J. Assam Sc. Soc.
Vol. 56, No. 1; June 2015, pp.61-74
ISSN : 0587-1925

PETROLOGY OF THE UMPYRTHA - PATHARKHAMMAH METAPELITES, MEGHALAYA IN NORTHEAST INDIA

***M. Rabha[1] and A.C. Mazumdar[2]**
[1]Department of Geology, Pragjyotish College, Guwahati-781009 (Assam)
[2]Department of Geological Sciences, Gauhati University, Guwahati-781014 (Assam)

**Corresponding author* : mridulrabha33@gmail.com

ABSTRACT

The petrographic analysis and study of mineral chemistry based on EPMA analyses of garnet-cordierite-sillimanite metapelites of the Umpyrtha- Patharkhammah region in the central part of the Shillong Meghalaya Gneissic Complex (SMGC) indicate that their metamorphic evolution is characterized by different metamorphic events. These include M_2 event, the post-S_1 / pre-S_2, characterized by granulite facies and high temperature melting; M_2, the syn-S_2 retrograde but intense fabric forming event and M_4 post-S_2,corona forming decompression event followed by extensive retrogression. The rare inclusions (sillimanite + biotite + quartz) within cordierite and less commonly developed garnet (M_2) indicate earliest high grade assemblage (M_1) of prograde evolutionary path. However, the P–T values retrieved in this study for M_2, M_2 assemblages are not realistic because of possible re-equilibration of the M_2 minerals during the M_3 and M_4 metamorphic events and of the M_2 minerals during the M_4 event.

Key words: Metapelites, Cordierite, Shillong Meghalaya Gneissic Complex, Granulite.

INTRODUCTION

Recently, the metapelites from the western part of the Shillong Meghalaya Gneissic Complex (SMGC) have attracted several workers (Gogoi 1975; Lal et al. 1978; Chatterjee et al. 2007 and 2011). However, except a few example (Chatterjee et al. 2011), study of the metapelites in the central part of SMGC is rare. In order to bridge the gap of the present status of our understanding on the metamorphic evolution of metapelites, we investigated the Umpyrtha- Patharkhammah region ($90^0 42^/$-$25^0 48^/$) in the central part of the SMGC which exposes extensive garnet-cordierite-sillimanite bearing metapelites. The present communication is an attempt towards an understanding of metamorphic evolution of the Umpyrtha- Patharkhammah metapelites through the study of mineral composition based on EPMA analyses, petrography and of metamorphic P-T conditions.

Geological Background

The SMGC, popularly known as the Gneissic Complex of the Shillong Plateau represents the extreme northeastern extension of the Indian Peninsular Shield (Evans 1964; Crawford 1974; Desikachar 1974). The SMGC constitutes the ancient Precambrian rocks covering a large domain, including parts of Meghalaya and adjoining hilly tracts of Goalpara and Kamrup districts of western Assam, and the hilly tracts of Karbi Anglong and Nagaon districts (Figure 1). The Precambrian rocks

