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The 3.1 Ga Nuggihalli chromite deposits, Western Dharwar craton (India): Geochemical and isotopic constraints on mantle sources, crustal evolution and implications for supercontinent formation and ore mineralization

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A B S T R A C T

Nuggihalli greenstone belt is one of the oldest greenstone belts (3.4–3.0 Ga) in the Western Dharwar craton, southern India. It consists of conformable metavolcanic (e.g., komatiite and komatiitic basalt) and metasedimentary rocks belonging to the Sargur Group. Sill-like ultramafic–mafic plutonic bodies are present within these schistose rocks which are in turn enclosed by tonalite–trondhjemite–granodiorite gneisses (TTG). The plutonic suite occurs as a layered succession of serpentinite (after dunite) and tremolite–chlorite–actinolite schist (after peridotite) hosting chromitite bodies, anorthosite, pyroxenite, and gabbro hosting magnetite bands. Whole-rock Sm–Nd data for the peridotite–anorthosite–pyroxenite–gabbro unit yield a correlation line with a slope corresponding to an age of 3125±120 Ma (MSWD=1.3) which is similar to ages of komatiitic rocks of the older greenstone belts in the craton. A whole rock Pb–Pb errorchron age of 2801±110 Ma (MSWD=102) has been obtained for the entire plutonic ultramafic–mafic suite; this represents (partial) redistribution/resetting of the U–Pb system during a younger metamorphic event and by the magmatic activity during formation of the younger greenstone belts. The positive ε_{Nd} values (+1.7 to +3.4) of the ultramafic–mafic rocks, and low initial $^{87}Sr/^{86}Sr$ values (at 3.1 Ga) of the gabbros (0.70097–0.70111) implies derivation of the parental magma from a depleted mantle source. The REE pattern of the metavolcanic schists bears resemblance with the pattern of Al-depleted komatiites. Major and trace element variation in the schists correspond with the fractionation trend exhibited by komatiites to komatiitic basalts in the older greenstone belts within the craton. Coherent patterns of whole-rock major and trace element data, along with the layered nature of the sill-like ultramafic–mafic rocks indicate that the plutonic and volcanic suites are related by analogous fractional crystallization processes. Comparison of our age data with global plutonic and volcanic ultramafic–mafic rock occurrences in greenstone belts supports an increase in komatiitic activity from 3.5 Ga to 2.7 Ga, which is most likely related to a supercontinent cycle. High-Mg magmas such as komatiites and their plutonic equivalents host important metal deposits like chromite, Ni-sulfide and minor PGE mineralization. The uneven distribution of metal deposits over time can be explained by supercontinent cycles. The 3.1 Ga chromite deposits of the Nuggihalli greenstone belt are perhaps related to the amalgamation stage of a supercontinent.

1. Introduction

Archean greenstone belts represent the site of continental crustal growth in the early Earth. The greenstone belts are composed of interlayered volcanic–sedimentary rocks that are surrounded by the tonalite–trondhjemite–granodiorite (TTG) gneisses (DeWit and Ashwal, 1995). Sill-like bodies of ultramafic and mafic rocks comprise an important component of greenstone belts, as for example in the Shurugwi greenstone belt (Zimbabwe craton; Stowe, 1987), Sukinda–Nuasahi–Jojohatu complexes in the Tomka–Daitari–Jamda–Koira greenstone belts (Singhbhum craton, eastern India; Mondal, 2009; Mondal et al., 2006), Nuggihalli–Holenarsipur–Krishnarajpet–Banasandra–Kalyadi greenstone belts (Western Dharwar craton, southern India; Mukherjee et al., 2010), Barberton greenstone

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belt (Jamestown Igneous complex, Kaapvaal craton, South Africa; DeWit et al., 1987), the Bird River sill within the Bird River greenstone belt (Superior craton, Canada; Mungall and Staff, 2008; Ohnenstetter et al., 1986), and the Obanga greenstone belt (Superior craton, Canada; Tomlinson et al., 2002). These ultramafic–mafic bodies are genetically related to high-Mg magmas such as komatiite, boninite or high-Mg siliceous basalt (Mondal, 2000; Mondal et al., 2006, 2007; Prendergast, 2008; Rollinson, 1997).

The relationship of the sill-like plutonic ultramafic–mafic rocks with the associated volcanics remains ambiguous. They have been considered to represent sill-like intrusions (Mondal et al., 2006; Prendergast, 2008), or these were originally sub-volcanic sill-like feeders to the overlying volcanic rocks that were tectonically emplaced alongside the volcanics during later deformation events (e.g., Lesher and Groves, 1986; Naldrett and Turner, 1977). Alternatively, they are also considered as the lower cumulate portion of thick komatiitic extrusions (Barnes et al., 1988; Donaldson et al., 1986; Hill et al., 1995). Resolving these questions requires precise geochronological data.

The main objective of our current research is to determine the age of the chromitite-bearing sill-like layered cumulates from the Nuggihalli greenstone belt, Western Dharwar craton, southern India (Fig. 1a). The sill-like layered unit comprises serpentinites (after dunite) and tremolite–chlorite–actinolite schists (after peridotite) that host chromitite bodies, anorthosites, pyroxenites, and gabbros that contain magnetite bodies. The plutonic suite is surrounded by the metavolcanic schistose unit of the older greenstone belts (supracrustals of the Sargur Group), which consists of the oldest rocks (3.4–3.0 Ga; Jayananda et al., 2008; Maya et al., 2011; Nutman et al., 1992; Ramakrishnan et al., 1994) reported from the Western Dharwar craton. Recent research by Mukherjee et al. (2010) has shown that the chromitite-bearing ultramafic–mafic plutonic suite was derived from high-Mg komatiitic basalt magma within an Archean suprasubduction zone setting.

