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Mineral chemistry and Thermobarometry of Metapelites from Bandihalli area, Tumkur district, Karnataka.

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***Abstract*— This paper mainly focuses on compositional studies on biotite, cordierite, garnet and orthoamphibole of Metapelites from Bandihalli area to understand the petrogenetic significance and to quantify the pressure-temperature conditions of metamorphism. Different types of Fe-Mg exchange thermometers like garnet-biotite and garnet-cordierite thermometers are used to deduce the temperature conditions of metamorphism.**

***Keywords*— Metapelites, Thermobarometry, Mineral chemistry, Cordierite, Garnet**

I INTRODUCTION

The Bandihalli association occurs as a linear belt stretching between Bandihalli and Raghavana Hosur (Fig. 1). The supracrustal rock occurs as enclaves of various sizes set within the gneisses. The supracrustal rocks are represented by metapelites, calc-silicate rocks, quartzites and iron formations. Other associated rocks are amphibolites, actinolite schist, gneisses and dolerite dykes. The regional foliation in this area is predominantly NNW-SSE with a steep easternly dips. The metapelites of the area are represented by cordierite-anthophyllite-garnet-biotite schist and biotite-quartz-schist. These rocks are widely exposed in the southern portions of the area and are sporadic in the northern portions. Several fresh representative samples of metapelites have been collected for detailed petrographic, mineral chemistry, whole rock geochemistry and for isotopic dating. Sample locations are given in the following geological map (Fig. 1).

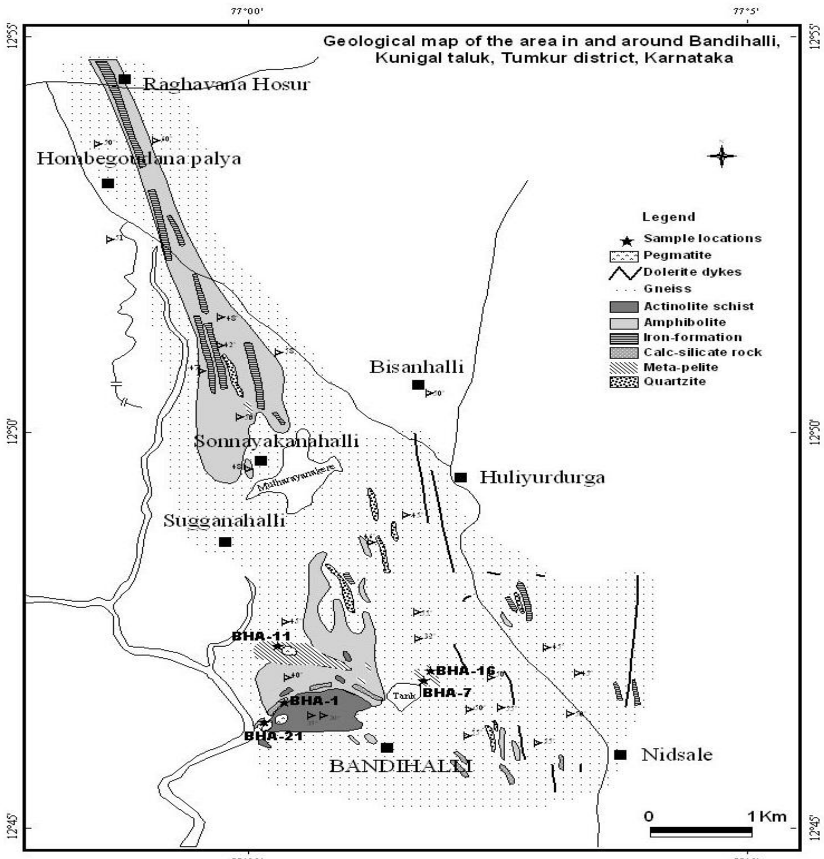

Fig. 1. Geological sketch map of Bandihalli area (modified after Mahabaleswar et al 1989).

II Analytical methods

Chemical compositions of the various minerals were determined by using a JEOL-JXA-8600 electron microprobe at Yamaguchi University, Japan and with a CAMECA SX-50 Electron Probe Microanalyzer (EPMA) at the Petrological Laboratory of Geological Survey of India, Kolkata.

JEOL-JXA-8600 Superprobe electron microprobe:

The instrument is operated with an accelerating voltage of 15 kV, specimen current of 20nA, and count times of 10s for Si, Ca, Mn, A1, Ti and Fe, and 30s for other elements. An electron beam focussed to less than 5 µm for spot analysis. The probe data were processed by on-line computer using the Oxide ZAF in the XM-86PAC program composed by JEOL Ltd. The relative error in the determination is about 1% at the 40wt% level, about 5% at the 1 wt% level, and about 20% at the 0.2 wt% level.

