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Chromites from meta-anorthosites, Sittampundi layered igneous complex, Tamil Nadu, southern India

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ABSTRACT

Chrome-spinels of anorthosite-hosted chromitite bodies from Sittampundi layered igneous complex, southern India, metamorphosed under eclogite-facies condition have been studied. Besides anorthosites as the dominant rock type discontinuous layers of peridotite, pyroxenite and lenses of gabbroic granulite/eclogite occur at the bottom of the complex. Chromite grains are deformed exhibiting features of intra-crystalline deformation and exsolved needle shaped rutile inclusions. Chrome-spinels are of refractory grade with Cr_2O_3 and Al_2O_3 contents varying between 34–40 wt.% and 23–28 wt.% respectively. In the bivariate Cr# (=Cr/[Cr + Al]) vs. Mg# (=Mg/[Mg + Fe^{2+}]) diagram, Sittampundi chromitites show close affinity with the Archean Fiskenaesset type deposit. The calculated Al_2O_3 values for the parental melt of Sittampundi chromitites are consistent with the Al_2O_3 content of mid-ocean ridge basalts whereas the values for FeO/MgO ratio are higher. It is suggested that an initial basic magma, similar to that of mafic granulite composition evolved in the magma chamber through fractionation of peridotite and pyroxenite to Fe,Al-rich basaltic melt, parental to the chromitite bands.

1. Introduction

The composition of chromite in chromitite bodies is used as a petrogenetic and geotectonic indicator (Cameron, 1975; Dick and Bullen, 1984; Stowe, 1994; Barnes, 1998; Mondal et al., 2006). Although, subsolidus reequilibration and/or metamorphism could modify the primary high-*T* composition of Cr-spinel (Irvine, 1967; Mitra et al., 1992; Eales and Reynolds, 1986; Barnes, 2000; Lord et al., 2004), massive chromitite minimizes the effects of reequilibration with adjacent silicates during cooling, and thus is likely closest to its magmatic composition. Suita and Streider (1996) showed that, regardless of the metamorphic changes, the cores of Cr-spinel grains in massive chromitites preserve the chromite's primary chemical composition.

The Neoarchaean Sittampundi Complex, Tamil Nadu, southern India (Bhaskar Rao et al., 1996) is a metamorphosed anorthositic complex, preserving an original igneous stratigraphy overprinted by high-grade metamorphic assemblages (Subramaniam, 1956; Janardhanan and Leake, 1975; Windley and Selvan, 1975; Windley et al., 1981). The origin of the Sittampundi Complex, southern India has been the subject of controversy for some time. The first report of granulites from the Sittampundi area was made by Iyer (1933) who described the mafic granulites of the area as the early differentiates of the magma parental to the felsic granulites, mostly anorthosites. Subramaniam (1956) first described Sittampundi anorthositic complex as a metamorphosed layered igneous complex while Naidu (1963) and prior to that Nehru (1955) opined the anorthosite-gneisses as originating from marly and pelitic sediments. However, later workers (Windley and Selvan, 1975; Ramadurai et al., 1975; Janardhanan and Leake, 1975) recognized and emphasized the Sittampundi Complex as an Archean layered anorthositic igneous complex.

The meta-anorthosites of the Sittampundi Complex that contain conformable horizons of chromite rich layers, henceforth described as chromitite, are grouped into stratiform rather than Alpine-type (Subramaniam, 1956). Ghisler (1970) compared the chromite deposits of the Sittampundi Complex with that of early Precambrian metamorphosed, folded, stratiform-type Fiskenaesset deposit of West Greenland. The complex was subducted to pressure >20 kbar at a temperatures >1000 °C (Sajeev et al., 2009), later exhumed and that the subduction–exhumation gave rise to a hairpin-type anticlockwise *P–T* trajectory, probably in the latest Neoproterozoic–Cambrian (Santosh and Sajeev, 2006). This paper focuses on the detailed description of the petrological characteristics, mineral chemistry of chromitites of Sittampundi layered igneous complex with special emphasis on the composition of the parental melt from which the chromitites crystallized. This study has immense importance in understanding the processes that control the composition of the melt and the mechanism that triggers the precipitation of the Fe-rich chromites in association with highly calcic plagioclase, typical for some Archean anorthosites, in a subduction-controlled milieu.

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2. Geological setting

Sittampundi layered complex is dominantly a metamorphosed anorthositic body within Palghat–Cauvery Suture Zone (PCSZ). This suture zone represents the eastern extension of the Mozambique Suture (Collins and Windley, 2002) in Madagascar that signifies the closure of the Mozambique Ocean in the Neoproterozoic, leading to the amalgamation of Gondwana supercontinent (Meert, 2003; Collins, 2006; Meert and Lieberman, 2008; Santosh et al., 2009a,b). Recently, Yellappa et al. (2011) reported ca. 2.5 Ga Neoarchaean subduction system from this zone. The PCSZ marks a tectonic boundary between Archean Dharwar continental block to the north and Proterozoic Madurai block to the south. These crustal blocks have different isotopic characteristics, age, structure, metamorphism and magmatism (Harris et al., 1996; Bartlett et al., 1998; Meissner et al., 2002; Bhaskar Rao et al., 2003). Besides anorthosites as the dominant rock type discontinuous layers of ultramafics viz. peridotites, pyroxenites and lenses of gabbroic granulite/eclogite occur at the bottom of the complex.