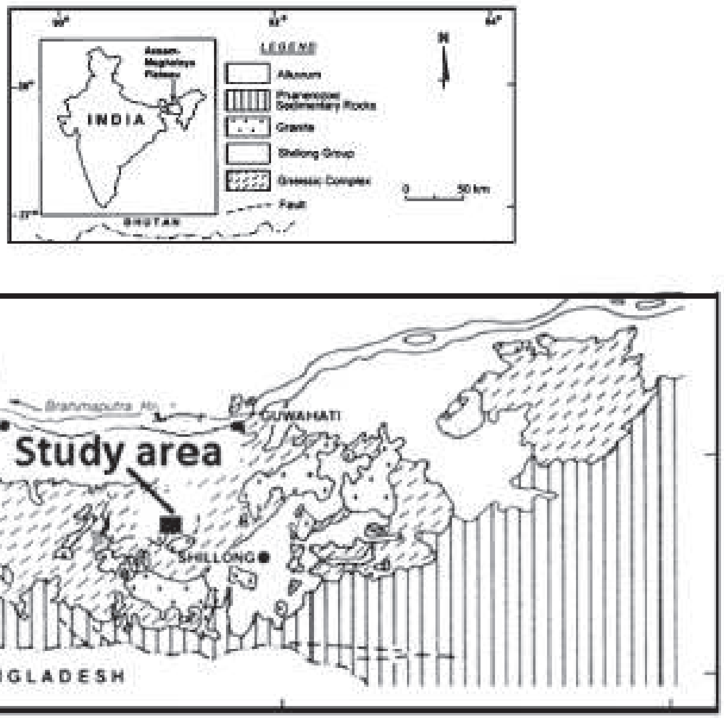

Fig. 1: Geological map of the Shillong Plateau (Simplified from Geological Survey of India (1973)

of the Garo-Goalpara Hills are dominated by granulite-amphibolite facies metabasic rocks interleaved with impure meta-calcareous gneisses, quartzofeldspathic gneisses and banded iron formations. By contrast, granulites of the Khasi-Jaintia Hills area are dominated by metapelites and quartzofeldspathic gneisses, with locally predominant mafic / calc-silicate granulites (Gogoi 1963; Mazumdar 1976; Lal et al. 1978). In the easternmost part of the SMGC, Precambrian gneisses are overlain by NE-trending, greenschist facies intra-cratonic sediments of the Shillong Group. The basement gneisses and the Shillong supracrustals of the Khasi-Jaintia Hills are intruded by Proterozoic–Early Paleozoic granite plutons.

Our investigation indicates that the Precambrian rocks of the study area are characterized by intercalation of metapelites, amphibolites / basic granulites, calc-silicate gneisses and banded iron formations within regionally developed quartzofeldspathic gneisses (Figure 2).

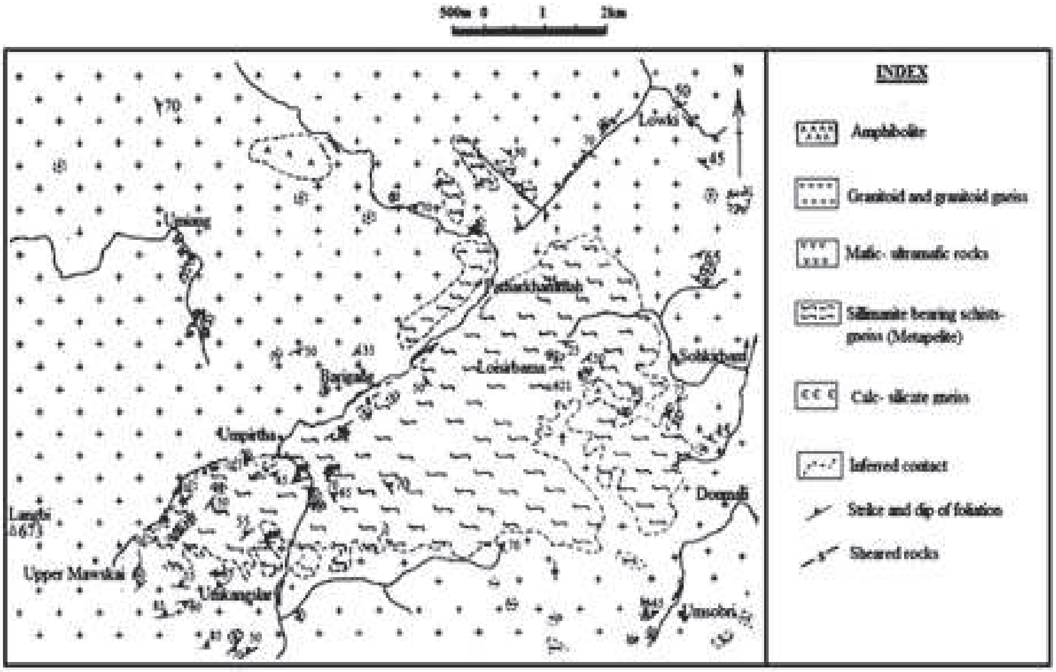

Fig. 2: Geological map of the Patharkhammah- Umpyrtha area modified after GSI (1992)

Structurally, the rocks show evidences of polyphase ductile deformations consisting of three phases of folding viz. F_1, F_2 and F_3 Figure 3A and 3B. The earliest recognised fabric in the area is alternate felsic (melt) and mafic layerings localized at rootless hinges of F_1 folds. The penetrative foliation S_2 in the area strikes dominantly NE-SW with relatively moderate dip towards SE.

