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# High-Mg low-Ni olivine cumulates from a Pan-African accretionary belt in southern India: Implications for the genesis of volatile-rich high-Mg melts in suprasubduction setting

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ABSTRACT

We report petrologic, geochemical, fluid inclusion and stable isotopic data from an unusual spinel dunite occurring within metasedimentary units of the Late Neoproterozoic–Cambrian accretionary belt in the southernmost part of the Southern Granulite Terrain in India. The volatile-rich dunite is mainly composed of cumulus olivine with intercumulus ilmenite, phlogopite, spinel, graphite, Ni-bearing pyrrhotite and calcite. The olivine is Mg-rich (Fo ∼ 96) and unusually poor in Ni. Spinel, even though a minor component, is Mg–Al type (Mg# ∼ 0.92) and is depleted in Cr (Cr# < 0.01). Phlogopite is highly magnesian (Mg# around 0.95–0.97) with high K/(K + Na) ratios of 0.93–1.00 similar to phlogopite reported from mantle-derived peridotites. Ilmenite is dominantly geikielite with Mg# ranging from 0.56 to 0.62. The calcite in this rock exhibits LREE-enriched nature with a pronounced negative Eu anomaly. Carbon stable isotope analyses on the calcite and graphite from the dunite yielded $\delta^{13}C$ compositions comparable with mantle values. Raman peaks of matrix and inclusion graphites show highly crystalline character. The data reported in this study suggest formation of the spinel dunite from an Mg-rich melt enriched in C–O–H–S volatiles with low Ni and Cr. The silica activity appears to have been too low for the crystallization of plagioclase, pyroxenes and amphiboles. The formation of such a melt depleted in Cr, Ni and Fe suggests an early removal of Fe–Ni sulfide and Cr-rich spinel resulting in the depletion of Cr, Fe and Ni and enrichment of Mg and Al in the residual melts from which the high-Mg olivine and Mg–Al spinel cyrstallized. Fe and Ni partitioned to sulfide phase rather than olivine in shallow upper mantle/deep lower crustal levels under high sulfur fugacity. The spinel dunite of present study, together with similar ultramafic cumulate rocks occurring as dismembered units in other localities of the Neoproterozoic–Cambrian accretionary belt in southern India probably represents partial melting under the presence of volatiles in a mantle wedge within a suprasubduction setting.



## 1. Introduction

The Southern Granulite Terrain (SGT) in India has figured prominently in the reconstructions of Late Neoproterozoic–Cambrian Gondwana supercontinent assembly (e.g. Collins et al., 2007). Recent studies on the geological, geochronological and geophysical features from various crustal blocks and suture zones within the SGT have provided evidence for Neoproterozoic subduction of the Mozambique Ocean lithosphere followed by final collisional suturing and incorporation of the crustal blocks within the Gondwana supercontinent (e.g. Santosh et al., 2009, and references therein). The multiple subduction and accretion regimes during Neoarchean and Neoproterozoic in the southern part of Peninsular India have been further confirmed from detailed investigations on suprasubduction zone complexes and arc magmas from this region (e.g. Yellappa et al., 2010, 2012; Chetty et al., 2011; Teale et al., 2011; Sato et al., 2011; Santosh et al., 2011; Ram Mohan et al., 2012). Two major zones of oceanic closure are identified in the SGT, one in the north at the southern margin of the Dharwar Craton designated as the Palghat-Cauvery Suture Zone (PCSZ), and the other in the south termed as the Achankovil Suture Zone (ACSZ). The ACSZ has been variously interpreted in previous studies as a major Late Proterozoic transcrustal structure (Windley et al., 1994; Rajesh et al., 1998; Sacks et al., 1997; Guru Rajesh and Chetty, 2006)

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and as a suture zone (Santosh et al., 2009) with recent geophysical data (Dhanunjaya Naidu et al., 2011) confirming this zone to be a collisional suture. The metamorphic pressure–temperature–fluid history of granulite facies rocks occurring along this zone and their exhumation paths have been addressed in several studies (Santosh, 1987; Santosh et al., 1991a; Cenki et al., 2002; Ishii et al., 2006). However, the magmatic units within this zone have not been investigated in detail, particularly the ultramafic intrusive complexes such as those at Kakkaponnu near Punalur within the ACSZ, and similar other dismembered units further south within the accretionary belt including those at Vattiyoorkavu (V) and Arumanellur (A). Detailed characterization of these ultramafic units is critical to the understanding of the suprasubduction zone tectonics and accretionary history of this major Pan-African belt in Gondwana.

An unusual suite of ultramafic rocks comprising dunite, glimmerite and spinellite along with unique ultrapotassic rocks has been reported from the ACSZ in previous studies (e.g. Santosh et al., 1991b; Rajesh et al., 2004, 2010; Rajesh and Arai, 2006). Although rock units with high MgO are common in ophiolitic mantle sections from suprasubduction environments (Sűhr et al., 1998, 2003; Zanetti et al., 2006; Hébert et al., 2012), the cumulate rock reported in this study has unique mineral assemblages and chemical characteristics. We investigate the petrology, mineral and whole rock chemistry, and perform fluid inclusions and stable isotope analyses to evaluate the magma tectonics. The volatile-enriched sulfide–calcite–graphite bearing spinel dunite at Kakkaponnu provides important constraints on magma generation in a wedge mantle, modification through suprasubduction zone processes and incorporation within an accretionary belt associated with the Neoproterozoic–Cambrian subduction–collision regime in the southernmost part of the Indian Gondwana fragment.

