JOURNAL GEOLOGICAL SOCIETY OF INDIA
Vol.93, February 2019, pp.153-156

New Occurrence of Sapphirine-spinel-bearing Granulite from NW of Chilka Lake, Eastern Ghats Belt, Odisha

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ABSTRACT

A new locality of sapphirine-spinel-bearing granulites from the Kaithapalli area which lies NW of Chilka Lake, Odisha is reported. The area tectonically forms a northern part of Eastern Ghats belt. It occurs as small enclaves within the khondalite and pelitic granulite. The mineral assemblage includes spinel-sapphirine-garnet-cordierite-orthopyroxene-sillimanite-biotite-k-feldspar-plagioclase-quartz. Development of reaction textures and symplectites are common in the sapphirine-spinel granulites which have been used to describe reaction history. The relative X_{Mg} values among various minerals are as follows: cordierite > biotite > sapphirine > orthopyroxene > garnet > spinel. The P-T evolution of these sapphirine-spinel granulites constrained through the pseudosection modelling in the NCKFMASH model system using Perple_X software indicate conditions of ultra-high temperature (UHT) metamorphism. The P-T estimates computed by isopleths define a retrograde trajectory with decompression of c.2.5 kbar from P-T_{max} of c.10.5 kbar at c.950 ºC. The sequence of reactions as deduced from the symplectite assemblages, together with pseudosection modelling, from the Kaithapalli area, offer greater opportunities for providing a better picture of petrological evolution of northern part of the Eastern Ghats Belt (EGB).

INTRODUCTION

The quartz-bearing sapphirine-spinel granulites occur in few localities in the northern part of the Eastern Ghats belt (EGB) viz. Sunakhala and other localities that lie along the National Highway-16 (Pant et al. 2006; Das et al. 2012; Bose et al. 2016). Kaithapalli area (N 19º51'21", E 85º18'46") is an integral part of EGB because of the presence of localized sapphirine-spinel-bearing granulite in the northern part of the Eastern Ghats belt (Fig. 1a, b). Sapphirine-spinel-bearing granulite is rich in biotite, dark to light bluish grey in colour, massive with coarse-grained bluish sapphirine and ink blue cordierites embedded in the matrix (Fig. 2) Sapphirine-spinel bearing granulites are the potential tool for the derivation of the P-T trajectory of metamorphism because they preserve signatures of metamorphic crystallization through arrested textures. These reaction textures, when combined with pseudosections, provide a far more complete description of the various evolutionary stages of crust which is regarded as a definite aid in deciphering the dynamic processes. The investigation of UHT metamorphism from the northern part of the Eastern Ghats belt has received little attention in the light of modern mineralogy and petrology. Because of the limited study and that too in a few selected areas, the crustal evolution of this region remains an enigma. In this contribution, petrography, mineral chemistry, and metamorphic conditions of Kaithapalli sapphirine-spinel-bearing granulites are discussed in order to obtain an integrated geodynamic picture of the Eastern Ghats belt.

GEOLOGICAL SETTING

The investigated area around Kaithapalli area constitutes a part of Precambrain terrain of the northern part of the Eastern Ghats belt which is characterized by the granulite facies rocks that include pelitic granulites and khondalites. The Chilka lake anorthosite suite is one of the most important marker events in the Eastern Ghats belt. These are unmetamorphosed and contain xenoliths of khondalites and pelitic granulites (Sen et al. 1995). This suggests that the anorthosite intruded after the major metamorphic event in the EGB. The chronology of granulite formation in the EGB remains uncertain. Younger superimposed metamorphism, in particular of Pan African age is documented in EGB (Mezger and Cosca, 1999). High precision geochronological suites of minerals from EGB are quite scarce (Prakash et al. 2014). The wide variation in age of granulites is due to reactivation and may be interpreted as different imprints of magmatic events after the main phase of granulite facies metamorphism (Dasgupta et al. 2013).

Textural Relations and Interpretation of Metamorphic Reactions

The detailed petrographic study has unveiled the presence of various mineral parageneses which are grouped as follows.

A-1 Sillimanite-free sapphirine-spinel granulites (Spr + Spl + Crd + Opx + Bt +Kfs +Qtz +Pl ± Grt);

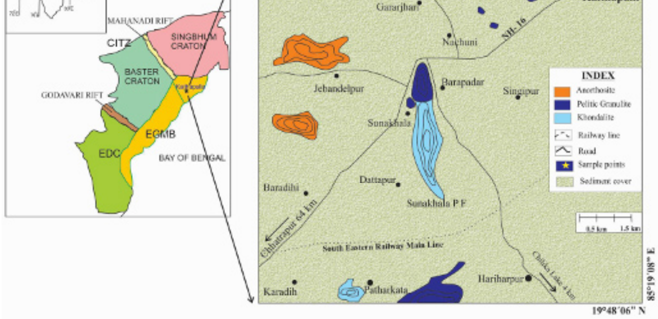

Fig.1. (a) Simplified map showing the position of the Proterozoic Eastern Ghats Belt (EGB) along with other adjacent cratons. **(b)** Geological map of the area around Kaithapalli.