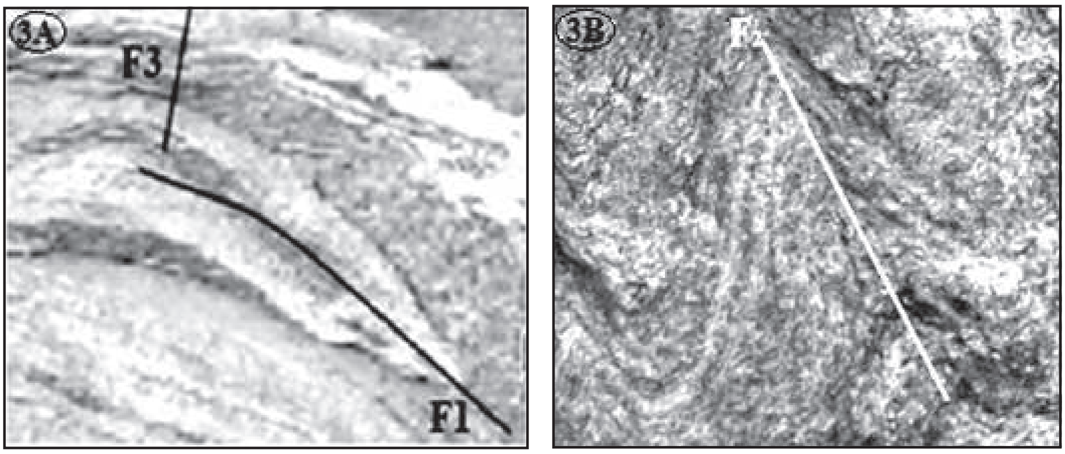

Fig. 3A and 3B: Three phases of folding episodes F_1, F_2 and F_3

MATERIALS AND METHODS

The samples for EPMA analyses were prepared separately and was polished it up to super fine stage using different grades of diamond paste. Electron probe micro-analyses of different minerals were performed with CAMECA SX-100 Super probe electron microprobe (EPMA) at IIT Kharagpur, India. The accelerating voltage 15KV, a beam current of 20nA and typical counting times of 20-40 seconds to yield 0.5-1% $1s$ standard deviation of counts.

RESULTS AND DISCUSSION

Mineral composition and metamorphic assemblage and relevant mineral reactions

EPMA mineral analysis data, structural formulae and relevant elemental ratios of different representative samples (garnet, biotite, cordierite, and plagioclase) are given in Table 1, 2, 3 and 4 respectively.

Table 1: Electron Probe Micro Analytical (EPMA) data and structural formulae of Garnet in metapelites of the Umpyrtha- Patharkhammah region

Garnet	203-C2-DP15(Core)	203-C2-DP16(Rim)	203-C1-DP1(Core)	203-C1-DP2(Rim)	203-C2-DP8(Rim)	203-C2-DP9(Core)	203-C2-DP10
SiO_2	35.965	36.166	36.895	37.051	36.281	35.988	36.284
TiO_2	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Al_2O_3	21.102	21.277	21.249	21.531	21.040	21.301	21.049
$Cr_2O_{2=3}$	0.000	0.333	0.000	0.022	0.000	0.008	0.000
FeO	30.471	28.926	29.947	30.443	30.474	30.573	31.245
MnO	7.701	9.482	7.442	7.172	7.431	7.267	7.117
MgO	2.217	1.857	2.980	2.962	2.599	2.678	2.624
CaO	0.558	0.605	0.599	0.578	0.641	0.666	0.535
Na_2O	0.093	0.096	0.032	0.049	0.063	0.078	0.064
K_2O	0.002	0.008	0.000	0.000	0.000	0.012	0.000
IONS ON THE BASIS OF 12 OXYGENS							
Si	2.974	2.981	2.996	2.990	2.980	2.957	2.974
Al^{IV}	0.026	0.019	0.004	0.010	0.020	0.043	0.026
	3.000	3.000	3.000	3.000	3.000	3.000	3.000
Al^{VI}	2.030	2.048	2.030	2.038	2.017	2.020	2.007
Ti^{+4}	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Fe^{+3}	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	2.030	2.048	2.030	2.038	2.017	2.020	2.007
Fe^{+2}	2.107	1.994	2.034	2.054	2.093	2.101	2.142
Mn	0.539	0.662	0.512	0.490	0.517	0.506	0.494
Mg	0.274	0.228	0.361	0.357	0.319	0.328	0.321
Ca	0.050	0.054	0.052	0.050	0.057	0.059	0.047
cation	8.000	7.986	7.989	7.989	8.003	8.014	8.011

