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Estimating P-T Conditions of Metamorphic Rocks Exposed in Mawlu Area, Indaw Township, Sagaing Region with Isochemical Phase Diagram Sections

Aung Khin Soe[1] and Than Than Nu[2]

Abstract

The study area lies in Indaw Township, northeastern part of Sagaing Region. It is situated between Latitude 24° 20′ to 24° 35′ N and Longitude 96° 10′ to 96° 20′ E. The present study area is chiefly made up of metamorphic rocks and minor sedimentary rocks. They occupy the entire bulk of the Katha-Gangaw Range.On the basis of petrographic analysis, nine representative mineral assemblages are distinctive in various types of schists occurred in the study area (eight in metapilite and one in metabasite). According to mineral assemblages, the metamorphic rocks of the research area indicate lower greenschist facies to upper amphibolites facies. Isochemical pressure-temperature phase-diagram sections portray the theoretical equilibrium distribution of mineral assemblages and mineral compositions for a given bulk-composition. Isochemical sections for garnet-staurolite-sillimanite-muscovite-quartz, garnet-kyanite (sillimanite)-muscovite-quartz of pelitic rocks from sillimanite zone and garnet-actinolite-tschermakite-chlorite-biotite-quartz-epidote of metabasite rocks from garnet zone at Mawlu area, were calculated in the system MnO-Na_2O-CaO-K_2O-Fe_2O_3-MgO-Al_2O_3-SiO_2-H_2O-TiO_2 using bulk compositions derived by X-ray fluorescence (XRF) analysis. Procedures of calculation methods to produce P-T pseudosection diagrams are used to Perple-X computer program. These sections were constructed in the interval 2-12 kilobars, 400-800°C to cover the P-T conditions. The phase-diagram sections for the XRF derived composition indicates that the garnet zone and sillimanite zone metamorphic rocks occurred at approximately 3 kilobars to12 kilobars at 470-735°C.

Key words: Katha-Gangaw Range, Isochemical pressure-temperature phase-diagram, garnet zone, sillimanite zone

Introduction

The investigated area, Pinwe-Mawlu area, is situated in Indaw Township, northeastern part of the Sagaing Region. It lies between Latitude 24° 20′ to 24° 35′ N and Longitude 96° 10′ to 96° 20′ E. The area is bounded by vertical grids 140 to 280 and horizontal grids 940 to 150 in UTM maps of sheet No. 2496 02, sheet No. 2496 03, sheet No. 2496 06 and sheet N0.2496 07.The present area is about 21 km long in the N-S direction and 14 km wide in an E-W direction. It covers about 294 square km. The location map of the study area is shown in (Fig. 1).

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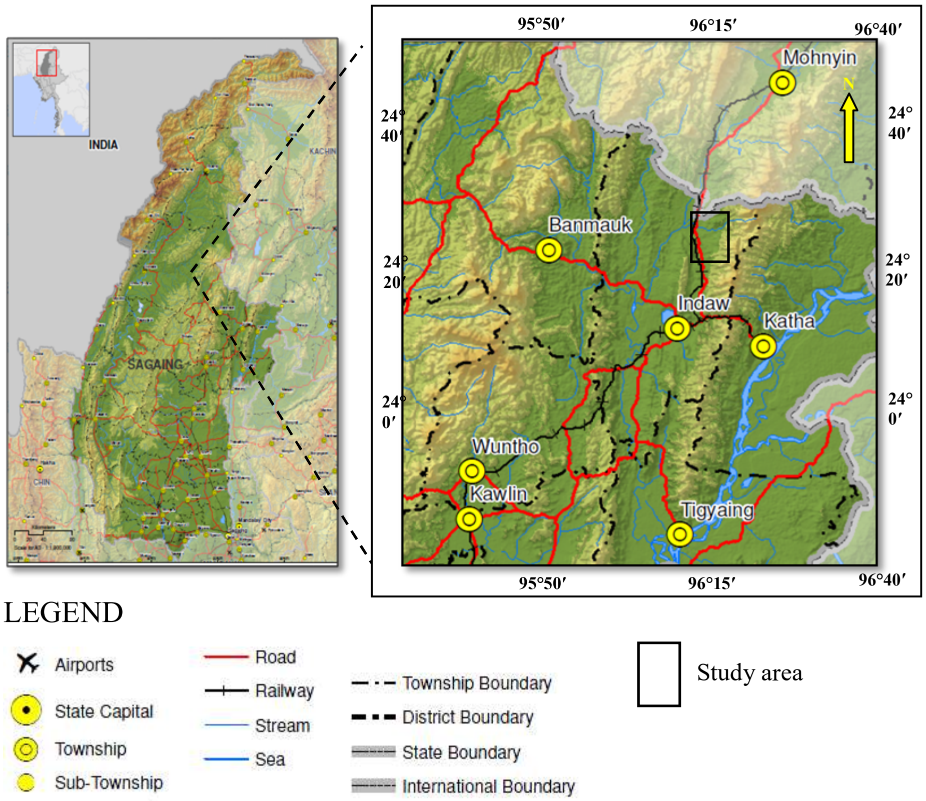