CAMECA SX-50 Electron Probe Microanalyzer:

The instrument is operated with an accelerating voltage of 15 keV, specimen current of 10nA and the beam size was 2-3µm. Natural mineral standards were used and a ZAF and PAP correction programmes were employed to correct the raw data.

III Mineral chemistry

The chemical data for the principal minerals like biotite, cordierite, garnet and orthoamphibole are presented in the following paragraphs. At the end various thermobarometric models are used to quantify the pressure-temperature conditions of metamorphism.

Biotite: The chemical data of biotite is presented in the Table. I. The structural formulas were calculated on the basis of 11 (O) atoms. All Fe is calculated as Fe^{2+}. The sum of Si and Al always exceeds 4. Biotites are more aluminous, having variable Al^{iv} content. The TiO_2 content in the biotites vary from 1.58-1.92wt %. Generally, they are poor in MnO, CaO and with considerable amount of Na_2O (0.24-0.43 wt %). On Ti Vs X_{Mg} diagram (Fig. 2), the biotites plot in the field of phlogopite.

Cordierite: The chemical data of cordierite are presented in Table. II. Mineral formulae were calculated on the basis of 18 (O) atoms. All analyzed cordierite grains have approximately ideal 5.00 Si and 4.00 Al atoms per formula unit (p.f.u). All Fe is calculated as Fe^{+2}. The cation sum is nearly 11.00, indicating only low amount of Fe^{3+}. Na and Ca contents of cordierites are extremely low. The analyzed cordierite are essentially Mg-cordierites and characteristically their X_{Mg} values (ranging from 0.73-0.75) are always more than the associated ferromagnesian minerals, because of the fact that Mg-atoms preferably occupy the octahedral position in the cordierite structure and cordierites with Fe^{+2} >1 pfu are rare in nature.

Table. I. Chemical analysis of Biotite.

Sample No.	BHA-07			
Oxides	1	5	7	13
SiO_2	37.153	37.658	37.727	36.42
TiO_2	1.922	1.667	1.588	1.627
Al_2O_3	18.235	18.392	18.049	17.998
Cr_2O_3	0.064	0.048	0.12	0
FeO	13.313	12.548	13.503	15.821
MnO	0	0.015	0	0.039
MgO	15.456	15.946	14.581	14.011
CaO	0.121	0.013	0.004	0.047
Na_2O	0.407	0.409	0.427	0.24
K2O	9.103	9.757	9.57	9.124
Total	95.774	96.453	95.569	95.327
Cation Numbers based on (O) 11				
Si	2.724	2.738	2.777	2.719
Ti	0.106	0.091	0.088	0.091
Al	1.576	1.576	1.566	1.584
Cr	0.004	0.003	0.007	0.000
Fe	0.816	0.763	0.831	0.988
Mn	0.000	0.001	0.000	0.002
Mg	1.689	1.728	1.599	1.559
Ca	0.010	0.001	0.000	0.004
Na	0.058	0.058	0.061	0.035
K	0.852	0.905	0.899	0.869
Total	7.835	7.863	7.828	7.850
X_{Mg}	0.674	0.694	0.658	0.612
X_{Fe}	0.326	0.306	0.342	0.388

Table. II. Chemical analysis of Cordierite.

BHA-07			
Oxides	6	8	9
SiO2	48.366	49.861	49.405
TiO2	0	0.01	0.001
Al2O3	33.367	33.266	32.937
Cr2O3	0	0	0.003
FeO	5.976	5.919	6.34
MnO	0.071	0.02	0
MgO	9.604	9.939	9.798
CaO	0.027	0.013	0.005
Na2O	0.185	0.172	0.131
K2O	0.003	0.001	0
Total	97.599	99.201	98.62
Cation Numbers based on (O) 18			
Si	4.966	5.027	5.021
Ti	0.000	0.001	0.000
Al	4.039	3.954	3.947
Cr	0.000	0.000	0.000
Fe	0.513	0.499	0.539
Mn	0.006	0.002	0.000
Mg	1.470	1.493	1.484
Ca	0.003	0.001	0.001
Na	0.037	0.034	0.026
K	0.000	0.000	0.000
Total	11.034	11.012	11.018
X_{Mg}	0.741	0.750	0.734
X_{Fe}	0.259	0.250	0.266