å

(Cont...)

XMg	0.092	0.078	0.122	0.121	0.107	0.110	0.107
XFe	0.709	0.679	0.687	0.696	0.701	0.702	0.713
XMn	0.181	0.225	0.173	0.166	0.173	0.168	0.164
XCa	0.017	0.018	0.018	0.017	0.019	0.020	0.016
CONCENTRATION OF GARNET END MEMBERS							
Py	9.205	7.769	12.196	12.077	10.663	10.961	10.677
Alm	70.965	67.877	68.741	69.618	70.127	70.184	71.308
Gro	1.665	1.819	1.762	1.693	1.890	1.959	1.564
Sp	18.165	22.536	17.302	16.612	17.320	16.896	16.451

Table 2. Electron Probe Micro Analytical (EPMA) data and structural formulae of Biotite in metapelites of the Umpyrtha- Patharkhammah region

Biotite	203-C2- DP17 (Core)	203-C2- DP18 (Rim)	203-C1-DP5 (Core)	203-C1-DP6 (Rim)
SiO_2	35.562	33.124	35.935	35.649
TiO_2	1.141	0.767	1.444	1.360
Al_2O_3	19.814	20.578	19.492	19.605
FeO	18.084	17.615	18.159	18.723
MnO	0.188	0.184	0.275	0.225
MgO	10.025	9.389	9.723	10.033
CaO	0.000	0.058	0.009	0.039
Na_2O	0.234	0.272	0.202	0.192
K_2O	9.377	9.556	9.413	9.230
Cl	0.041	0.029	0.000	0.000
F	0.356	0.249	0.020	0.000
IONS ON THE BASIS OF 22 OXYGENS				
Si	5.420	5.239	5.467	5.412
Al^{IV}	2.580	2.761	2.533	2.588
	8.000	8.000	8.000	8.000
Al^{VI}	0.980	1.074	0.961	0.919

(Cont...)

Ti^{+4}	0.131	0.091	0.165	0.155
Fe	2.305	2.329	2.310	2.377
Mn	0.024	0.025	0.035	0.029
Mg	2.278	2.214	2.205	2.271
	5.718	5.733	5.676	5.751
Na	0.069	0.083	0.060	0.057
Ca	0.000	0.010	0.001	0.006
K	1.823	1.928	1.827	1.787
	1.892	2.021	1.888	1.850
cation	15.610	15.754	15.564	15.601
X_{Fe}	0.503	0.513	0.512	0.511
X_{Mg}	0.497	0.487	0.488	0.489

Table 3. Electron Probe Micro Analytical (EPMA) data and structural formulae of Cordierite in metapelites of the Umpyrtha- Patharkhammah region

å

Cordierite	203-C2- DP12	203-C2- DP13	203-C2- DP14
SiO_2	48.682	48.361	48.223
TiO_2	0.000	0.000	0.000
Al_2O_3	33.026	32.670	32.825
$Cr_2O_{2=3}$	0.000	0.103	0.000
FeO	8.136	8.378	8.389
MnO	0.662	0.661	0.450
MgO	8.696	8.125	8.295
CaO	0.023	0.003	0.032
Na_2O	0.103	0.121	0.124
K_2O	0.000	0.038	0.013

IONS ON THE BASIS OF 18 OXYGENS

Si	4.973	4.994	4.977
Al^{IV}	0.027	0.006	0.023
	5.000	5.000	5.000

(Cont..)