Fig.(1) Location map of the study area

Distribution of rock units

The present study area is chiefly made up of metamorphic rocks with minor sediments. The metamorphic rocks are of Late Jurassic-Early Cretaceous Katha Metamorphic rock units and Miocene to Plio-Pleistocene Irrawaddy Formation. The pelitic to psammitic protolith may be inferred by the presence of predominant schist and quartzite of the investigated area. The presumable metabasite due to difference physical characters of surrounding rock units is occurred in the garnet biotite schist unit.

The widely spread rock unit, Katha Metamorphics, occupy both limbs of Katha-Gangaw Range, may be lithologically divided into eleven units (eight in metapelite, one in metabasite and two in metapsammite). They are (i) chlorite schist (ii) biotite schist (iii) muscovite schist (iv) garnet biotite schist (v) garnet muscovite schist (vi) paragonite garnet schist (vii) sillimanite garnet staurolite schist (viii) garnet kyanite (sillimanite) muscovite schist (metapelite) (ix) garnet actinolite schist (metabasite) (x) quartzite and (xi) micaceous quartzite (metapsammite). Garnet biotite schist is the most abundant metamorphic rock unit and this unit occupies the central and eastern part of the area

Mineral Assemblages and Metamorphic Facies

On the basis of petrographic analysis, nine representative mineral assemblages are distinctive in various types of schists occurred in the study area (eight in metapilite and one in metabasite). They are;

Mineral assemblages in metapelites

1. chlorite, muscovite,quartz,actinolite,chloritoid, epidote

2. biotite, muscovite, chlorite, K-feldspar,quartz
3. biotite, muscovite, chlorite,quartz
4. garnet, biotite, muscovite, quartz
5. garnet, biotite, muscovite,quartz, chlorite
6. garnet, paragonite,quartz, chlorite
7. garnet, staurolite, sillimanite, muscovite, quartz
8. garnet, kyanite, sillimanite, muscovite, quartz

Mineral assemblage in metabasite

9.garnet, actinolite, chlorite,biotite, quartz,epidote

The facies classification, nomenclature and representative mineral assemblages used in this research work was mainly based on Turner (1968), Yardley (1989), Bucher and Frey (1994), Winter (2010) and Bucher and Grapes (2011).

The mineral assemblage of Chl-Ms-Qtz is typical assemblage of chlorite schist. The occurrence of this mineral assemblage in chlorite schist clearly indicates that the rock develops in chlorite zone of lower greenschist facies.

The Bt-Ms-Chl-Kfs-Qtz assemblage is developed in the biotite schist and Bt-Ms-Chl-Qtz in muscovite schist. These assemblages are the characteristic of biotite zone of upper greenschist facies.

Grt-Bt-Ms-Chl-Qtz assemblage is common in garnet biotite schist and garnet muscovite schist. This assemblage is typically developed in the metapelite of garnet zone of lower amphibolites facies.

The mineral assemblage of Grt-Pg-Qtz-Chl is developed in paragonite garnet schist and it is the characteristic of garnet zone of lower amphibolite facies.

The Grt-St-Sil-Ms-Qtz assemblage is developed in sillimanite garnet staurolite schist and the Grt-Ky(Sil)-Ms-Qtz assemblage in garnet kyanite (sillimanite) muscovite schist. These mineral assemblages develop commonly fall within the sillimanite zone. Base on occurrence of these mineral assemblages that the metamorphic condition of these rocks reached up to upper amphibolites facies.

The Grt-Act-Chl-Epi-Qtz assemblage is developed in garnet tschermakite schist. This assemblage is equivalent to the eclogite facies transition of the metabasite rock.

The metamorphic rocks associated with mineral assemblages and metamorphic facies of the study area are list in Table (1).

