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Partial melting and *P–T* evolution of the Kodaikanal Metapelite Belt, southern India

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Abstract

The Kodaikanal region of the Madurai Block in southern India exposes a segment of high-grade metamorphic rocks dominated by an aluminous garnet–cordierite–spinel–sillimanite–quartz migmatite suite, designated herein as the Kodaikanal Metapelite Belt (KMB). These rocks were subjected to extreme crustal metamorphism during the Late Neoproterozoic despite the lack of diagnostic ultrahigh-temperature assemblages. The rocks preserve microstructural evidence demonstrating initial-heating, dehydration melting to generate the peak metamorphic assemblage and later retrogression of the residual assemblages with remaining melt. The peak metamorphic assemblage is interpreted to be garnet + sillimanite + K-feldspar + spinel + Fe–Ti oxide + quartz + melt, which indicates pressure–temperature (*P–T*) conditions around 950–1000 °C and 7–8 kbar based on calculated phase diagrams. A clockwise *P–T* path is proposed by integrating microstructural information with pseudosections. We show that evidence for extreme crustal metamorphism at ultrahigh-temperature conditions can be extracted even in the cases where the rocks lack diagnostic ultrahigh-temperature mineral assemblages. Our approach confirms the widespread regional occurrence of UHT metamorphism in the Madurai Block during Gondwana assembly and point out the need for similar studies on adjacent continental fragments.

Keywords: Kodaikanal Metapelite Belt; UHT metamorphism; Pseudosections; THERMOCALC; Southern India

1. Introduction

The process of partial melting and formation of migmatites is a common feature in most high-grade granulite terranes. The melting process and the behaviour of segregated melt have been studied by several workers from field characteristics (e.g., Vernon et al., 1990; Brown, 1994, 2004, 2005), geochemistry (e.g., Sawyer, 1991; Watt and Harley, 1993; Milord et al., 2001) and experiments (e.g., Thompson, 1982; Vielzeuf and Holloway, 1993; Carrington and Harley, 1995, 1996; Buick et al., 2004). Dehydration melting is accepted as the main process of melt production and mineral development in granulite facies rocks (e.g., Thompson, 1982; Vernon et al., 1990; Sawyer, 1991; Vielzeuf and Holloway, 1993; Watt and Harley, 1993; Brown, 1994; Carrington and Harley, 1995; Fitzsimons, 1996; Greenfield et al., 1998; Kriegsman and Hensen, 1998; Kalt et al., 1999; Berger and Kalt, 1999; Cenki et al., 2002; Milord et al., 2001; Brown, 2004, 2005). Conversely, it has been established that melt segregation during and after the melting of pelitic granulites is limited

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(Brown et al., 1995) and melt loss is necessary in order to preserve granulite facies assemblages (e.g., Fyfe, 1973; Hensen and Green, 1973; Waters, 1988; White and Powell, 2002; Brown, 2004, 2005). In a similar way, several recent studies (e.g., Jones and Brown, 1990; Kohn et al., 1997; Kriegsman and Hensen, 1998; Spear et al., 1999; Cenki et al., 2002) have investigated the consequences to the mineral assemblage evolution resulting from small amounts of melt remaining within a rock as it cools. Incomplete melt loss would result in the interaction of melt with solid constituents of a rock during its cooling (Ashworth, 1985; Waters, 1988; Clemens and Droop, 1998; Spear et al., 1999; Kriegsman, 2001; Brown, 2002; White and Powell, 2002; Cenki et al., 2002). In contrast the presence of granulite facies mineral assemblages demonstrate that significant melt loss has occurred. This in turn will limit the interaction between melt and the residue, which makes it difficult to assess the retrograde evolution.

The recent understanding of melt related retrograde process indicates the importance of considering melt when deciphering the pressure–temperature (*P*–*T*) conditions and *P*–*T* evolution paths. Detailed observations of the field relations and microstructural features are essential for providing a framework for understanding the *P*–*T* and exhumation history of migmatised high-grade rocks. Careful petrographic studies provide important information on the consumption or reappearance of certain index minerals at the different stages during the metamorphic evolution. Thermobarometric calibrations in the melt-involved assemblages may be problematic because they consider only sub-solidus equilibrium (Kriegsman and Hensen, 1998).

This study focuses on pelitic granulites (migmatites) of the Kodaikanal area in the Madurai Block in southern India, which show evidence of retrogression in the presnce of a melt. We integrate the petrological and geochemical features of the migmatitic rocks to decipher their *P*–*T* evolution by calculating *P*–*T* pseudosections that are able to account for the presence of a melt phase and its effect on the mineral assemblage evolution following the peak of metamorphism. The Mg–Al granulites in several locations within the Madurai Block preserve mineral assemblages typical of UHT granulites and show reaction microstructures indicating multistage decompression following the peak metamorphism (Raith et al., 1997; Sajeev et al., 2004; Tamashiro et al., 2004; Tateishi et al., 2004). In the present study on the migmatitic metapelites from Kodaikanal, although no such diagnostic UHT assemblages were identified, we trace the history of regional UHT metamorphism and clockwise *P*–*T* evolution from integrated microstructural studies and petrogenetic pseudosections.

2. Geological framework and field relations

The southern India terrane is composed of several Proterozoic granulite blocks dissected by major deep-crustal shear zones (Fig. 1a, b, c) and welded onto the Archean Dharwar Craton in the north (Drury and Holt, 1980; Drury et al., 1984). The Madurai Block lying to the south of the Palghat–Cauvery shear zone (Fig. 1b) consists of a wide range of granulite grade rocks including intercalated charnockites, enderbites, metapelites, calc-silicates and mafic granulites. Compared to the other granulite blocks in southern India, the Madurai Block has not so far been studied in detail with regard to its thermo-tectonic evolution. The metapelites in this block, particularly surrounding the Kodaikanal region are migmatitic and occur as lenses, slivers and layers of thickness varying from less than one meter to several metres. Although the precise structural framework of the metapelitic units has not been mapped in detail, it is known that these horizons extend for over several kilometres and occur in a wide area of a few hundred square km within the south, central and northern Madurai Block, with the Kodaikanal at the centre. Therefore, we collectively term the metapelitic units as the Kodaikanal Metapelite Belt (KMB) (Fig. 1c) in this study.

The prevailing geochronological and geochemical studies in this terrane (e.g., Jayananda et al., 1995; Bartlett et al., 1995; Santosh et al., 2003) indicate a protracted history on the basis of U–Pb zircon, monazite, huttonite and xenotime geochronology. Crustal growth occurred during the Archean and Proterozoic (3000–2100 Ma). Cooling ages are in the order of ca. 550 Ma (U–Th–Pb monazite; Sm–Nd garnet). Zircons with 1700 Ma cores mantled by successive rims with 820 Ma and 580 Ma occur throughout the block (Santosh et al., 2003). Ages from monazite, uraninite and huttonite ages as well as outermost mantles on zircons that range from 600–450 Ma. The granulite facies metamorphism and intense crustal rejuvenation in this block is correlated to the Late Neoproterozoic tectonothermal event.

U–Pb electron microprobe dating of monazite and zircon from a pelitic migmatite from near Kodaikanal within the KMB yielded an isochron age of ca. 557±15 Ma (Sajeev et al., unpublished data). Some of the rounded zircon cores have variable older ages ranging from Neoarchean through Paleoproterozoic to Neoproterozoic indicating multiple provenances and a history of fluvial transport for the KMB sediments (Sajeev et al. unpublished data), similar to the results obtained from zircons in the metapelites from the khondalite belt further south in southern Kerala (Santosh et al., 2005). However, majority of the zircon population including some of the cores as