Al^{VI}	3.949	3.970	3.970
Ti^{+4}	0.000	0.000	0.000
Fe^{+3}	0.051	0.030	0.030
	4.000	4.000	4.000
Fe^{+2}	0.644	0.693	0.694
Mn	0.057	0.058	0.039
Mg	1.324	1.251	1.276
Ca	0.003	0.000	0.004
Na	0.020	0.024	0.025
K	0.000	0.000	0.002
	2.048	0.005	2.040
cation	11.048	11.031	11.040
X_{Mg}	0.656	0.634	0.638
X_{Fe}	0.344	0.366	0.362

Table 4. Electron Probe Micro Analytical (EPMA) data and structural formulae of Plagioclase in metapelites of the Umpyrtha- Patharkhammah region

Plagioclase	203-C1- DP3	203-C1- DP4
SiO_2	65.330	64.849
TiO_2	0.000	0.003
Al_2O_3	23.501	23.420
$Cr_2O_{2=3}$	0.000	0.000
FeO	0.086	0.044
MnO	0.000	0.000
MgO	0.000	0.003
CaO	3.216	3.526
Na_2O	9.804	9.930
K_2O	0.179	0.136

(Cont...)

IONS ON THE BASIS OF 8 OXYGENS		
Si	2.820	2.810
Al	1.196	1.196
Fe^{+3}	0.003	0.002
	4.019	4.008
Fe^{+2}	0.000	0.000
Ca	0.149	0.164
Na	0.821	0.834
K	0.010	0.008
	0.980	1.006
cation	4.999	5.014
An	15.190	16.280
Ab	83.800	82.970
Or	1.010	0.750

å

Petrographically, the metapelites are medium grained rocks consisting dominantly of porphyroblasts of cordierite (X_{Mg}=0.63-0.66), and rare garnet (Alm$_{68-71}$ Prp$_{8-12}$ Grs$_2$Sps$_{17-22}$) which are infrequently wrapped around by continuous intergrowth of biotite (X_{Mg} = 0.49) + sillimanite + quartz +k feldspar + plagioclase (An$_{16}$) assemblage defining S_2 penetrative fabric of the rocks (Figure 4A). Inclusions of biotite + sillimanite + quartz assemblage within porphyroblastic cordierite (Figure 4B) or rare garnet constitutes the earliest metamorphic assemblage (syn- / post- S_1) whereas porphyroblastic cordierite and garnet represent post-S_1 /pre-S_2 assemblage. However, cordierite corona around relict grains of garnet (Figure 4C), post- dated S_2 fabric and stabilization of muscovite and Chlorite (Figure 4D) are the last of all phases in these metapelites formed during fluid induced retrogression. Thus the mineralogical development of metapelites of the area are summarised in Table 5.

The noteworthy mineralogical and textural relations identified several mineral reactions which in turn indicate mineralogical development of the metapelites. The

