SHORT COMMUNICATION

GRANULITE FACIES BIF FROM THE BETUL SUPRACRUSTAL BELT, CENTRAL INDIA

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Granulite facies BIF enclaves, hosted in a mafic-ultramafic intrusive complex, were recognized from the northern part of the Proterozoic Betul supracrustal belt in the Central Indian Tectonic Zone (CITZ). The petrographic study reveals three different stages of metamorphic mineral growth represented sequentially by orthopyroxene-clinopyroxene-plagioclase$_{(1)}$, rims of plagioclase$_{(2)}$ on magnetite and finally by coronal garnet. The mineral paragenesis suggests a post-peak decompression and final cooling.

Introduction

The ENE-WSW trending CITZ is a Proterozoic mobile belt, along which the northern Bundelkhand and southern Bastar Cratons were amalgamated (Fig. 1) (Radhakrishna, 1989; Acharyya and Roy, 2000). The CITZ is bounded by the Son Narmada North Fault (SNNF) in the north and the Central Indian Shear Zone (CIS) in the south. The CITZ contains low- to medium-grade supracrustal belts and granulite belts set in largely undifferentiated gneisses and granitoids. Major ductile shear zones, such as the Son-Narmada South Fault (SNSF) and the Tan Shear, mark the terrane boundaries within the CITZ. These shear zones provided avenues for profuse granitic magmatism (Roy and Hanuma Prasad, 2001a; Roy et al. 2002). Amongst the supracrustal belts of the CITZ, the northern Mahakoshal belt (c. 2.4-1.7 Ga), central Betul belt (c. 1.5 Ga) and southern Sausar belt (c. 1.4–0.9 Ga) are prominent. The granulite belts include the Makrohar Granulite belt (MKG), the Ramakona-Katangi Granulite belt (RKG) and the Balaghat-Bhandara Granulite belt (BBG). Recent P-T-t studies reveal that the RKG belt contains high-pressure granulites, which formed due to continent-continent collision (Bhowmik et al. 1999, 2000). This collisional event has been tentatively correlated with Mesoproterozoic tectonothermal event at c. 1.5 Ga (Rb-Sr, WR, Sarkar et al. 1986) as recorded in migmatitic gneiss (Bhowmik et al.1999; Roy and Hanuma Prasad, 2001b). On the other hand, the BBG belt formed in an extensional environment during the late Archaean and was reworked during the Mesoproterozoic (Ramachandra and Roy, 2001). Yedekar et al. (1990) opined that the BBG belt marks the Proterozoic suture between the Bundelkhand and Bastar cratons. However, Archaean age peak-metamorphism and extensional tectonic regime of BBG belt negate this opinion (Acharyya and Roy, 2000; Ramachandra and Roy, 2001; Roy and Hanuma Prasad, 2001b). Further, Roy and Hanuma Prasad (2001b) presented a plate tectonic model and argued that the RKG belt might represent the suture (c. 1.5 Ga?) between the Bundelkhand and Bastar cratons. Not much data is available from the MKG belt, except for the fact that these granulites occur as enclaves (tectonic?) within c. 1.5 Ga old mylonitized granites.

In view of the above, recognition and characterization of granulite facies rocks provide major clues for the better understanding of the tectonic evolution of CITZ. In this direction our studies around the Betul belt revealed the presence of several ENE-WSW trending enclaves of BIF granulites. These granulites, which are hitherto undescribed, are set in intrusive ultramafic-mafic and granitic suite of rocks. In this contribution we describe the field occurrence, mineralogical association and possible metamorphic reactions. Implications of these newly identified granulite facies rocks on the tectonic evolution of CITZ are also discussed.

Geological Setting

The ENE-WSW trending Betul belt is a prominent supracrustal belt of the CITZ (Fig. 1). Basic-acidic bimodal volcanics and a quartzite-pelite-carbonate-BIF sedimentary association represent the supracrustal lithology of the belt. The supracrustal rocks have undergone polyphase deformation producing at least three generations of structures. The first generation structures (D_1), represented