Subramaniam (1956) and Naidu (1963) suggested the complex consisted of a single stratigraphic succession. Later, Ramadurai et al. (1975) recognized the complex comprising of a repeated stratigraphic sequence, the duplication being the result of the isoclinal anticline structure. The co-magmatic rocks of the Sittampundi Complex have a whole rock Sm–Nd isochron age of ca. 2935 ± 60 Ma interpreted as the time of first metamorphism soon after its emplacement (Bhaskar Rao et al., 1996). Ghisler (1970) and Windley and Selvan (1975) compared the rocks of this complex to the pre-metamorphic folded Fiskenaesset-type stratiform complex of Greenland.

The Sittampundi Complex is surrounded by amphibolite grade hornblende-biotite gneisses and migmatitic hornblende gneisses (TTG gneisses) (Fig. 1). Although the contact with the TTG gneisses is ill preserved, the anorthosites of the complex are intruded by tongues and pegmatitic veins of TTG gneisses. Moreover, the Sittampundi Complex is structurally more deformed than the surrounding. It has been folded into a tight isoclinal antiform, not seen in the TTG gneisses, which later refolded by an open fold with N–S trending axial plane giving rise to the present arcuate map pattern. Replica of the earlier fold is sometimes seen within anorthosites (Fig. 2a). Noteworthy to mention here is that a key feature of wedge exhumation in a subduction zone is the development of an isoclinal anticline (Kawai et al., 2007). So, on the basis of (a) differences in structural complexity and grade of metamorphism, (b) cross cutting relation between TTG gneisses and the anorthosites of the complex and (c) tectonic enclave like appearance of the complex, it appears that the Sittampundi Complex is older and intruded by TTG gneisses. Rollinson et al. (2010) also established the same age relationship in case of Fiskenæsset anorthositic complex, West Greenland. Within the anorthosite gneiss of the Sittampundi Complex, distinct bands and lenses of chromitite and chromiferous amphibole-rich bands of varying dimensions are present in the entire complex. The general strike of this band varies from WNW–ESE in the western part to ENE–WSW in the central part and to NW–SE in the eastern part.

3. Petrography

The metamorphosed co-magmatic rocks of the Sittampundi Complex include a range of anorthositic variants that host chromitite bands and lenses of mafic–ultramafic granulites.

3.1. Mafic–ultramafic granulites

The mafic–ultramafic granulitic rocks cover a variety of rock types ranging from meta-websterites, sometimes garnet-bearing to garnetiferous meta-gabbros. The meta-pyroxenites are considered to be fractionated remnants somewhere near the bottom of the complex (Ramadurai et al., 1975; Janardhanan and Leake, 1975; Sajeev et al., 2009). The meta-gabbros consist of mineral assemblagegarnet + clinopyroxene ± orthopyroxene + amphibole + plagioclase + ilmenite. Sajeev et al. (2009) identified lensoid retrogressed eclogite within this meta-gabbro layer where orthopyroxenes are completely absent and garnets contain rutile needles and omphacite inclusions, suggesting a near-peak eclogite-facies condition. Although plagioclase is never found as porphyroblasts in our samples, it occurs as symplectitic intergrowth with amphibole around garnet in association with both clinopyroxene and orthopyroxene (Fig. 2b). The peak metamorphic assemblages were later overprinted by retrogressed assemblages due to fluid influx and related hydration during decompression. Clinopyroxene porphyroblasts are altered to amphiboles along margins and those occurring as small inclusions in garnets are completely converted to amphiboles because of the fluid inflow along the cracks and fractures of the host garnets.

3.2. Chromitite

Chromitites were sampled mainly from trenches made across the strike of the chromitite layers around Karungalpatti village (Fig. 1). Chromitites occur as bands/layers with a maximum thickness of 5 m within anorthosites. Bands are devoid of pyroxenes and consist mainly of chromites and amphiboles with varying proportions; rest is occupied by accessory rutiles. These melanocratic massive bands are generally dark in color and they contain about 60–70% of granular chromite with the remaining 30% constituted by amphibole and other accessory minerals. With increasing proportion of amphibole, the rock grades into chromiferous which constitutes up to 70% amphibole and remaining chromite with other accessory minerals. These amphibole-rich bands are distinctly bottle-green in color, due to their enrichment in chromium. The amphiboles within the chromitite layers often show preferred orientations parallel to the primary layering. A layer parallel crude foliation is observed in chromitites where smaller chromite grains are elongated and aligned parallel to it (Fig. 3a). Thin sections parallel to foliations show relict cumulus texture although the euhedral margins of the chromite grains are modified (Fig. 3b). Chromites contain abundant silicate inclusions, larger inclusions are found to be amphiboles. These included amphiboles themselves contain tiny chromite grains, depicting simultaneous crystallization of these two minerals (Fig. 3c). No relict pyroxene was observed either as inclusion within chromites or as coexisting phases with the chromites.

Chromite grains exhibit features of intracrystalline deformation like development of polygonal, new faceted grains within older grains (Figs. 3d and e). Polycrystalline, mosaic of subgrains characterized by networks of dislocations, seen as bright lines in back scattered electron (BSE) images are commonly observed in chromites (Fig. 3f). Rutiles, the common accessory mineral, occur in two distinct modes. Larger independent grains are present coexisting with chromites (Fig. 3g) whereas, tiny exsolved needle/lath shaped rutile inclusions are arranged in crystallographic directions within chromites (Fig. 3h). Similar rutile exsolution had been earlier described by Ghisler (1970) from Fiskenaesset Complex, Greenland.

4. Mineral chemistry

Electron Probe Micro Analysis (EPMA) was carried out from the Geological Survey of India, Kolkata Laboratory on polished sections with a CAMECA SX100 Electron Probe Micro Analyzer at 15 kV, 12 nA using 1 μm beam diameter. Instrument calibration was per-