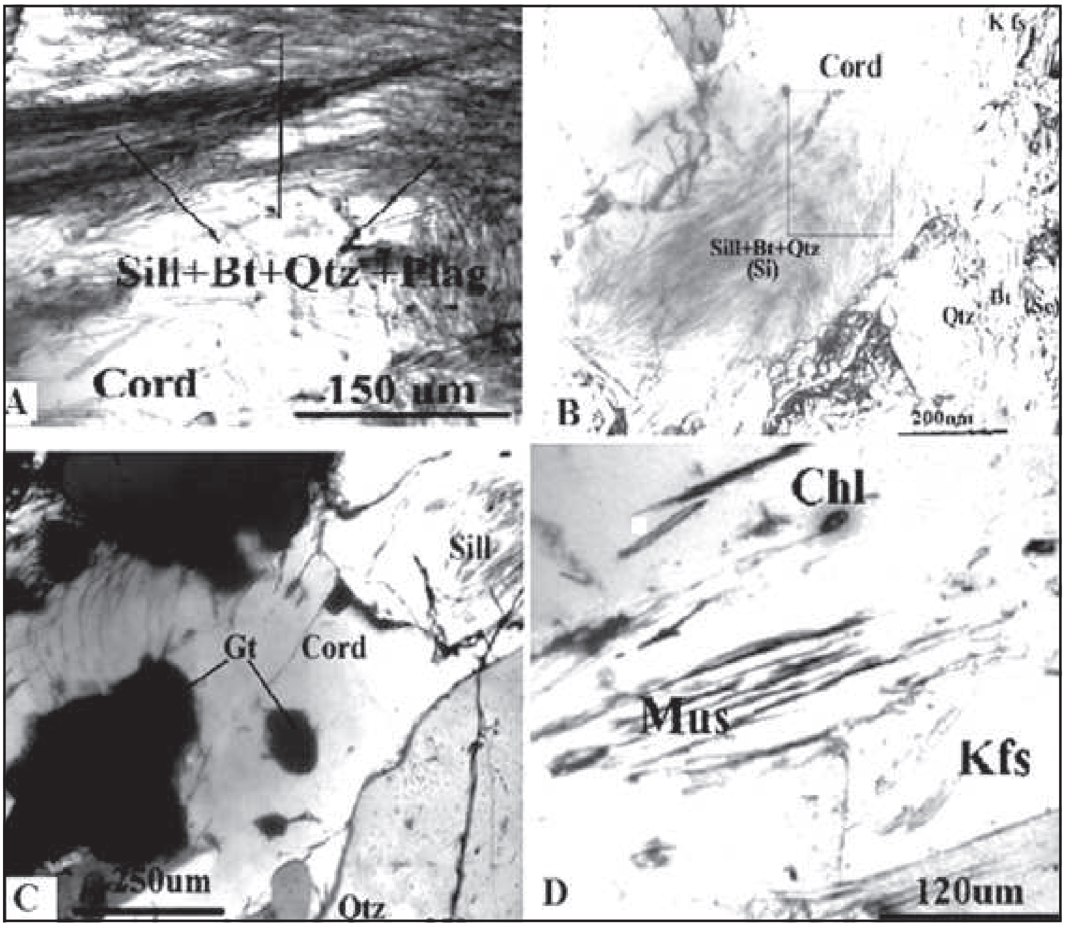

Fig. 4: Textural relations in the Umpyrtha-Patharkhammah metapelites. (Mineral abbreviations are Bt: biotite; Cord: cordierite; Gt: garnet; Qtz: quartz; Kfs: k-feldspar; Mus : muscovite). (A) Intimate intergrowth of quartz, biotite, sillimanite, plagioclase at the border of cordierite representing syn-S_2 foliation. (B) Sillimanite+biotite+quartz inclusion trails (M_1) within cordierite porphyroblast pre-kinematic with respect to the external schistosity (Se) defined by coarser biotite flakes (M_3). (C) Cordierite corona separating enclosed relict grains of garnet (M_2) from sillimanite and quartz (M_3). (D) Development of secondary muscovite and chlorite at the border of k-feldspar.

Table 5. Mineral paragenetic sequence of metapelites of the Umpyrtha- Patharkhammah area

M_1 (syn-S_1 / post-S_1)	Biotite + Sillimanite + Quartz
M_2 (post-S_1, / Pre-S_2)	Cordierite ...... Garnet + K Feldspar+ Plagioclase + Biotite + Sillimanite + Quartz
M_3 (syn-S_2)	Biotite + Sillimanite + Quartz .... Plagioclase
M_4 (post-S_2)	Cordierite Corona, Muscovite, Chlorite

ubiquitous presence of syn-S_1 / post-S_1 inclusion assemblage, biotite + sillimanite + quartz (M_1) within porphyroblastic cordierite (Figure 4B) and rare relict grains of garnet indicate the formation of the post-S_1 / pre-S_2 cordierite and garnet porphyroblasts (M_2) through the high temperature melting reaction,

Biotite + Sillimanite + Quartz = Garnet + Cordierite + melt (1)

The syn-S_2 stabilization of biotite + sillimanite + quartz at the expense of cordierite and garnet is evident from textural features such as development of biotite + sillimanite + quartz intergrowth at the margin of cordierite (Figure 4A) and rarely of garnet which extended as penetrative S_2 foliation. This indicates the following cordierite and garnet dissolution reactions in presence of H_2O.