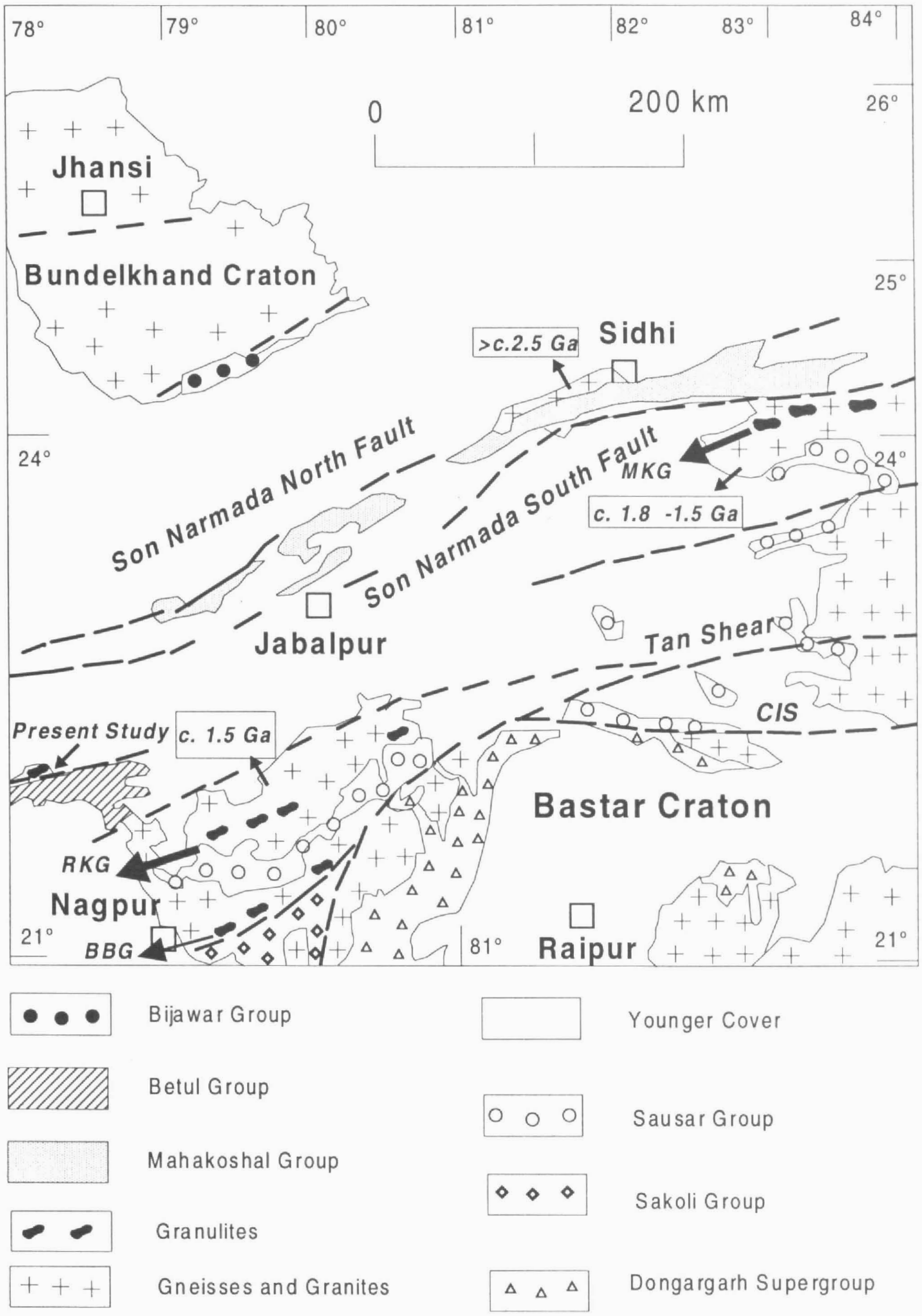

Fig. 1. Lithotectonic assembly of the CITZ with the location of the BIF granulites of the present study. **BBG** – Balaghat-Bhandara Granulite Belt; **RKG** – Ramakona-Katangi Granulite Belt, **MKG** – Makrohar Granulite Belt, **CIS** – Central Indian Shear Zone (*after* Roy et al. 2001).

by tight isoclinal to reclined folds, are generally confined to outcrop scale. The second generation structures (D_2), which are manifested in the form of tight to isoclinal, upright to inclined folds, define the ENE-WSW regional tectonic trend of the belt. The D_2 structures are superposed by N-S trending broad, open folds, which represent the third generation structures (D_3). The supracrustal rocks have undergone greenschist to lower amphibolite facies metamorphism, encompassing both D_1 and D_2 stages of deformation. Number of ductile shear zones were developed during the D_2 deformation. Ultramafic-mafic and granitic bodies, syn- to post-kinematic with reference to D_2 deformation, were emplaced in the belt. A large ultramafic-mafic intrusive complex was located along the northern part of the belt. The ultramafic-mafic complex is made up of a pyroxenite-norite-gabbro-diorite suite of rocks. These rocks were deformed in certain domains and intruded by the granitic rocks. A syn-kinematic granite (with D_2) yielded a whole rock Rb-Sr age of c. 1.5 Ga (quoted in Raut and Mahakud, 2002). The Betul supracrustal belt and its environs are interpreted to be part of a Proterozoic continental magmatic arc (Roy and Hanuma Prasad, 2001b).

