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Characterization of oxide assemblages of a suite of granulites from Eastern Ghats Belt, India: Implication to the evolution of C–O–H–F fluids during retrogression

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We document complex intergrowth involving spinel–ilmenite–magnetite–hematite–corundum–rutile in various combinations from a suite of granulite facies rocks of Eastern Ghats Belt, India. Individual oxide phase shows considerable compositional variation among textures and samples. These textures arguably developed by oxidation reaction of early spinel and ilmenite solid solution from near-peak to subsequent retrogressive stages. Oxygen fugacity is measured at a constant pressure of 8 kbar and different temperatures estimated from geothermometric analyses involving oxide and silicate-bearing equilibria in different samples. The calculated fO_2 values are 2–3 log units higher than the QFM buffer except for one sample. Uncertainties in fO_2 calculation in some samples arise presumably due to extensive compositional readjustment of different oxide systematics at lower temperatures. The persistence of high fO_2 in mineral assemblages could be inherited from an oxidized precursor, but field evidence and presence of H_2O–CO_2-rich fluid inclusions in the studied samples imply possible involvement of externally-derived oxidizing fluid in the later part of the retrograde history. Recent experimental and natural data suggest CO_2 charged brine solution could be suitable for oxidation of mineral assemblages. Presence of brine inclusions are not detected, but fluorine enriched nature of biotite grains could possibly provide some indication for its presence. The mixed fluid possibly has its source in the crystallizing mafic magma emplaced at the lower crust that is exposed in the adjacent area.

1. Introduction

Granulite facies metamorphism is generally considered to be fluid-deficient (Harley, 1989). Alternate possibilities invoke the presence of a fluid phase that is either internally buffered by mineral equilibria or externally monitored (cf. Newton et al., 1980). The composition of the fluids can generally be constrained to the C–O–H system, although recent natural data indicate the presence of halogen-rich brine (Markl and Piazolo, 1998; Tsunogae et al., 2003). In many granulite grade metamorphic rocks, oxidizing fluids play a significant role in imposing mineralogical and textural variations. Fe–Ti–Al-bearing oxide minerals such as magnetite, hematite, ilmenite, spinel, corundum, and rutile can act as monitors to ascertain the role of oxidizing fluids during metamorphism of such rocks (Frost et al., 1988; Lindsley et al., 1990; Ghiorso and Sack, 1991; Andersen et al., 1991; Harlov, 1992). Oxygen fugacity controls the Fe^{2+}/Fe^{3+} content of these oxides and, in turn, their stability in the *P–T* field. It is well-known that mineral assemblages such as titaniferous magnetite–ilmenite can profitably be used to infer the fO_2 condition of metamorphism at specified temperatures (Andersen and Lindsley, 1988; Ghiorso and Sack, 1991; Andersen et al., 1991). Such oxide equilibria have common usage in igneous rocks (Frost and Lindsley, 1991; Ghiorso and Sack, 1991), but their application is rather limited in metamorphic rocks, presumably due to the uncertainties regarding the estimation of pristine oxide composition under prolonged cooling during retrogression (Harlov, 2000). Therefore, suitable application of this technique requires detailed microprobe analyses of the phases and careful reintegration to obtain the original composition.

In this communication, we document intricate textural features from Fe–Mg–Ti–Al oxides in a suite of granulite facies rocks from the Eastern Ghats Belt, India (Fig. 1). We explain the variability of textural features among different oxides by the active but varying involvement of an oxidizing fluid during the retrogressive stage of metamorphic evolution. In the study area, the host rock is a leptynitic gneiss (quartz–perthite–plagioclase–garnet–ilmenite gneiss, sample