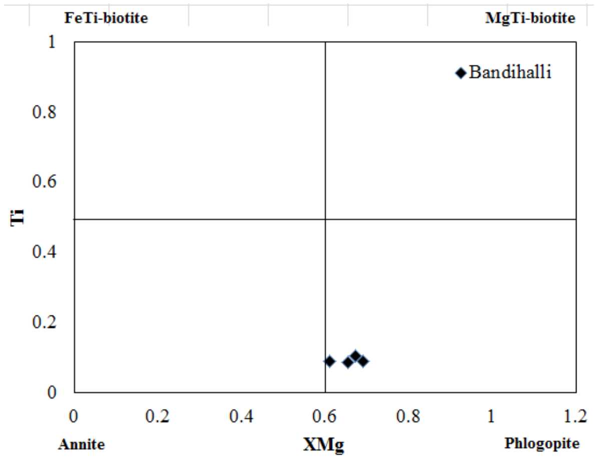

Fig. 2. Plot of X_{Mg} Vs Ti of biotites

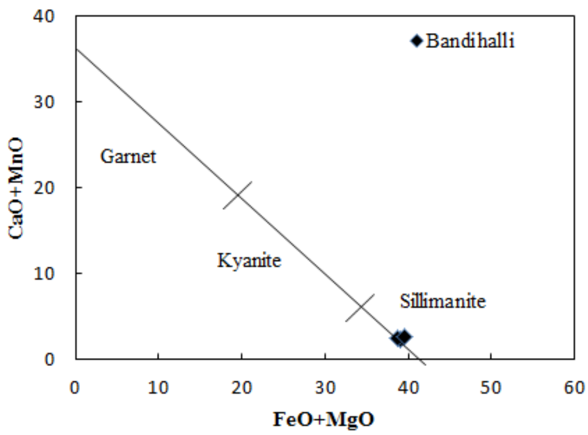

Fig. 3. Nature of variation of (FeO+MgO) with (CaO+MnO) in garnets (after Sturt, 1962).

Table. III. Chemical analysis of Garnet.

Sample No.	BHA-07		
Oxides	2	3	4
SiO2	38.179	39.027	38.385
TiO2	0.022	0.024	0.031
Al2O3	21.316	21.488	21.129
Cr2O3	0.046	0.047	0
FeO	32.71	32.306	34.378
MnO	0.894	0.889	0.996
MgO	6.258	6.333	5.139
CaO	1.454	1.481	1.622
Na2O	0.002	0.013	0
K2O	0	0	0.012
Total	100.881	101.608	101.692
Cation Numbers based on (O) 24			
Si	5.983	6.045	6.014
Ti	0.003	0.003	0.004
Al	3.938	3.924	3.903
Cr	0.006	0.006	0.000
Fe	4.287	4.185	4.505
Mn	0.119	0.117	0.132
Mg	1.462	1.462	1.200
Ca	0.244	0.246	0.272
Na	0.001	0.004	0.000
K	0.000	0.000	0.002
Total	16.042	15.990	16.032
X_{Mg}	0.239	0.243	0.196
X_{Fe}	0.701	0.696	0.737
X_{Mn}	0.019	0.019	0.022
X_{Ca}	0.040	0.041	0.045

Table. IV. Chemical analysis of Orthoamphibole.

Sample No.	BHA-07		
Oxides	10	11	12
SiO2	45.339	46.688	46.5
TiO2	0.232	0.21	0.237
Al2O3	12.75	11.115	12.406
Cr2O3	0.037	0.013	0
FeO	23.995	24.042	23.927
MnO	0.247	0.26	0.189
MgO	12.963	13.744	13.667
CaO	0.428	0.409	0.386
Na2O	1.087	1.139	1.114
K2O	0.006	0.001	0.012
Total	97.084	97.621	98.438
Cation Numbers based on (O) 23			
Si	6.739	6.896	6.798
Ti	0.026	0.023	0.026
Al	2.234	1.935	2.138
Cr	0.004	0.002	0.000
Fe	2.983	2.970	2.925
Mn	0.031	0.033	0.023
Mg	2.872	3.025	2.978
Ca	0.068	0.065	0.060
Na	0.313	0.326	0.316
K	0.001	0.000	0.002
Total	15.272	15.275	15.266
XMg	0.490	0.505	0.504
XFe	0.510	0.495	0.496

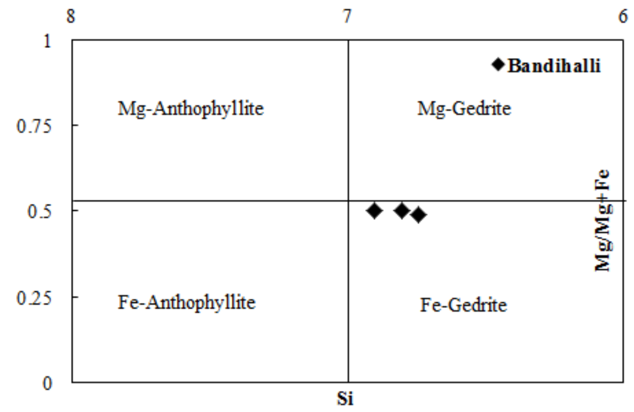

Fig. 4. Compositions of Orthoamphiboles (after Leake, 1978)

Table. V. Calculated temperatures at 5kb pressure.