The metasedimentary granulites of the present study were recognized in the northwestern part of the Betul belt (Fig.2). They are represented by BIF and marble, and occur in the form of several detached outcrops hosted by the ultramafic-mafic and granitic suite of rocks. Exposures of high-grade rocks spread over 2 km along the strike and attain an average width of 50 m. Enclaves of BIF, both as independent lithounit and as interlayered BIF-marble sequence, are found

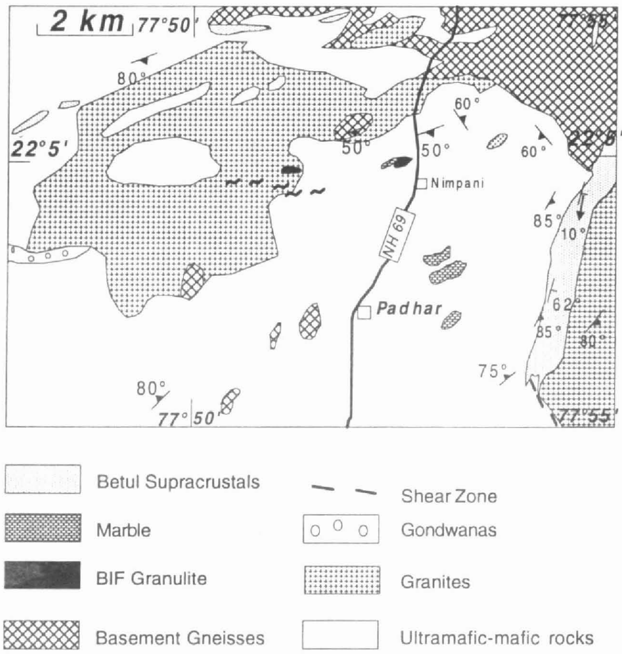

Fig.2. Geological map of the study area showing the disposition of granulite facies enclaves.

in the area. Good exposures of the interlayered BIF-marble are located north and west of Nimpani (22°5' – 77°53') on the Betul–Itarsi highway. The granulite facies BIF is coarse-grained and contains mesobands of silicate - and iron-rich layers (Fig. 3). This compositional banding trends ENE-WSW with steep dip to south. The compositional banding presumably represents original bedding of the rock, which was later mimicked by the metamorphic layering. Open folds with N-S axial planes are developed over the compositional banding. The associated marble is massive and rarely exhibits bedding, which is parallel to that in the BIF. The pyroxenite-gabbro-norite members of the host ultramafic-mafic complex are massive, except along the ductile shear zones where they exhibit a well developed ENE-WSW trending mylonitic foliation. They are coarse-grained, massive and exhibit magmatic cumulate textures. Thin section study revealed the presence of occasional granoblastic recrystallization textures in them. The presence of both magmatic and high grade metamorphic textures suggests that the igneous complex was emplaced in deep crustal levels, where the rocks underwent high-grade metamorphism closely following magmatic crystallization.

As indicated earlier, the high-grade rocks are separated from the low- grade supracrustal association of the Betul belt by ultramafic-mafic and granitic rocks (Fig. 2). Thus, the relationship between the high-grade rocks and the low-grade volcano-sedimentary supracrustal belt is not clear. However, the structural grain in both high- grade as well as low-grade rocks is conformable. Further, both are intruded by ultramafic-mafic and granitic suite of rocks. In addition, both the suites contain similar lithological assemblages (BIF-carbonate). Thus, it is likely that both high-grade and low-grade rocks may form part of the same lithotectonic assemblage.