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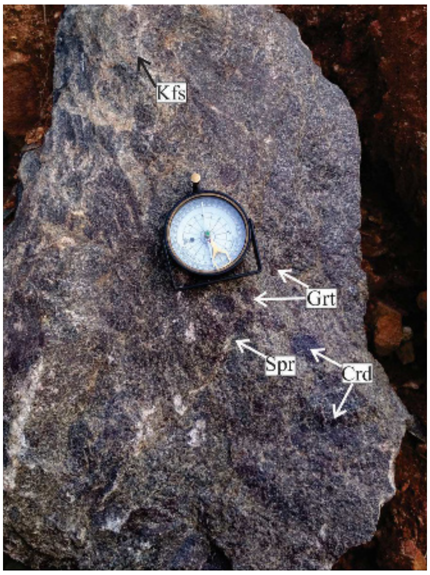

Fig.2. The studied sapphirine-spinel-bearing granulite from Kaithapalli area. Note the coarse-grained aggregates of sapphirine (Spr), cordierite (Crd), K-feldspar (Kfs) and Garnet (Grt).

A-2 Orthopyroxene-free sapphirine-spinel granulites (Spr + Spl + Crd + Grt + Kfs +Pl + Qtz);

A-3 Sapphirine-free spinel-cordierite granulites (Sil + Crd + Spl + Grt + Bt + Kfs + Pl + Qtz)

Besides the minerals mentioned above, the assemblages may include minor ilmenite, magnetite, rutile, apatite and zircon.

Texturally coarse prisms of spinel are separated by quartz and form orthopyroxene and sillimanite (Fig. 3a) which may be attributed to the reaction such as:

Spinel +quartz = orthopyroxne + sillimanite (1)

Xenoblasts of garnet are rimmed by fine symplectites intergrowths of orthopyroxene and cordierite (Fig. 3b) which may be related to a garnet breakdown, a reaction characteristic of decompression.

Garnet + quartz = orthopyroxene +cordierite (2)

Skeletal sapphirine are separated from quartz by a moat of cordierite (Fig. 3c), suggesting reaction

$Sapphirine_{2:2:1}$ + quartz = cordierite (3)

$Spr_{2:2:1}$: subscripts indicate the sapphirine end member molar ratio of $MgO:Al_2O_3:SiO_2$.

Blocky sillimanite is separated from coarse porphyroblasts of garnet and spinel-cordierite symplectites rims garnet. (Fig. 3d). This textural evidence favours the reaction:

Garnet + sillimanite = spinel + cordierite

MINERAL CHEMISTRY

The chemical compositions of representative minerals (Table 1) were obtained using JEOL JXA-8230 EPMA housed in the Advanced Facility for Microscopy and Microanalysis (AFMM) at the Indian Institute of Science, Bangalore. The acceleration voltage during analysis was 15 kV and the beam current 12 nA. The calibration was done using natural and synthetic silicates as well as oxides. X_{Mg} value in the analysed garnets ranges between 0.42- 0.45. Spinels are generally dominated by the solid solutions of Mg-spinel-hercynite and magnetite. The X_{Mg} [=Mg/(Fe^{2+}+Mg)] ranges from 0.38 to 0.41. The analyses of biotite display a narrow range of X_{Mg} from 0.71 to 0.72. The Sapphirine is fairly iron-rich (10.42 wt% FeO) and highly aluminous (63.64 wt% $A1_2O_3$). It consists of MgO, Al_2O_3, SiO_2, and FeO. X_{Mg} [(Mg/Mg+Fe^{2+})] values of orthopyroxenes range between 0.68 and 0.69 with high Ti contents, ranging from 0.31 to 0.59. Cordierite is analytically richer in magnesium than coexisting phases (X_{Mg}: 0.90). X_{Ca} in plagioclase is around 0.24 and X_K in potash feldspar is 0.87.