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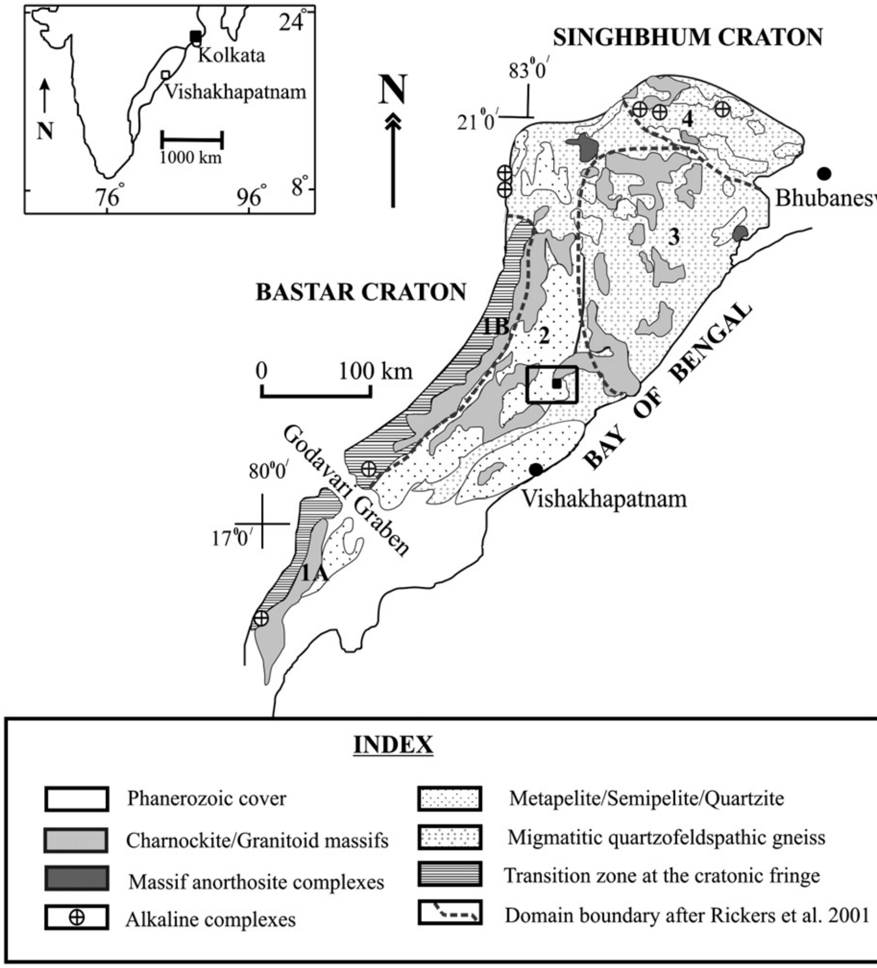

Fig. 1. Geological map of Eastern Ghats, India showing the location of the study area (in the box). General map of India, showing the position of the Eastern Ghats Belt, is given in the inset at the upper left hand corner. Dotted lines indicate the isotopic domain boundaries and bold Roman numbers represent domain names after Rickers et al. (2001).

EGB-4e; Fig. 2a) showing spectacular stromatic banding parallel to the gneissic foliation. The gneissic foliation has a general trend of NE–SW and is marked by mm to cm thick alternate garnet–biotite-rich mafic and quartzofeldspathic leucocratic layers. A dark colored, foliation-parallel, impersistent layer of aluminous granulite (spinel–cordierite–garnet–orthopyroxene–quartz granulite, samples EGB-4a, EGB-4Q) occurs within the leptynitic gneiss (Fig. 2b). At the boundary of these two rocks, a grey-colored zone with greasy appearance is developed and is represented by a hybrid rock of broadly charnockite composition (quartz–perthite–plagioclase–garnet–orthopyroxene gneiss, sample EGB-4c). The contact between these two rocks (samples EGB-4e and EGB-4c) is transitional in terms of mineralogy (sample EGB-4b). A pegmatite (sample EGB-4g) cuts through the foliation of the leptynite (Fig. 2c) and its origin is attributed to crystallization in the presence of a halogen-rich aqueous fluid subsequent to a major structural event. Our field and petrographic data indicate that all the rocks from this suite, except for the pegmatite, experienced multiple stages of high-grade metamorphism and accompanying deformation. The pegmatite, on the other hand, was emplaced later than the major foliation-forming event, but experienced at least one phase of metamorphism and deformation (Bose et al., 2007).

2. Background geology

Granulite facies rocks of diverse bulk chemistry are exposed in the Eastern Ghats Belt that forms a regional high-grade terrane along the eastern coast of India (Fig. 1). Petrological studies in this belt suggest that this polymetamorphic and polydeformed terrane experienced an early UHT metamorphism (>1000 °C) at a deep-crustal level (corresponding to 8–10 kbar pressure) followed by isobaric cooling along an anticlockwise *P*–*T* trajectory (Sengupta et al., 1990; Dasgupta et al., 1995; Mukhopadhyay and Bhattacharya, 1997; Das et al., 2006). A recent geochronologic study suggests that the UHT metamorphism in the central part of this belt (Domain 2 after Rickers et al., 2001) occurred at ca. 1.25–1.10 Ga (Simmat and Raith, 2008) and was subsequently been overprinted by a Grenvillian-age tectonometamorphic event (~0.95 Ga), and later by a Neoproterozoic Pan-African event (~0.55 Ga) (Dasgupta and Sengupta, 2003; Dobmeier and Raith, 2003; Simmat and Raith, 2008 for review).

The present study area is located near Shimliguda (N 18°18′7″, E 82°57′59″) in the central part of the Eastern Ghats Belt belonging to the Domain 2 of Rickers et al. (2001) (Fig. 1). Recently, Das et al. (2006) reported conspicuous intergrowth textures involving garnet and spinel from the aluminous granulite of this area, which bears imprints of a prograde segment of the overall anticlockwise *P*–*T* loop. Post-peak evolution involved early cooling, followed by decompression. The associated members of the rock suite (barring the pegmatite body as discussed later) experienced the same metamorphic and deformation history that leads us to assume that the retrogressive evolution of these rock units occurred during the same *P*–*T* regime.

3. Analytical methods

Selected samples from the granulite-facies rocks were analyzed using a JEOL JXA-8900 Electron Probe Microanalyzer at the Kobe University,