Assemblage Stability Diagrams

Assemblage stability diagrams, or pseudosections, are diagrams that display the stable mineral assemblages for a specific bulk rock composition over a range of P-T conditions. Isochemical P-T phase diagram sections provide important information on mineral assemblage stability in P-T space. Pseudosections are relatives of the petrogenetic grid. The great advantage of pseudosections is that they predict the stable mineral assemblage and composition of minerals at P-T-X conditions. Pseudosections can be computed by very different technique and different computer programs.

Calculation Methods

The pressure-temperature (P-T) conditions of the present area's phase diagram sections were computed from the bulk rock composition. There are several methods available for estimating effective bulk composition. One method utilizes the result of a bulk rock X-ray fluorescence analysis as an estimate of the effective composition. For this calculation, the model chemical system MnNCKFMASH was used with the bulk rock composition obtained from XRF analysis (Table 2). They were carried out at Department of Geological Survey and Mineral Exploration, Ministry of Natural Resources and Environmental Conservation. The amount of H_2O component involved in the calculation for the bulk rock composition was assumed as the loss of ignition of XRF analysis and thus represents the water content available for equilibration of the observed mineral assemblage.

Table (1) Mineral assemblages and metamorphic facies of the study area

Type of Metamorphism	Rock Group	Representative Rock	Mineral Assemblage	Metamorphic Facies
Regional Metamorphism	Metapelites	Chlorite schist	chlorite,muscovite, quartz,actinolite, chloritoid, epidote	Greenschist Facies
		Biotite schist	biotite, muscovite, chlorite,K-feldspar,quartz	
		Muscovite schist	biotite, muscovite, chlorite,quartz	
		Garnet biotite schist	garnet, biotite, muscovite, quartz	Amphibolite Facies
		Garnet muscovite schist	garnet, biotite, muscovite,quartz, chlorite	
		Paragonite garnet schist	garnet,paragonite, quartz, chlorite	
		Sillimanite garnet staurolite schist	garnet, staurolite, sillimanite, muscovite, quartz	
		Garnet kyanite (sillimanite) muscovite schist	garnet, kyanite (sillimanite), muscovite, quartz	
	Metabasite	Garnet actinolite schist	garnet, actinolite, chlorite,biotite, quartz,epidote	Eclogite Facies Transition

For predicting the P-T conditions of high grade metamorphic rocks which are sillimanite garnet staurolite schist and garnet kyanite (sillimanite) schist, the MnNCKFMASH chemical system was used. All the calculations were done by the thermodynamic database of Holland & Powell (1998 and updated version, 2003). Mixing properties of phases used for the calculation were taken from White *et al.*,(2007) for solution model of melt, garnet from Holland & Powell (2001) and mica from Coggan & Holland (2002). Procedures of calculation methods to produce P-T pseudosection diagrams by using Perple-X computer program are shown in (Fig. 2).

These sections were constructed in the interval 2-12 kilobars, 400-800°C to cover the P-T conditions of the Pinwe-Mawlu area. White *et al*. (2000) presented the isochemical and T-X sections and activity models for use with the Holland & Powell (1998) thermodynamic dataset with the components TiO_2 and Fe_2O_3 added to the base chemical system K_2O-FeO-MgO-Al_2O_3-SiO_2-H_2O (in Tinkham and Ghent, 2005).

Table (2) Bulk rock analytical data (XRF) of Sample AKS-2,3 and 4(Metapelites)

XRF-derived bulk analysis (mass %)	sillimanite garnet staurolite schist (AKS-2)	Garnet kyanite(sillimanite) schist (AKS-3)	garnet kyanite (sillimanite) schist (AKS-4)
MgO	0.0785	-	-
Al_2O_3	23.2	25.2	26.2
SiO_2	64.7	65.4	57.9
K_2O	2.76	0.554	3.32
CaO	0.180	0.174	0.225
TiO_2	1.25	1.25	1.05
Fe_2O_3	6.66	6.71	9.58
Na_2O	0.297	-	0.614
ZrO_2	0.363	0.368	0.398

Table (3) Bulk rock analytical data (XRF) of Sample AKS-1 (Metamafic)

XRF-derived bulk analysis (mass %)	Garnet-actinolite schist (AKS-1)
MgO	2.15
Al_2O_3	12.9
SiO_2	57.3
K_2O	0.0822
CaO	7.15
TiO_2	2.76
MnO	0.155
Fe_2O_3	15.1
Na_2O	1.01
ZrO_2	0.463