Cordierite + K-Feldspar + H_2O = Biotite + Sillimanite + Quartz (2)

Garnet + K-Feldspar + H_2O = Biotite + Sillimanite + Quartz (3)

Chatterjee et al. (2011) identified the generation of biotite + sillimanite + quartz + plagioclase (M_3) assemblage in the metapelites by garnet melt back dissolution reaction, as follows.

Garnet + K-Feldspar + Melt = Biotite + Sillimanite + Quartz+ Plagioclase (4)

One of the prominent features of the Umpyrtha- Patharkhammah metapelites is formation of large cordierite rim enclosing relict grains of garnet (M_2) adjacent to sillimanite and quartz (M_3) (Figure 4C). The development of cordierite corona at the interphase between garnet and sillimanite+ quartz possibly formed through the reaction,

Garnet + Sillimanite + Quartz = Cordierite (5)

Development of cordierite corona (M_4) assumes special importance and it implies decompression (post-S_2). The preservation of corona texture requires a dominantly static environment, therefore implying little deformation subsequent to M_3. The other (post-S_2) mineralogical changes include formation of chlorite at the border of k- feldspar (Figure 4D) and muscovite after biotite.

Metamorphic P-T condition

The P–T conditions of equilibrium in the metapelites of the Umpyrtha – Patharkhammah area were obtained from geothermobarometric computation as shown in Table 6.

Compositions of cores of pre-S_2 garnet and cordierite were used to retrieve the temperature for (post-S_1, / pre-S_2) granulite facies (M_2) assemblage. Composition

Table 6. Average P- T values of the Umpyrtha –Patharkhammah metapelites.

Geothermometry				
	Bhattacharya, Mazumdar and Sen (1988)	Bhattacharya et al. 1992, (HW- Hackler and Wood; GS- Ganguly and Saxena)		Henry et al. (2005)
	Cord-Gt	Gt- Bt (HW)	Gt- Bt (GS)	Ti in Biotite
Pre- S_2 (M_2)	620^0C	-	-	-
Syn S_2 (M_3)	-	490^0C	470^0C	540^0C
Geobarometry				
Pre – S_2 (M_2)	At 620^0C Gt- Qtz-Sill-Cord Barometer (Holland & Powell, 1994)			
	3.8 kb			

of nearest neighbour Post- S_1 garnet (rim) – syn-S_2 biotite and Ti – contents of syn- S_2 biotite were used for computing temperature of later metamorphic episode (M_3) using biotite-garnet geothermometer **(** Bhattacharya et al. 1992.) and Ti-in-biotite geothermometer (Henry et al. 2005) respectively (Table 6). For metamorphic pressure, the cordierite–garnet–sillimanite–quartz barometer (Holland and Powell, 1994) was used. The average P-T values are shown in the Table 6. It is apparent (Table 6) that the peak metamorphic temperature and pressure related to M_2 (post-S_1, / pre-S_2) garnet- cordierite pairs (620^{0}C / 3.8 kb.) and temperature for M_3 (syn-S_2) biotie + sillimanite + quartz assemblage (480^{0}C and 540^{0}C according to garnet –biotite pairs and Ti- content in Biotite respectively) is unrealistic for high grade metamorphic assemblage. This inconsistency of estimated temperature values because of possible re-equilibration of the M_2 minerals during the M_3 and M_4 metamorphic events and of the M_3 minerals during the M_4 event. For the same reason our estimated pressure shows a low value. (Table 6)

CONCLUSION

±

The present study points out that the poly-metamorphic evolution of the Umpyrtha-Patharkhammah metapelites is characterised by two distinct high grade metamorphic events (M_1 and M_2) followed by subsequent retrogression (M_3 and M_4). The earliest high grade metamorphic event is evidenced from rare inclusion phases within cordierite (M_2) and garnet (M_2) prior to attainment of peak metamorphic event (post-S_1, / pre-$S_{2,}$ M_2- assemblage). The peak metamorphic event is characterized by the production of high temperature garnet cordierite bearing melt due to heating and loading. The next stage (syn-S_2 M_3-assemblages) is related to solid state fabric forming event possibly due to cooling and loading which leads to the subsequent development of sillimanite + biotite +quartz plagioclase (S_2 penetrative fabric) replacing high temperature garnet cordierite bearing assemblage. The last metamorphic event (post–S_2, M_4- assemblage) is characterized by an extensive re-stabilization of cordierite corona at the expense of garnet and sillimanite + quartz indicating a period of decompression and subsequent stabilization of low temperature muscovite – chlorite assemblage before closing of metamorphic event. It is also indicated that modification of mineral compositions due to possible re-equilibration of the M_2 minerals during the M_3 and M_4 metamorphic events and of the M_3 minerals during the M_4 event.