Petrography

The granulite facies Banded Iron Formation contains orthopyroxene (Opx), clinopyroxene (Cpx), magnetite (Mag), quartz (Qtz), plagioclase ($Pl_{1\&2}$), hercynite (Hc), ilmenite (Ilm), coronal garnet (Grt) and grunerite. Apatite represents the dominant accessory phase. The micro-structure is distinctly granoblastic with coarse-grained Opx, Cpx and $Pl_{(1)}$ porphyroblasts sharing mutual grain boundaries. Opx, which is the dominant silicate phase, is poikiloblastic in shape and contains inclusions of quartz and magnetite. EPMA data reveal it to be ferrosilite ($Fs_{65}\,En_{35}$) in composition. In rare cases the inclusion trails preserve a relic schistosity fabric. Some of the Opx grains contain exsolved Cpx. Cpx is medium–grained, pale green or brown in colour, non-pleochroic and occurs as stubby prismatic crystals. Compositionally it falls in diopside-hedenbergite range ($di_{50}\,hed_{50}$). Rare exsolved pigeonite ($Wo_{18}En_{32}Fe_{50}$) is noted in some of the Cpx grains. Magnetite is idioblastic to subidioblastic and contains exsolved grains of hercynite and rare ilmenite. In some cases hercynite, which probably formed through granular exsolution, occurs as rims around

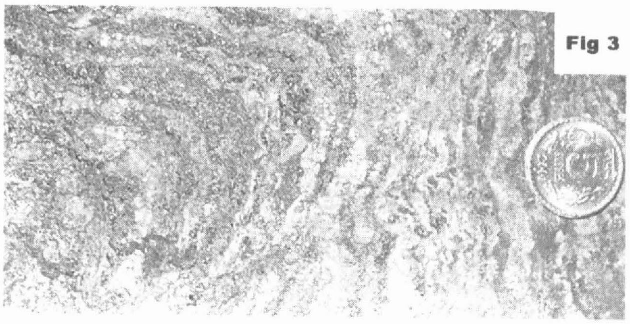

Fig.3. Thinly layered granulite facies BIF of the study area. Diameter of the coin is 2.5 cm.

magnetite. $Plagioclase_{(1)}$ is medium-grained, euhedral and shares mutual boundaries with Cpx, Opx and Qtz. In such cases it appears to be part of the peak metamorphic assemblage. In addition, thin rims of $plagioclase_{(2)}$ on magnetite against Cpx are occasionally noted (Fig. 4). Compositional banding represented by Pl-Cpx- and Mag-Opx- rich layers is noticed and may depict original compositional layering. Garnet in the assemblage occurs as thin coronas around magnetite/spinel against Opx (Fig. 5). The coronal garnet has often grown into coarse, skeletal crystals resembling porphyroblasts. In such case, they envelop the earlier formed minerals. Garnet ($Alm_{86}Py_5Gro_7Sp_2$) is distinctly almandine in composition. It is to be noted that garnet and plagioclase are mutually exclusive in their appearance. Grunerite is fibrous in form and occurs as rims around pyroxenes. It post-dates all the above described minerals.

The associated marble exhibits granoblastic texture, represented by polygonal carbonate (calcite) grains. The

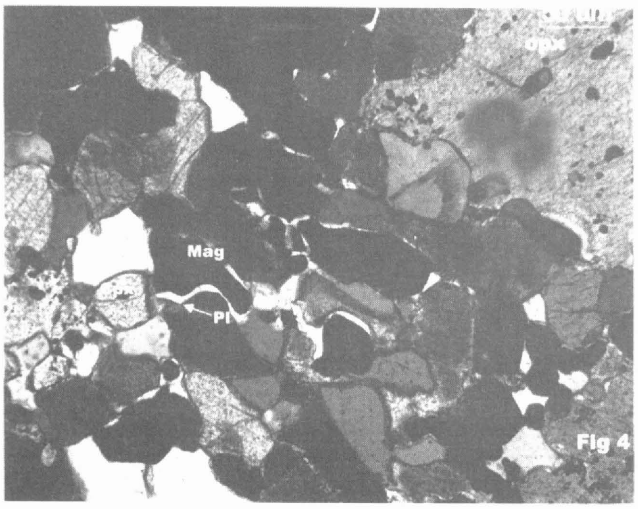

Fig.4. Plagioclase rim on magnetite grown against Cpx. Under polarized light.