Isochemical Phase-Diagram of Sillimanite Garnet Staurolite Schist of Sample AKS-2

Isochemical section was constructed in the ten component system MnO-Na_2O-CaO-K_2O-Fe_2O_3-MgO-Al_2O_3-SiO_2-H_2O-TiO_2 using the program Perple-X. A pure H_2O fluid is considered in excess in all calculations. The pure H_2O fluid used in calculations is likely only an approximation to the actual compositions of fluid. The P-T conditions of pseudosection were derived from the following bulk composition: K_2O=2.76, Fe_2O_3=6.66, MgO=0.0785, Al_2O_3=23.2, SiO_2=64.7, TiO_2=1.25, Na_2O=0.297, CaO=0.18, ZrO_2=0.363. The resulting figure (Fig.3) shows the P-T conditions of the amphibolites facies assemblage of garnet-staurolite-sillimanite-muscovite-quartz. This assemblage stability field (10 in figure 3) is predicted from approximately 3.65 kilobars to 7.1 kilobars and 570°C to 670°C.

Isochemical Phase-Diagram of Garnet Kyanite(Sillimanite)Schist of Sample AKS-3

An isochemical section for the XRF derived bulk rock composition is shown in (Fig.4). The pseudosection is computed base on the bulk composition: K_2O=0.554, Fe_2O_3=6.71, Al_2O_3=25.2, SiO_2=65.4, CaO=0.174, TiO_2=1.25, ZrO_2=0.368. The stability field of garnet is marked by thick line in (Fig. 4). This figure indicates that the lower temperature stability of garnet is 530°C at 2 kilobars and 580°C at 12 kilobars. The amphibolites facies assemblage of garnet-kyanite-muscovite-quartz-zircon-ilmenite (field 22 in figure 4) is predicted to extend from approximately 7 kilobars to >12 kilobars and >630°C. Garnet-sillimanite-muscovite-quartz-zircon-ilmenite assemblage's stability (field 23 in figure 4) is predicted approximately >3 kilobars and >600°C.

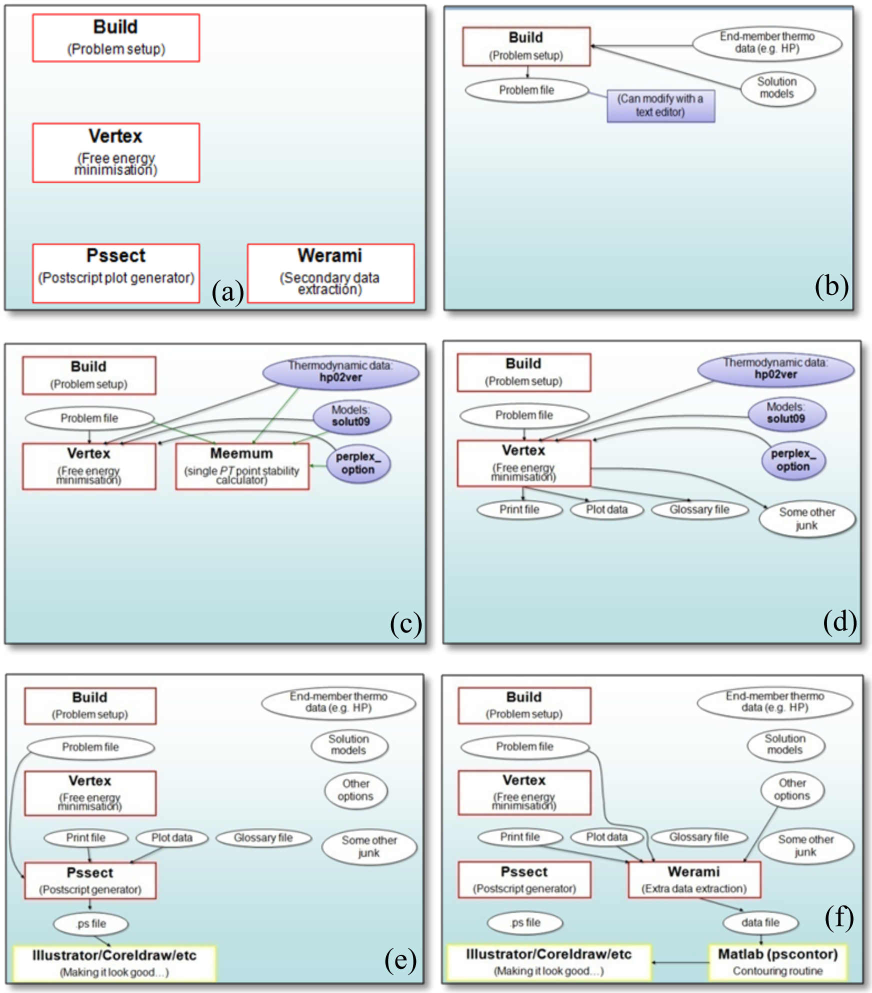
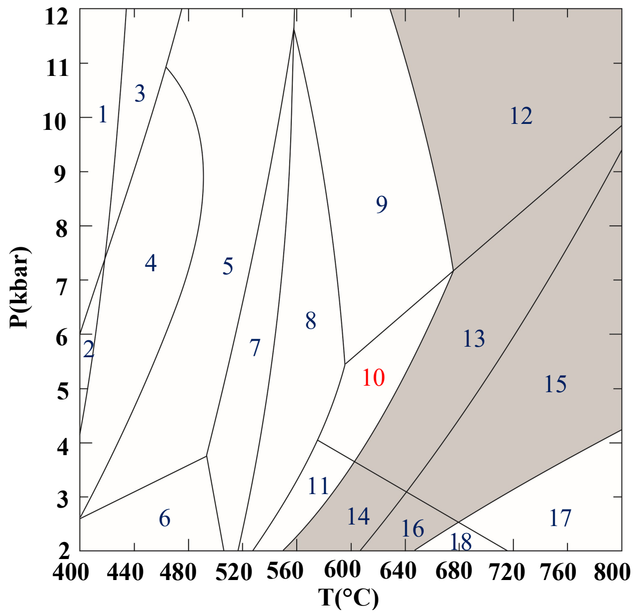