Area Name	Bandihalli	
Sample No.	BHA-07	
Thermometry	*Garnet-Biotite*	T in ^{0}C
	Thompson 1976	560
	Holdway & Lee 1977	548
	Ferry & Spear 1978	533
	Perchuk & Laurent'va 1983	558
	Dasgupta et al 1991	558
	Bhattacharya et al 1992	566-578
	Garnet-Cordierite	T in ^{0}C
	Thompson 1976	628
	Holdway & Lee 1977	616

Garnet: Stochiometric calculations of the garnet on the basis of 24 (O) atoms give near ideal 6.00 Si and ~4.00 Al pfu is presented in Table. III. This suggests the presence of only small amount of Fe^{+3}. Generally, studied garnet crystals are almandine-pyrope rich. The X_{Mg} values are 0.20-0.24 whereas X_{Fe} values vary from 0.70-0.74. On (FeO+MgO) Vs (CaO+MnO) diagram (Fig. 3), all the garnet plot in the sillimanite zone.

Orthoamphibole: The chemistry of orthoamphiboles is presented in Table. IV. The cations are calculated on the basis of 23 (O) atoms and their sums are found to be greater than 15.00. Orthoamphibole is generally characterized by low MnO, CaO, Na_2O and considerable amount of TiO_2. However notable quantity of CaO and Na_2O are seen in some analyses. These orthoamphiboles compositionally correspond to gedrite as inferred from Leake's (1978) diagram (Fig. 4).

IV GEOTHERMOBAROMETRY

Geothermobarometry is a technique that utilizes the temperature and pressure dependence of the equilibrium constant (K_{eq}) to infer temperature and pressures of equilibration of mineral assemblages. In metamorphic terrains it can constrain actual P-T paths during metamorphism and in conjunction with geochronology can be used to characterize P-T-t paths, potentially tectonic history.

Geothemometers:

Geothemometers are those equilibria that are broadly temperature dependent (large ΔH and ΔS) and relatively insensitive to pressure (small ΔV). A steep slope for equilibrium constant isopleths in the P-T space make up a good geothemometers. There are essentially two types of thermometers; 1.Exchange thermometers and 2.Solvus thermometers.

Exchange thermometers are mainly based on the exchange of Fe and Mg between coexisting silicates. Garnet-biotite, garnet-orthopyroxene, garnet-clinopyroxene and garnet-cordierite mineral pairs are well known example for exchange thermometers.

Solvus thermometers rely on the compositional variability of two coexisting, structurally related phases that are connected to the miscibility solvus in a T-X space. Miscibility gaps are clearly temperature dependent and hence serve largely as thermometers. Orthopyroxene-clinopyroxene and plagioclase-alkali feldspar mineral pairs are noted examples for solvus thermometry.

Garnet – Biotite thermometer:

The coexistence of garnet-biotite provides a thermometer that has been calibrated from natural assemblages by Thompson 1976 and from experiment by Ferry and Spear 1978. These thermometers are affected by Ca, Mn, Ti and Al^{vi} solution in biotite (and by Ca and Mn solution in garnet) and are believed to be accurate to ±50^{0}C. The thermometer of Ferry and Spear agrees with that of Thompson to within 50^{0}C for temperatures below 700^{0}C, but for T>700^{0}C, Ferry and Spear's thermometer infers significantly higher temperatures. Garnet-biotite thermometer is based on Fe-Mg distribution between the two minerals. For the estimation of the peak metamorphic conditions only garnet cores and matrix biotite are used.

In this study garnet-biotite geothermometric models of Bhattacharya et al (1992), Dasgupta et al (1991), Perchuk & Lavrent'eva (1983), Ferry and Spear (1978), Holdway and Lee (1977) and Thompson (1976) have been used for calculating temperatures for the studied metapelites and the estimates are listed in the Table. V.