In this study we present the first whole-rock Sm–Nd, Pb–Pb, and Rb–Sr isotope studies, and major and trace element geochemistry of the sill-like plutonic ultramafic–mafic rocks and associated schistose metavolcanic rocks from the Nuggihalli greenstone belt. Geochronological study of these rocks is significant as they are integral in defining the lithospheric evolution, and formation and stabilization of the Western Dharwar craton. Major and trace element geochemistry has been utilized to distinguish magmatic fractionation processes from the effects of alteration, metamorphism, and crustal contamination in the rocks, and also to determine the nature of the parental magma and mantle source. Integrated trace element and isotope geochemistry helps to elucidate the relationship between the plutonic ultramafic–mafic suite and the metavolcanic schistose unit in the Nuggihalli greenstone belt, as their contact relations have been obliterated in the field.

2. Geological background

The Nuggihalli greenstone belt is situated in the Western Dharwar craton in southern India (Fig. 1a). A 500 km long, N–S trending intrusive body of Closepet Granite (2.5 Ga; Taylor et al., 1988) has sub-divided the craton into a western and an eastern component (Fig. 1a). The Western Dharwar craton comprises older Archean supracrustal rocks that constitute the Sargur Group (Swami Nath and Ramakrishnan, 1981). The Sargur Group consists of sediments and igneous rocks that were metamorphosed to greenschist and amphibolite facies. The meta-igneous lithologies occur as both intrusive and volcanic ultramafic–mafic rocks with a compositional range from komatiite to komatiitic basalts and tholeiites (Ramakrishnan et al., 1994). The ultramafic–

(a)

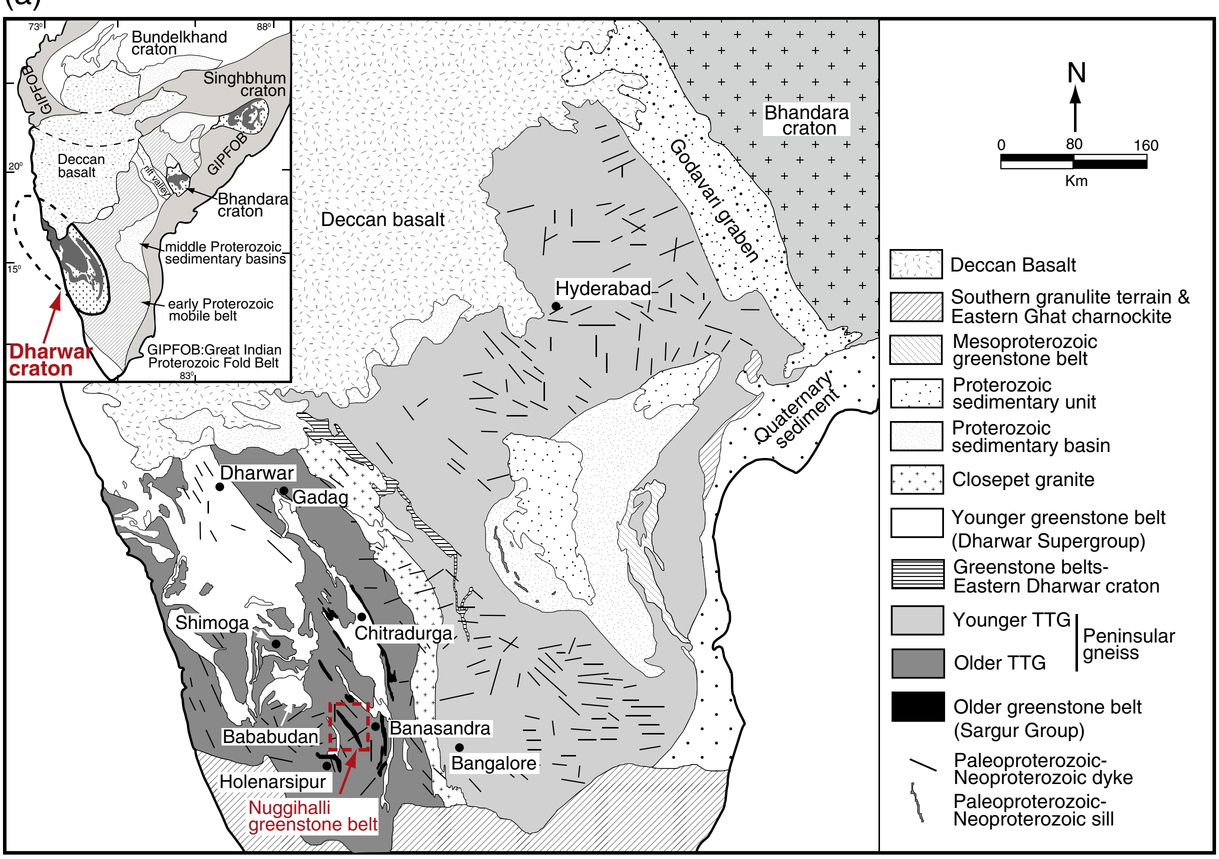

Fig. 1. (a) Generalized geology of the Dharwar craton showing location of the Nuggihalli greenstone belt (after Murthy, 1987; cited in Devaraju et al., 2009). Inset map portrays the generalized geology of the Indian shield showing Dharwar craton (compiled by Mondal et al., 2006; after Leelananadam et al., 2006; Radhakrishna and Naqvi, 1986). (b) Geology of the Nuggihalli greenstone belt showing locations of the chromite mining districts (after Jafri et al., 1983; cited in Devaraju et al., 2009). Sample locations are marked.