Fig. (2) Procedure calculation methods to produce pseudosections (a to f) by using Perple-X (Source: ETH web link in Wai Yan Lai Aung, 2016))

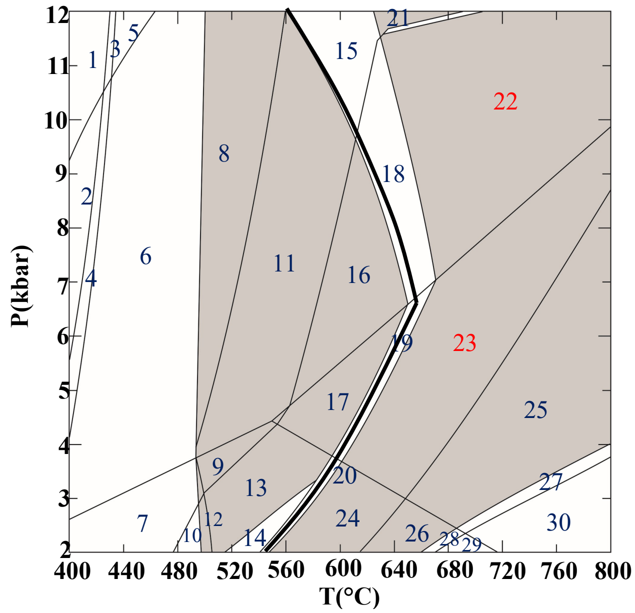


(1). Cld-Cp-Ms-Prl-Qtz
(2). Cld-Ms-Sud-Prl-Qtz
(3). Ky-Cld-Cp-Ms-Qtz
(4). Ky-Cld-Ms-Sud-Qtz
(5). Ky-Cld-Ms-Clin-Qtz
(6).And-Cld-Ms-Clin-Qtz
(7).St-Cld-Ms-Clin-Qtz
(8). Grt-St-Ms-Clin-Qtz
(9). Grt-Ky-St-Ms-Qtz
(10). Grt-Sil-St-Ms-Qtz
(11). Grt-And-St-Ms-Qtz
(12). Grt-Ky-Ms-Qtz
(13). Grt-Sil-Ms-Qtz
(14). Grt-And-Ms-Qtz
(15). Grt-Sil-Sa-Qtz
(16). Grt-And-Sa-Qtz

Fig. (3) Isochemical sections with stable assemblage fields of sillimanite garnet staurolite schist of Sample AKS-2.