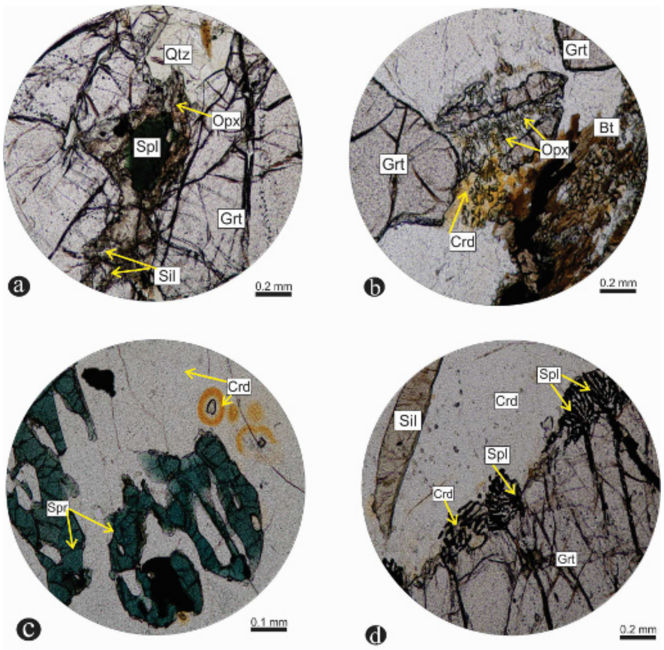

Fig.3. Photomicrographs illustrating textural relations in the sapphirine-spinel-bearing granulite under plane polarized light (PPL): (a) spinel and quartz are separated by sillimanite and orthopyroxene; (b) symplectitic intergrowth of orthopyroxene-cordierite around corroded garnet; (c) intergrowth of cordierite and sapphirine; (d) spinel–cordierite symplectite around embayed garnet along sillimanite. Mineral abbreviations are taken from Kretz (1983).

METAMORPHIC CONDITIONS

Based on the dominant minerals and their chemical compositions, the phase equilibria of the Kaithapalli granulites from the EGB can be modelled in the system NCKFMASH. A P-T pseudosection for sapphirine-spinel-bearing granulite (sample no. S-15) has been calculated using the software Perple_X 6.66 version (Connolly, 2005) (Fig. 4). The P–T conditions derived through X_{Mg} isopleths of garnet, orthopyroxene and cordierite give a peak temperature of around 950°C at 10.5 kbar. The development of spectacular orthopyroxene-cordierite, and spinel–cordierite symplectites characterize the subsequent stages of metamorphism. A P–T path may be drawn on the basis of calculated isopleths and measured mineral chemistry obtained by EPMA. Retrograde decompressive P-T paths, however, have been reported from the adjacent Eastern Dharwar Craton (Prakash et al. 2017) and Southern Granulite Terrane (Prakash and Arima, 2003; Prakash et al. 2007, 2010, 2018). Till now, there are only a few known occurrences of sapphirine-bearing granulites in the northern part of the EGB. The new findings from the Kaithapalli area in the EGB seem to fit into the above list of Mg-Al granulite occurrences that formed under UHT conditions. The maximum pressure of 10.5 kbar indicates that these granulites were formed at a depth of nearly 33 km below the present surface level during the late Archean time. If we consider the present crustal thickness of 35 km in Eastern Ghats Belt (Chaudhuri et al. 2016), it implies that at 2.5 to 2.6 Ma ago, Archean crust was 65 km thick. The production of such abnormally thick crust could be explained by continent collision and underthrusting beneath the converging continents. The P-T-t path (this

Table 1. Representative microprobe analyses of the coexisting minerals (sample no- S15)

