 615°C at 10 kb (Winkler, 1979).

According to temperature and pressure indicated by the presence of minerals in marble, calc-silicate rock, quartzite and gneisses, the minimal and maximal temperature can be assumed at 550°C- 730°C and the pressure range is 3.5 kb-10 kb. The estimated P-T condition describes in figure (4) in which the temperature, pressure, depth and facies description are established by Winter, 2013.

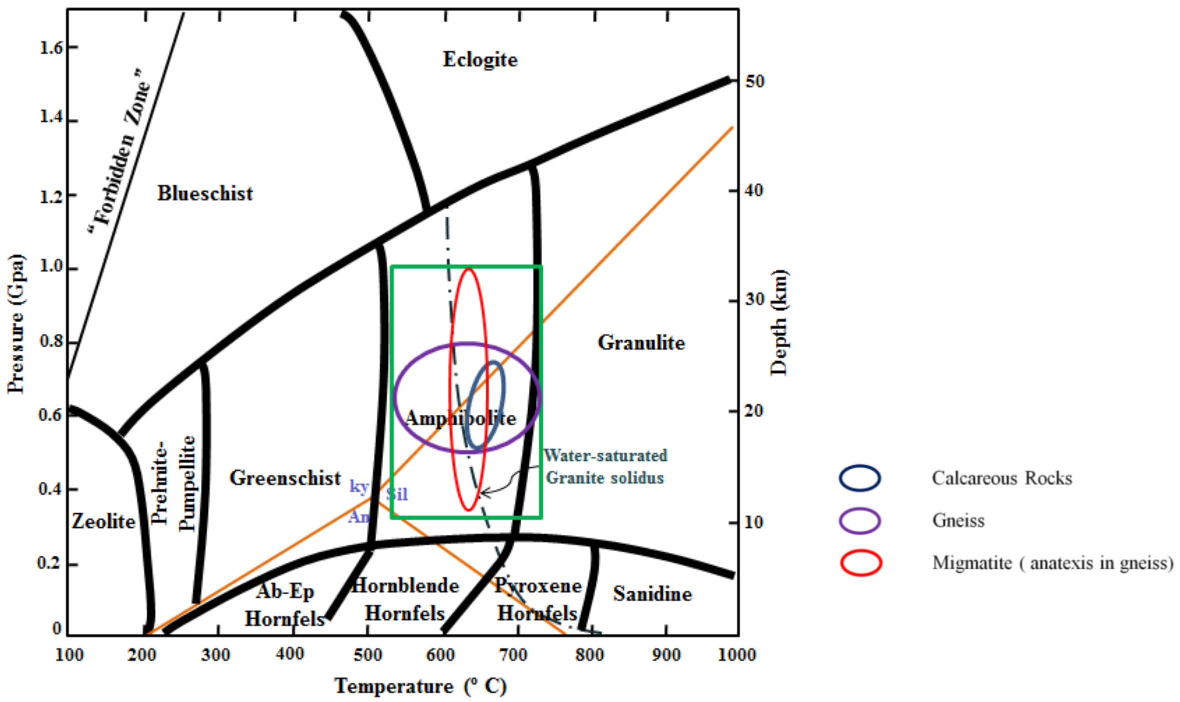


Figure (4) Temperature-Pressure diagram showing the two major types of metamorphic facies series (after John D. Winter, 2013)

SUMMARY AND CONCLUSIONS

The study area is bounded by latitude 22°42'00"N to 22°54'00"N and longitude 96°19'00"E to 96°27'00"E. The study area lies in one inch topographic map No. 93-B/5.

The study area was investigated for estimating the metamorphic grade of metamorphic rocks, examining the petrogenesis of rock units encountered and discussing the metamorphic facies and zone of metamorphic rocks.

According to petrographical studies, 2 mineral assemblages in quartzite, 5 mineral assemblages in marble, 5 mineral assemblages in calc-silicate rocks and 11 mineral assemblages in gneiss.

The formation of diopside and forsterite in the same slide referred to the following reaction:

3tremolite + 5calcite = 11diopside + 2forsterite + 5CO_2 + 3H_2O (after Wrinkler, 1979)

In gneiss units, the occurrence of garnet, biotite and sillimanite indicates these rocks may have been formed in **upper amphibolite facies** (Butcher and Frey, 1994). High-grade metamorphism is characterized by the isograd "K-feldspar + 4Al_2SiO_5 (sillimanite)".

Almandine garnet may have been found by the following equation;

2muscovite + 2biotite + 1quartz = 4K-feldspar + 1almandine + 4Al_2SiO_5 + 4H_2O

Paragenesis diagnostic of high grade pelitic gneiss are – K-feldspar, almandine, biotite, plagioclase and quartz which is formed at **almandine-high grade metamorphism**.

The association of hornblende and plagioclase is also stable in the sillimanite zone and this clearly places the **sillimanite-almandine subfacies** in the almandine-amphibolite facies (Fyfe *et al.,* 1958).

The process of anatexis in gneiss gives the following mineral assemblage as muscovite + quartz + plagioclase + H_2O = anatectic melt consisting of the component of K-feldspar + Ab-richer plagioclase + quartz depending on their amounts previously present in the gneiss, plus Al_2SiO_5 + H_2O dissolved in the melt, biotite also participates in anatectic melting.

The occurrences of migmatite in gneiss units indicates the highest grade of metamorphic zone and represents the culmination of high grade metamorphism under hydrous condition that characterized **the granulite facies**.

According to temperature and pressure indicated by the presence of minerals in metamorphic rocks, the minimal and maximal temperature can be assumed at 550°C - 730°C and the pressure range is 3.5kb – 10kb.

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