Isochemical Phase-Diagram of Garnet Kyanite(Sillimanite)Schist of Sample AKS-4

The P-T pseudosection was computed from bulk rock composition of the sample AKS-4 (K_2O=3.32, Fe_2O_3=9.58, Al_2O_3=26.2, SiO_2=57.9, CaO=0.225, TiO_2=1.05, Na_2O=0.614, ZrO_2=0.398). An isochemical section for the XRF derived bulk rock composition is shown in (Fig. 5). The stability of garnet marked by the thick blue line in figure, indicates that the lower temperature stability of garnet is 520°C at 2 kilobars and 570°C at 12 kilobars. The equilibrium conditions is expected to correspond to 620-780°C and >7.1 kilobars in the field (6 in figure 5) of garnet-kyanite-muscovite-quartz-zircon-ilmenite. The stability field (7 in figure 5) of garnet-sillimanite-muscovite-quartz-zircon is predicted to extend from approximately 3.3 to 8.5 kilobars and 610 to 735°C.

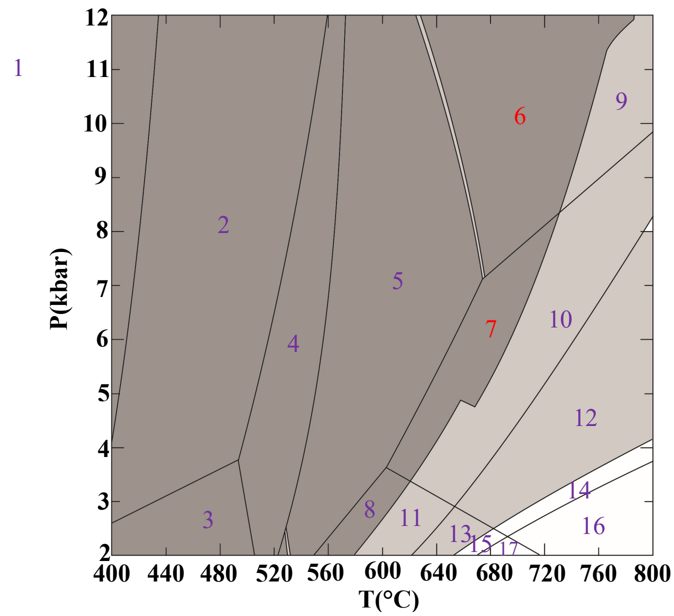


(1). Ms-Cld-Lws-Zrn-Prl-Rt-Dsp
(2). Ms-Pg-Cld-Zrn-Prl-Rt-Dsp
(3). Ms-Ky-Cld-Lws-Zrn-Prl-Rt
(4). Ms-Pg-Ky-Cld-Zrn-Prl-Rt
(5). Ms-Ky-Cld-Lws-Zrn-Qtz-Rt
(6). Ms-Pg-Ky-Cld-Zrn-Qtz-Rt
(7). Ms-And-Cld-Zrn-Qtz-Rt
(8). Ms-Pg-Ky-Cld-Zrn-Qtz-Rt
(9). Ms-And-St-Zrn-Qtz-Rt
(10). Ms-Pg-And-Cld-Zrn-Qtz-Ilm
(11). Ms-Ky-St-Zrn-Qtz-Rt
(12). Ms-And-Cld-Zrn-Qtz-Ilm
(13). Ms-And-St-Zrn-Qtz-Ilm
(14). Ms-And-St-Zrn-An-Qtz-Ilm
(15). Ms-Grt-Ky-St-Zrn-Qtz-Rt
(16). Ms-Ky-St-Zrn-Qtz-Ilm
(17). Ms-Sil-St-Zrn-Qtz-Ilm
(18). Ms-Grt-Ky-St-Zrn-Qtz-Ilm
(19). Ms-Grt-Sil-St-Zrn-Qtz-Ilm
(20). Ms-Grt-And-St-Zrn-Qtz-Ilm
(21). Ms-Grt-Ky-Zrn-Qtz-Rt
(22). Ms-Grt-Ky-Zrn-Qtz-Ilm
(23). Ms-Grt-Sil-Zrn-Qtz-Ilm
(24). Ms-Grt-And-Zrn-Qtz-Ilm
(25). Grt-Sil-Zrn-Sa-Qtz-Ilm
(26). Grt-And-Zrn-Sa-Qtz-Ilm
(27). Grt-Sil-Zrn-Sa-Qtz-Ilm-Hc
(28). Grt-And-Zrn-Sa-Qtz-Ilm-Hc
(29). And-Zrn-Sa-An-Qtz-Ilm-Hc
(30). Sil-Zrn-Sa-An-Qtz-Ilm-Hc

Fig. (4) Isochemical sections with stable assemblage fields of garnet kyanite (sillimanite) schist of Sample AKS-3. Thick blue line separates P-T space of garnet.