	Core	Rim	Core	Rim	Core	Rim	Core	Rim	Core	Rim	Symp-lectite	Matrix	Matrix
	Grt	Grt	Spl	Spl	Bt	Bt	Spr	Spr	Opx	Opx	Crd	Pl	Kfs
SiO_2	39.82	39.51	0.00	0.00	40.62	40.70	12.24	12.68	49.63	49.54	50.13	62.72	65.60
TiO_2	0.00	0.00	0.00	0.00	2.72	2.55	0.00	0.05	0.00	0.00	0.00	0.02	0.01
Al_2O_3	22.65	22.60	61.61	62.00	15.04	14.82	63.64	62.24	7.79	7.75	33.65	24.00	18.90
Cr_2O_3	0.02	0.05	0.29	0.12	0.05	0.12	0.05	0.04	0.05	0.05	0.01	0.00	0.00
FeO*	25.04	26.47	27.11	27.08	10.82	11.29	9.35	10.42	18.86	19.15	2.29	0.00	0.02
MnO	0.19	0.17	0.00	0.02	0.00	0.00	0.02	0.00	0.04	0.10	0.02	0.00	0.00
MgO	11.51	10.61	10.53	9.42	15.94	15.77	14.84	14.79	23.59	23.27	11.28	0.02	0.00
CaO	0.07	0.09	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.03	0.02	4.86	0.10
Na_2O	0.04	0.02	0.05	0.05	0.12	0.15	0.00	0.02	0.03	0.01	0.03	8.51	1.41
K_2O	1.21	1.20	0.00	0.01	10.12	10.28	0.00	0.00	0.01	0.01	0.03	0.28	14.95
Total	**100.64**	**100.80**	**99.59**	**98.70**	**95.42**	**95.67**	**100.14**	**100.26**	**100.02**	**99.91**	**97.46**	**100.42**	**100.99**
O	12.00	12.00	4.00	4.00	22.00	22.00	10.00	10.00	6.00	6.00	18.00	8.00	8.00
Si	3.01	3.00	0.00	0.00	5.90	5.92	0.73	0.76	1.81	1.82	5.05	2.76	2.99
Ti	0.00	0.00	0.00	0.00	0.30	0.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al	2.02	2.02	1.96	1.99	2.58	2.54	4.49	4.41	0.34	0.33	4.00	1.25	1.01
Cr	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fe^{3+}	0.00	0.00	0.03	0.01	0.00	0.00	0.04	0.06	0.00	0.00	0.00	0.00	0.00
Fe^{2+}	1.58	1.68	0.58	0.61	1.32	1.37	0.43	0.47	0.58	0.59	0.19	0.00	0.00
Mn	0.01	0.01	0.00	0.00	1.32	1.37	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mg	1.30	1.20	0.42	0.38	3.45	3.42	1.32	1.33	1.29	1.27	1.69	0.00	0.00
Ca	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.23	0.01
Na	0.01	0.00	0.00	0.00	0.03	0.04	0.00	0.00	0.00	0.00	0.01	0.73	0.12
K	0.12	0.12	0.00	0.00	1.88	1.91	0.00	0.00	0.00	0.00	0.00	0.02	0.87
$X_{Mg}/ X_{Ca}/ X_K$	0.45	0.42	0.41	0.38	0.72	0.71	0.74	0.72	0.69	0.68	0.90	0.24	0.87

X_{Mg} = Mg/(Mg + Fe); X_{Ca}= Ca/(Ca+Na+K); X_K = K/(K+Na+Ca); *Total iron as FeO

study), from the thermal calculation of England and Thompson (1984), suggests that the thermal relaxation and erosion follow tectonic crustal thickening in collision belt. There are various possibilities for the continental collision in the Eastern Ghats belt (see Mukhopadhyay and Basak, 2009 and references therein). One of the possiblities being that the Southern Granulite Belt jointly with Eastern Ghats belt collided with stable Archean Dharwar Craton along the shear zone during the late Archean time (Drury et al. 1984). It is desirable to supplement these earlier investigations by a detailed petrological investigation from this region to throw light for a better understanding of the tectono-metamorphic evolution of the northern part of the EGB, and also highlight important gaps in the prevailing knowledge with respect to UHT metamorphism.

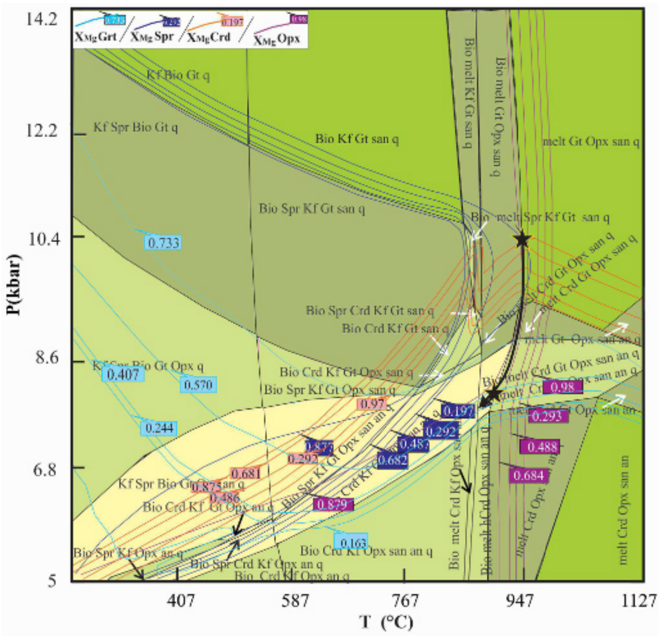

Fig. 4. P-T pseudosection calculated for the sapphirine-spinel-bearing granulite (sample no. S15) in the model system Na_2O-CaO-K_2O–FeO–MgO–Al_2O_3–SiO_2–H_2O (NCKFMASH). Bulk composition in weight % (Na_2O-1.70, SiO_2-60.78, Al_2O_3- 14.20, FeO-9.85, MgO-9.0, CaO-1.01, K_2O-2.05, H_2O- 0.77). The inferred isothermal decompressional P–T path is shown by the arrow. Distribution of the calculated composition isopleths of different minerals for the calculated pseudosection: X_{Mg} garnet, X_{Mg} orthopyroxene, X_{Mg} sapphirine and X_{Mg} cordierite.

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(Received: 26 November 2018; Revised form accepted: 28 December 2018)