ACKNOWLEDGEMENT

We acknowledge the anonymous reviewer for his valuable suggestions and instruction for modifying and improving the manuscript. We are also thankful to Mr. Pritom Borah, Research Scholar, Department of Geological Sciences, Gauhati University for his valuable assistance.

REFERENCES

1. Bhattacharya A., A.C. Mazumdar and S.K. Sen (1988) Fe-Mg mixing in cordierite: Constraints from natural data and implications for cordierite – garnet geothermometry in granulites. *American Mineralogist.* 73(3-4): 338-344
2. Bhattacharya A., L. Mohanty, A. Maji, S.K. Sen and M. Raith (1992) Non- ideal mixing in the phlogopite-annite binary : Constraints from experimental data on Mg- Fe partioning and reformulation of the biotite-garnet geothermometry. *Contrib. Mineral Petrol*. 111(1): 87-93
3. Chatterjee N., A. Bhattacharya, B.P. Duarah and A.C. Mazumdar (2011) Late Cambrian Reworking of Paleo-Mesoproterozoic Granulites in Shillong Meghalaya Gneissic Complex (Northeast India): Evidence from *PT* Pseudosection Analysis and Monazite Chronology and Implications for East Gondwana Assembly. *The Jour. Geol*. 119: 311–330
4. Chatterjee N., A.C. Mazumdar, A. Bhattacharya, and R.R. Saikia (2007) Mesoproterozoic granulites of the Shillong-Meghalaya Plateau: evidence of westward continuation of the Prydz Bay Pan-African suture into North-eastern India. *Precambrian Res*. 152: 1–26
5. Crawford A.R. (1974) Indo-Antarctica, Gondwanaland and pattern of the distortion of a granulite belt. *Tectonophysics*. 22: 141-157
6. Dash C.R. and B. Chatterjee (1992) Geology of Patharkhammah – Umpyrtha area, East Khasi hills district, Meghalaya. *Geol. Surv.India Publ*.125(4): 24-26
7. Desikachar S.V. (1974) A review of the tectonic and geologic history of Eastern India, in term of Plate tectonics theory. *Jour. Geol. Soc. India* 15: 137-149
8. Evans P. (1964) The tectonic framework of Assam. *Jour. Geol. Soc. India*. 5: 80-96
9. Gogoi K. (1975) The Geology of the Precambrian rocks in the north-western part of the Khasi and Jaintia Hills, Meghalaya. *Geol. Surv. Ind. Misc. Publ*. 23(1): 37- 48
10. Gogoi K. (1963) The geology of parts of the Khasi Hills along the south-western and south-eastern extension of the Sonapahar and structure of the main Sonapahar belt, Assam. Unpublished Report of Geol. Surv. Intl. Prog
11. Henry D.J., C.V. Guidott, and J.A. Thomson (2005) The Ti-saturation surface for low-to-medium pressure metapelitic biotites: Implications for geothermometry and Ti-substitution mechanisms. *American Mineralogist*. 90: 316-328
12. Holland T.J.B. and R. Powell (1994) An internally consistent dataset with uncertainties and correlations: Application to geobarometry, worked examples and a computer program. *Jour. Meta. Petrol*. 6: 273 -384
13. Lal R.K., D. Ackermand, F. Seifert and S.K. Haldar (1978) Chemographic relationships in sapphirine-bearing rocks from Sonapahar, Assam, India. *Contrib. Miner. Petrol*. 67: 169–187
14. Mazumdar S.K. (1976) A summary of the Precambrian Geology of Khasi Hills, Meghalaya. *Geol. Ind. Misc. Publ*. 23(2): 311-334