Isochemical Phase-Diagram of Garnet-Actinolite Schist of Sample AKS-1

Similar to the former samples, the P-T pseudosection was computed in the MnO-Na_2O-CaO-K_2O-Fe_2O_3-MgO-Al_2O_3-SiO_2-H_2O-TiO_2 system for the following bulk rock composition of the sample AKS-1(K_2O=0.0822, Fe_2O_3=15.1, MgO=2.15, Al_2O_3=12.9, SiO_2=57.3, CaO=7.15, TiO_2=2.76, MnO=0.155, Na_2O=1.01, ZrO_2=0.463). The XRF derived bulk rock composition of isochemical section of metamafic rock is shown in (Fig. 6). The P-T conditions of eclogite facies transition assemblage (field 7 in figure 6) is predicted approximately 4 kilobars to 12 kilobars and 470°C to 500°C.



(1). Ms-Cld-Zrn-Prl-Qtz

(2). Ms-Ky-Cld-Zrn-Qtz

(3). Ms-And-Cld-Zrn-Qtz

(4). Ms-St-Cld-Zrn-Qtz

(5). Ms-Grt-St-Zrn-Qtz

(6). Ms-Grt-Ky-Zrn-Qtz

(7). Ms-Grt-Sil- Zrn-Qtz

(8). Ms-Grt-And-Zrn-Qtz

(9). Ms-Grt-Ky-Zrn-Ab-Qtz

(10). Ms-Grt-Sil-Zrn-Ab-Qtz

(11). Ms-Grt-And-Zrn-Ab-Qtz

(12). Grt-Sil-Zrn-Ab-Sa-Qtz

(13). Grt-And-Zrn-Ab-Sa-Qtz

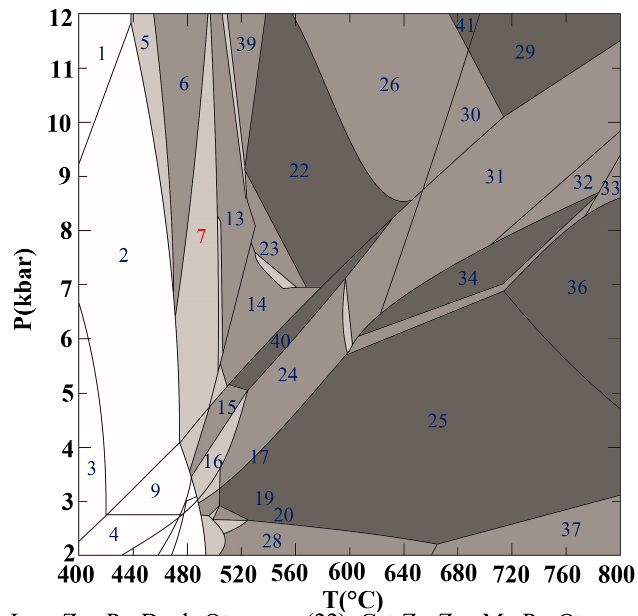
(14). Grt-Sil-Zrn-Ab-Sa-Qtz-Hc

(15). Grt-And-Zrn-Ab-Sa-Qtz-Hc

(16). Sil-Zrn-Ab-Sa-An-Qtz-Hc

(17). And-Zrn-Ab-Sa-An-Qtz-Hc

Fig. (5) Isochemical sections with stable assemblage fields of garnet kyanite (sillimanite)schist of Sample AKS-4.



