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Peraluminous sapphirine–cordierite pods in Mg-rich orthopyroxene granulite from southern India: Implications for lower crustal processes

J.R. Shazia [a], M. Santosh [b,c], K. Sajeev [a,*]

[a] Centre for Earth Sciences, Indian Institute of Science, Bangalore 560 012, India
[b] Department of Natural and Environmental Science, Kochi University, Akebono-cho 2-5-1, Kochi 780-8520, Japan
[c] Journal Center, China University of Geosciences Beijing, 29 Xuehuan Road, Beijing 100083, China

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ABSTRACT

Sapphirine–cordierite intergrowths occur as pods within garnet-absent, high-Mg orthopyroxene-granulite xenoliths in the Kambam valley, Madurai Block, southern India. Whereas the cores of the pods are composed of sapphirine (X_{Mg} = 0.871–0.897) – cordierite (X_{Mg} = 0.892–0.931) intergrowth along with rutile, zircon and monazite, the rims are characterized by cordierite, apatite, plagioclase, K-feldspar, quartz and minor calcite. The surrounding matrix comprises orthopyroxene (maximum Al_2O_3 4.1 wt.%, X_{Mg} 0.848–0.850), plagioclase, biotite and quartz, similar to the assemblage in the surrounding charnockites. Sapphirine in the Kambam rocks is characterized by high Al contents with an end-member composition in the range of 7:9:3 and 3:5:1. The occurrence of peraluminous sapphirine in association with cordierite and in the absence of phases such as sillimanite and garnet is distinct from ultrahigh-temperature assemblages in other localities within the Madurai Block. The peraluminous composition of the pods suggests that these domains could represent cryptic pathways through which aluminous melts migrated. The reaction of such peraluminous melts with Mg-rich orthopyroxene in the host granulite at temperatures of 1025 °C and pressures around 8 kbar as computed from phase equilibria modeling followed by an isobaric cooling is inferred to have generated the sapphirine–cordierite pods. The unusual high-Mg orthopyroxene granulite suggests interaction of supracrustal rocks with mafic magmas, which probably acted as the heat source for the partial melting of lower crust and UHT metamorphism.

1. Introduction

Most of the sapphirine assemblages reported so far in supracrustal rocks worldwide are from Mg–Al-rich granulite facies rocks, particularly those which have undergone ultrahigh temperature (UHT) metamorphism (Harley, 1998a, 2004, 2008; Brown, 2006; Kelsey, 2008 and references therein; Santosh et al., 2007; Tsunogae et al., 2011). Sapphirine is a chain silicate with stoichiometry $M_8(T_6O_{18})O_2$ (Moore, 1969) and the major cations in the crystal structure show Tschermak's substitution within the stoichiometric range of $Mg_4Al_4[Al_4Si_2O_{18}]O_2$ to $Mg_3Al_5[Al_5SiO_{18}]O_2$. The composition of sapphirine provides important clues on crustal metamorphism, since it greatly depends on the associated minerals and in turn the pressure–temperature conditions. Thus, high Si–Mg sapphirines (2Si per formula unit i.e., close to 2:2:1 composition) are typical of high-grade, UHT rocks and are often associated with orthopyroxene, garnet and quartz (Christy, 1989a; Harley, 1998a,b; Sajeev and Osanai, 2004; Tateishi et al., 2004; Santosh et al., 2007, in press; Sajeev et al., 2010; Belyanin et al., 2012). Metamorphic temperatures recorded from such sapphirine-bearing assemblages usually exceed 900 °C. The sapphirine–quartz is regarded as the robust diagnostic UHT mineral assemblage (e.g., Harley, 2004, 2008; Kelsey, 2008). Sapphirine has also been identified in some high-pressure rocks, where kyanite in eclogite is replaced by a plagioclase-sapphirine symplectite through reaction with omphacite during decompression (e.g., Johansson and Möller, 1986; Liati and Seidel, 1996; Godard and Mabit, 1998; Möller, 1999; Elvevold and Gilotti, 2000; Simon and Chopin, 2001; Săbău and Alberico, 2001). The composition of these sapphirines is reported to be Al-rich (1Si per formula unit). Sapphirine with a composition that is more aluminous than 7:9:3 is termed peraluminous (Schreyer and Abraham, 1975; Warren and Hensen, 1987). Schreyer and Abraham (1975) experimentally shows that sapphirine is stable at all high-grade low-aH_2O crustal conditions with higher-temperature and suitable bulk chemical composition. In most of the natural examples sapphirine stable with Mg–Al rich assemblages (e.g., Opx–Grt–Sil) stabilized at very high temperature and lower pressure conditions (Kelsey et al., 2004), however, the peraluminous sapphirine normally associated with Ca–Al rich assemblages (e.g., Cpx–Sil/Ky) stable at low temperature high pressure side of the P–T space (e.g., Christy, 1989b).

Here we report for the first time an unusual occurrence of peraluminous sapphirines within Mg-rich orthopyroxene-granulites

* Corresponding author. Tel.: +91 80 2293 3404.
E-mail address: sajeev@ceas.iisc.ernet.in (K. Sajeev).

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from southern India. Based on petrologic studies, we characterize this unique assemblage and evaluate the possible mode of origin of the rocks.