Garnet-Cordierite thermometer:

A Garnet-cordierite thermometer has been calibrated by Wells (1979). This is very sensitive to change in X_{Fe} in either phase, and since garnet may not be homogenous, temperatures below peak metamorphism may be recorded. However, peak temperatures from this thermometer have been found to be consistent with other thermometers (Harris and Jayaram 1982). Its calibration is based on the experimental work of Hensen and Green (1971), which was conducted in the hydrous system. More recently, Martignole and Sisi (1981) provide a thermodynamic model for cordierite break-down in the anhydrous system, which reverse the slope on the garnet and cordierite isopleths and thereby provide an alternative garnet-cordierite thermometer more suitable for granulite assemblages which are characterized by low P_{H2O}.

Garnet-cordierite thermometer is based on Fe-Mg exchange between co-existing garnet-cordierite assemblages. To assess the temperatures of equilibration of cordierite-garnet assemblages of Bandihalli area metapelites, thermometric models proposed by Holdway & Lee (1977) and Thomson (1976) have been attempted. The calculated temperatures produced by these thermometers are listed in the Table. V. The temperatures are calculated using uniform pressure of 5kb. The uncertainty of these thermometers is around ± 75^0C.

Temperature estimation based on Ti-Al^{iv} contents in biotites:

A distinct increase in Ti content of biotite in amphibolite to granulite facies transitions has been reported from many localities in literature (Hormann, et al (1980); Dymek (1983); Hansen et al (1984a, b); Schreurs (1985)). After a detailed investigation of biotite chemistry has shown the interdependence of Ti and Al^{iv} in relation to grade of metamorphism. Schreurs (1985) has also suggested that Ti-Al^{iv} contents in biotites can be used for a rough metamorphic estimate. Accordingly he has proposed the following divisions:

1. Low to intermediate amphibolite facies

   Ti < 0.3 atoms/formula unit

   500-650^0 C

   Al^{iv} > 0.85 atoms/formula unit

2. Intermediate to high amphibolite facies

   0.3< Ti > 0.45 atoms/formula unit

   650-700^0 C

   0.55<Al^{iv} < 0.85 atoms/formula unit

3. Low to intermediate granulite facies

   Ti > 0.45 atoms/formula unit

   700^0 C

   Al^{iv} < 0.55 atoms/formula unit

The Ti-Al^{iv} contents of studied biotites do not fit into the scale, because of the retrogressive or secondary nature of biotites.

V DISCUSSION AND CONCLUSION

In this study several garnet-biotite and garnet-cordierite geothermometric models are used. The accuracy of garnet-biotite thermometers are claimed to be up to 50 ^{0}C and the calculations are made at an assumed pressure of 5kb. Some of the garnet-biotite pairs produced slightly higher temperatures. This feature is recorded by all the thermometers that have been used in the study. Temperature estimate using Bhattacharya et al (1992) for metapelites produced relatively higher temperatures 578-566^0C, which may corresponds to cooling path. The other thermometers produced relatively lower temperature estimates.

The garnet-cordierite geothermometric model of Holdway & Lee (1977) gives temperatures 616^0C whereas Thompson (1976) gives a temperature of 628^0C. The temperatures are calculated using uniform pressure of 5kb. The uncertainty of these thermometers is around ± 75^0C.

The assemblage orthoamphibole + aluminosilicate represents relatively high pressure condition, the equivalent low pressure assemblage will be represented by staurolite + cordierite + orthoamphibole at low temperatures and garnet + cordierite + orthoamphibole at higher temperatures. This enables relative evaluation of P-T conditions of several common assemblages (Spear & Schumacher, 1982). Significantly, staurolite is absent in the pelitic assemblages of Bandihalli. Thus in the assemblages where staurolite is absent, coexistence of garnet and cordierite represent relatively intermediate pressure and high-temperature conditions of the medium grades of upper amphibolite-granulite facies, where coexistence of sillimanite and k-feldspar are absent. The pelites of Bandihalli clearly show two generations of orthoamphibole. From textural evidence, it is clear that the anthophyllite is of the first generation, whereas gedrite is of second generation.

Conclusions:

1. The chemical data of biotites indicates they are Phlogopite in nature, cordierites are Mg-rich cordierite, garnets are almandine-pyrope rich and orthoamphiboles corresponds to gedrite in composition.
2. The P-T estimates obtained are 5kb and $533\text{-}628^0$ C, which indicate that the area has undergone upper amphibolite-low granulite facies condition of metamorphism.
3. The $Ti\text{-}Al^{iv}$ contents of studied biotites do not fit into the scale, because of the retrogressive or secondary nature of biotites.
4. The overall mineral assemblages as well as their relationship indicate a near isobaric cooling path.

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