(1). Grt-Act-Bt-Cld-Lws-Zrn-Pg-Daph-Qtz
(2). Grt-Act-Bt-Cld-Zo-Zrn-Pg-Daph-Qtz
(3). Grt-Bt-Cld-Zo-Zrn-Pg-Clin-Daph-Qtz
(4). Grt-Act-Bt-Zrn-Pg-Clin-Daph-An-Qtz
(5). Grt-Act-Bt-Cld-Zrn-Pg-Daph-Qtz
(6). Grt-Act-Bt-Cld-Zrn-Pg-Qtz
(7). Grt-Act-Bt-Cld-Zo-Zrn-Pg-Qtz
(8). Grt-Act-Bt-Zo-Zrn-Pg-Mrg-Qtz
(9). Grt-Act-Bt-Cld-Zrn-Pg-Daph-An-Qtz
(10). Grt-Bt-Zrn-Pg-Clin- Daph-Ab-An-Qtz
(11). Grt-Bt-Cld-Zrn-Clin-Daph-Ab-An-Qtz
(12). Grt-Bt-Cld-Zrn-Ath-Clin-Ab-An-Qtz
(13). Grt-Bt-Cld-Zo-Zrn-Pg-Qtz
(14). Grt-Bt-Zo-Zrn-Pg-Mrg-Qtz
(15). Grt-Act-Bt-Zrn-Pg-An-Qtz
(16). Grt-Act-Bt-Zrn-Pg-Ab-An-Qtz
(17). Grt-Act-Bt-Cld-Zrn-Ath-Pg-An-Qtz
(18). Grt-Act-Bt-Cld-Zrn-Ath-Ab-An-Qtz
(19). Grt-Act-Bt-Zrn-Ab-An-Qtz
(20). Grt-Act-Bt-Zrn-Ath-Ab-An-Qtz
(21). Grt-Bt-Zrn-Ath-Clin-Ab-An-Qtz
(22). Grt-Zo-Zrn-Ms-Pg-Qtz
(23). Grt-Bt-Zo-Zrn-Ms-Pg-Qtz
(24). Grt-Bt-Zrn-Pg-Ab-An-Qtz
(25). Grt-Bt-Zrn-Ab-An-Qtz
(26). Grt-Ky-Zo-Zrn-Ms-Pg-Qtz
(27). Grt-Zrn-Ms-Pg-Ab-An-Qtz
(28). Grt-Bt-Zrn-Ath-Ab-An-Qtz
(29). Grt-Ky-Zrn-Ms-Ab-Qtz
(30). Grt-Ky-Zo-Zrn-Ms-Ab-Qtz
(31). Grt-Ky-Zrn-Ms-Ab-An-Qtz
(32). Grt-Sil-Zrn-Ms-Ab-An-Qtz
(33). Grt-Sil-Zrn-Ab-Sa-An-Qtz
(34). Grt-Zrn-Ms-Ab-An-Qtz
(35). Grt-Bt-Zrn-Ms-Ab-An-Qtz
(36). Grt-Zrn-Ab-Sa-An-Qtz
(37). Grt-Bt-Fa-Zrn-Ab-An-Qtz
(38). Grt-Act-Bt-Cld-Zrn-Pg-An-Qtz
(39). Grt-Cld-Zo-Zrn-Ms-Pg-Qtz
(40). Grt-Bt-Zrn-Pg-An-Qtz
(41). Grt-Ky-Zrn-Ms-Pg-Qtz

Fig. (6) Isochemical sections with stable assemblage fields of Garnet-Actinolite Schist of Sample AKS-1.

Discussion and Conclusion

The paragenesis of the study area can be established on the basis of mineral assemblages observed in each rock type with additional constraints provided by P-T conditions calculated from XRF-analytical data.

The occurrence of Chl-Ms-Qtz mineral assemblage in chlorite schist clearly indicates that the rock develops in low-grade metamorphism of lower greenschist facies condition. From biotite schist, through muscovite schist, garnet biotite schist, garnet muscovite schist, sillimanite garnet staurolite schist and garnet kyanite (sillimanite) schist, the metamorphic grade gradually increased through lower amphibolites facies to upper amphibolites facies conditions. With reference to well-documented reactions and petrogenetic grids, the temperature affected on the various rock types range from ~400°C up to 700°C at the pressure of 4 to 6 kilobars.

The P-T calculation from the bulk composition gives that the approximate P-T conditions are as follow. Analyzed samples of AKS-3 and AKS-4 are garnet kyanite (sillimanite) schists from Nankye Chaung near Mawlu village. The whole P-T ranges of sillimanite garnet kyanite schists in the study area are approximately correspond to 3 kbar to >8.5 kbar at 600-780°C. Sillimanite garnet staurolite schist of analyzed sample AKS-2 is predicted from approximately 3.65 kilobars to 7.1 kilobars and 570°C and 670°C. The metamafic rock of garnet-actinolite schist corresponds to approximately 4 kilobars to 12 kilobars and 470°C to 500°C.

Therefore, the whole P-T ranges of the study area may be 3 kilobars to >12 kilobars at 470-735°C. According to facies series concept proposed by Miyashiro, 1961 (in Bucher and Frey, 1994; Winter, 2010), the sequence of metamorphic facies encountered in the study area could be amphibolites facies to eclogite facies transition.

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