2. Geological background

The tectonic framework of southern India is defined by an Archean granite–greenstone terrain in the north onto which was accreted several granulite facies blocks in the south along the Palghat–Cauvery shear zone system (Fig. 1), considered as an oceanic suture in recent studies (e.g., Santosh et al., 2009, 2011b). The Proterozoic granulite blocks in the south preserve evidence of polyphase deformation and multiple tectonothermal and multiphase exhumation histories (Raith et al., 1997; Santosh et al., 2003; Sajeev et al., 2004, 2006; Sajeev and Santosh, 2006). The Madurai Block bound by the Palghat–Cauvery Shear Zone in the north and the Achankovil Shear Zone in the south is the largest among these granulite blocks. The Neoproterozoic high-grade metamorphic rocks occurring in this block include charnockites, hornblende–biotite gneiss, calc-silicates and mafic granulites and minor magmatic intrusives. Intercalated sapphirine-bearing lithologies have been reported from several localities in this block including those of Palni Hills (Raith et al., 1997), Ganguvarpatti (Sajeev et al., 2004; Tamashiro et al., 2004) and Rajapalaiyam (Tateishi et al., 2004; Tsunogae and Santosh, 2011), among others. In all these cases, the sapphirine-bearing Mg–Al granulites have indicated metamorphism under ultrahigh-temperature conditions with $T > 1000$ °C. Tateishi et al. (2004) reported an occurrence of sapphirine + quartz in textural equilibrium in a metapelitic rock from Rajapalaiyam in the south of the Madurai Block providing unequivocal evidence for UHT conditions.

The sapphirine-bearing rock reported in this study is located 7 km west of Kambam town in in situ outcrops within orthopyroxene-bearing granulites at the southern margin of the Madurai Block (Fig. 1). The area was first mapped by Anto et al. (1998). The wedge-shaped Kambam valley, which is a NNE- to NE-trending deep fault, is bordered by the Cardamom Hills to the west and the Varushanad Hills to the east. The dominant rock types are calc-silicate rocks intercalated with orthopyroxene granulites and two pyroxene mafic granulites. Minor syenite and carbonatite intrusives occur close to the sapphirine-bearing granulite (Fig. 2). The garnet–biotite gneisses in the vicinity carry patch-, lens- and vein-type, incipient charnockites, indicating fluid-controlled dehydration along structural pathways.

Unlike other sapphirine-bearing silica-deficient Mg–Al granulites in the Madurai Block, the sapphirine in the Kambam rocks

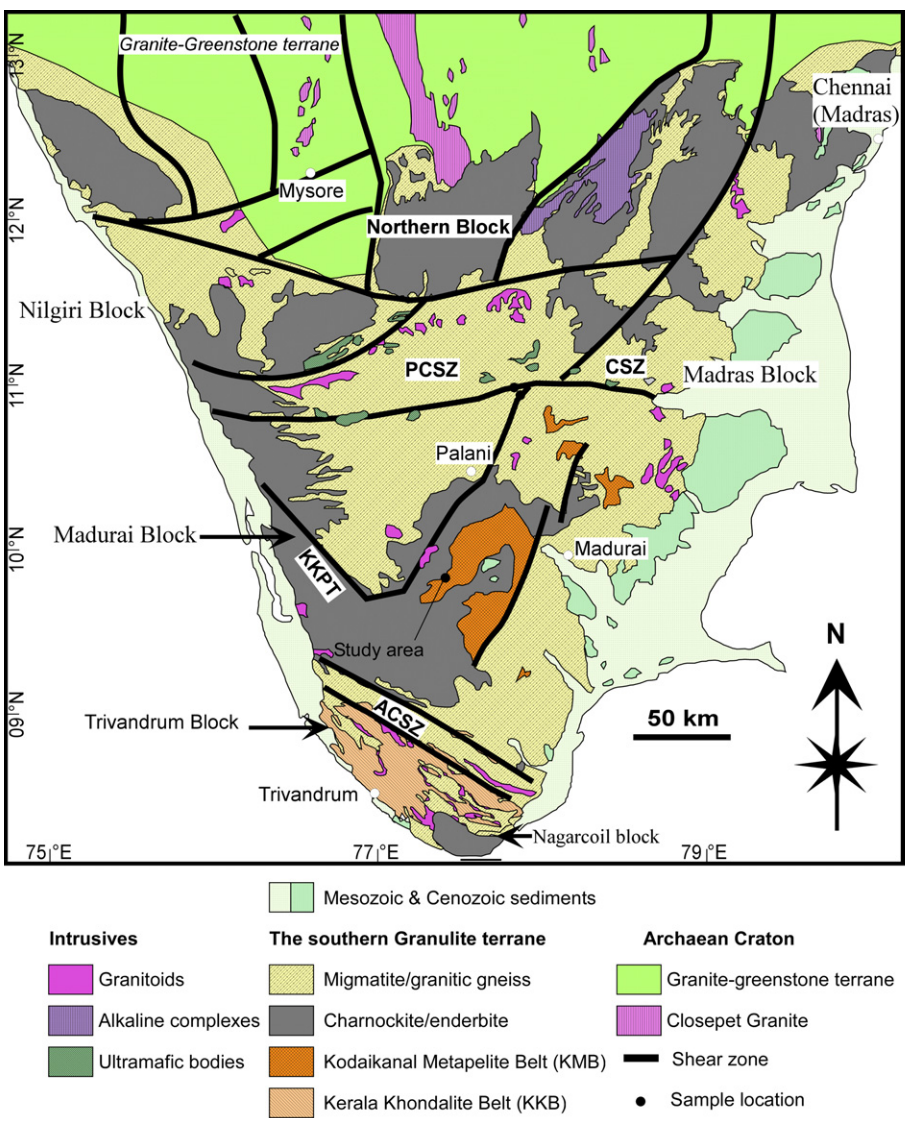

Fig. 1. Tectonic framework of southern India. Modified after Geological Survey of India (1995).