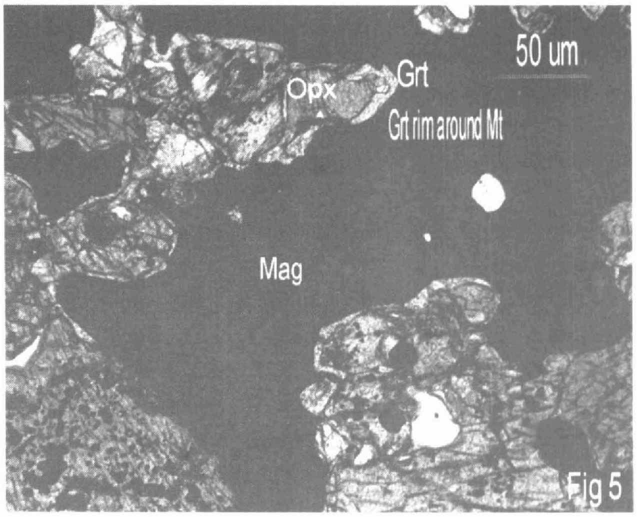

Fig.5. Garnet corona around magnetite grown against Opx. Under polarized light.

silicate phases in the marble include forsterite, diopside, clinohumite, tremolite, antigorite, talc and epidote. Among the above, forsterite dominates over the others and shares mutual boundaries with carbonate and clinohumite. Tremolite, antigorite, talc and epidote represent retrograde phases in the rock. Granular carbonate – tremolite rims are seen around some of the forsterite grains, which mark retrogression at high X_{CO_2} (*cf.* Satish Kumar, 1999).

Metamorphic Reactions and P-T Conditions

The petrographic study shows that the peak metamorphic mineral assemblage in the BIF is represented by Opx, Cpx, Pl along with Qtz, Hc and Mag. No relict amphibole could be recognized in the pyroxenes, which might suggest that the hydrous phases were completely consumed during the prograde reaction. The above mineral assemblage, coupled with the distinct granoblastic texture and absence of any hydrous phases, argue in favour of granulite grade metamorphic conditions. Banded Iron Formation with granulite facies mineral assemblages are reported from several high grade terrains in India. They include, Banded Iron Formations from Deobhog area of Eastern Ghat Mobile Belt (Neogi and Das, 2000), Ongole area of Nellore schist belt (Rao et al. 1996) and Halgur area of southern Karnataka (Devaraju and Laajoki, 1986). In all these occurrences the Banded Iron Formations are characterized by the co-existing Opx and Cpx ± Grt as peak metamorphic mineral assemblages. P-T estimate studies carried out on Banded Iron Formations as well as the associated rocks from these localities yielded temperature in the range of 750-950°C. By analogy, a similar temperature may be assumed for the present study area also. The peak metamorphism in the study area was followed by the growth of plagioclase and coronal garnet. The plagioclase rims on Mag – Spl against Cpx may point towards the following reaction:

$$\text{Cpx} + \text{Mag-Spl (Hercynite)} + \text{Qtz} \rightarrow \text{Plag} + \text{Opx} + O_2$$

(*cf.* Neogi and Das, 2000)

This reaction is considered to mark decompression (Neogi and Das, *ibid*). Garnet in the assemblage occurs as corona around Mag-Spl against Opx, which can be explained by the following reaction:

$$\text{Opx} + \text{Mag-Spl} + \text{Qtz} \rightarrow \text{Grt} + O_2$$

(cf. Neogi and Das, 2000).

This reaction is diagnostic of near isobaric cooling. This stage was followed by late stage hydration, during which the grunerite replaced both the pyroxenes.

Implications

The anhydrous peak metamorphic mineral assemblage and textural relationships show that the Banded Iron Formation has undergone granulite facies metamorphism. The co-existing Cpx-Opx-Pl may indicate high temperature conditions during peak metamorphism. The high heat flow conditions might have been facilitated by the intrusion of the ultramafic-mafic rocks, which were also recrystallized under ambient P-T conditions subsequent to their emplacement. The spatial association of basic magmatism and granulite facies metamorphism corroborate the magmatic arc tectonic setting inferred for the Betul belt and its environs (Roy and Hanuma Prasad, 2001b). Textural relationships also suggest that the peak metamorphism in the area was followed by decompression and finally by isobaric cooling. However, the above inferred P-T path and tectonic environment need to be verified through a precise thermobarometric evaluation study of the P-T evolutionary history.

As indicated earlier the CITZ contains three parallel granulite belts, viz., MG, RKG and BBG belts (Fig. 1). The granulites of the present study lie north of the RKG belt and possibly in the strike continuation of the MG belt. Such a correlation with the MG belt seems tenable as the MG belt is also intruded by a pyroxenite-gabbro-norite-anorthosite suite of rocks (Pichaimuthu, 1990). However, no P-T as well as mineral paragenesis data are available from the MG belt to confirm this contention.

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