## 2. Geological framework

### 2.1. Regional geology

The Southern Granulite Terrain (SGT) in India occupies a key position in Gondwana reconstructions. The Proterozoic mosaic of southern India comprises a collage of crustal blocks dissected by many Neoproterozoic–Cambrian transcrustal ductile shear/suture zones (Fig. 1). Among the shear/suture zones, the Palghat Cauvery Shear Zone (PCSZ) toward the north and Achankovil Shear Zone (ACSZ) in the south have been prominently considered for continental reconstructions within the Gondwana assembly (e.g. Windley et al., 1994; Rogers, 1996; de Wit et al., 2001; Santosh et al., 2009). The present study area, in and around the Kakkaponnu village, is located within the ACSZ. The ACSZ, with a dominant NW–SE trend represents a terrain boundary that separates the Madurai block (MB; a block that comprises dominantly charnockite massifs intercalated with tonalitic/granodioritic gneisses and metasedimentary units) from the Trivandrum Block (TB; consists dominantly of metasedimentary gneisses including leptynites and khondalites with intercalated calc-silicates and charnockites) to the south. The ACSZ appears as a prominent lineament in aeromagnetic and satellite images (Drury and Holt, 1980). The ACSZ also shows a prominent magnetic signature (Rajaram et al., 2003) and a well-defined lithological and isotopic boundary (Harris et al., 1996; Bartlett et al., 1998). The major lithological units of ACSZ include garnet–biotite gneiss, garnet-, sillimanite- and graphite-bearing metapelites (khondalites), orthopyroxene and cordierite-bearing charnockites, two-pyroxene granulites, calc-silicate rocks and several linear quartzite bands (cf. Santosh, 1987). Ishii et al. (2006) obtained $P$–$T$ estimates up to 8.5–9 kbar and 940–1040 °C from cordierite- and orthopyroxene-bearing lithologies, mainly granulites, along the ACSZ suggesting an ultrahot-orogen. Metamorphic ages from the charnockites in the ACSZ range between 548 ± 2 Ma and 526 ± 3 Ma (Ghosh et al., 2004). Anomalous juvenile isotopic compositions and model ages have been noted in the rocks along the ACSZ (Sm–Nd model age 1400–1300 Ma with $\varepsilon_{Nd} = -3.1$ to $-6$; Harris et al., 1994; Bartlett et al., 1998) relative to the blocks to the north and south. Neoproterozoic ages have been estimated from zircons in metasedimentary gneisses along the southern margin of the ACSZ (Collins et al., 2007; Kröner et al., 2012), supporting the Nd data and suggesting that a young package of sedimentary rocks were deposited in this region. EPMA zircon data from the ACSZ have also yielded Neoproterozoic ages that have been interpreted as constraining the age of deposition (Santosh et al., 2006a,b).

Magmatism within the ACSZ is represented by a suite of alkali granitoids generated during post-collisional extension or rifting, with electron microprobe monazite age from one of the plutons indicating 550 ± 25 Ma (Santosh et al., 2005). A younger population of monazites yielding ages of 515 ± 16 Ma that correlated to high-grade metamorphism is also identified (Santosh et al., 2005). Rajesh et al. (2004, 2006, 2009) and Rajesh and Arai (2006) reported an unusual suite of spinel-bearing rocks from the ACSZ. Sandiford and Santosh (1991) and Rajesh et al. (2010) described the mineral chemistry of a unique suite of hibonite–kalsilite–leucite–perovskite bearing rocks, suggesting an ultrapotassic melt influx in this zone.

### 2.2. Sample locality

The ultramafic intrusive complex investigated in this study occurs as isolated exposures around the Kakkaponnu village and adjacent areas with dimensions of approximately 4.5–5 km in length and 0.30–0.50 km in width within the high-grade supracrustal rocks of the ACSZ (Fig. 2). The supracrustal sequences are composed of garnet and biotite-bearing gneisses which have undergone intense deformation and shearing and preserve mineral lineations, foliations, mylonitization and asymmetric augen structures. The phlogopite mineralization in Kakkaponnu area with the ultramafic complex was mined for industrial purposes. The lithological units in this complex, as mapped from SE to NW are: spinel- and phlogopite-bearing dunite, graphite- and spinel-bearing glimmerite, phlogopite- and graphite-bearing spinellite and baddeleyite–apatite–spinel–phlogopite (BASP) rock (Fig. 2). The lithological heterogeneity of this ultramafic intrusive complex has been previously documented in Rajesh et al. (2004, 2006, 2010) and Rajesh and Arai (2006). The boundary between the various ultramafic lithological units and their contact with the surrounding metasedimentary units are masked by intense weathering and thick vegetation. However, our field studies show that the intrusive complex is roughly parallel to the general NW–SE trend of the ACSZ.

In this study, we examine the spinel dunite, the samples of which were collected from two well-cuttings at a distance of approximately 300 m separation, adjacent to the abandoned phlogopite mine. The lateritized host rocks are garnet–biotite and garnet–biotite and sillimanite bearing granulite facies metapelites. The dark gray to jet black ultramafic rock is massive and generally fine-grained, but at places shows medium-grained texture. All the samples examined in this study are fresh apart from the secondary serpentinization. Visible glittery flaky graphite, calcite, sulfide and phlogopite occur in hand specimen. Some spinel dunite samples host well grown hexagonal crystals of graphite.

## 3. Petrography

Under the microscope, the spinel dunite is characterized by the assemblage olivine + spinel + phlogopite + ilmenite + calcite + graphite + sulfide ± magnetite. A cumulate-type of texture