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# Continental lithospheric evolution: Constraints from the geochemistry of felsic volcanic rocks in the Dharwar Craton, India

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ABSTRACT

Felsic magmatism associated with ocean–ocean and ocean–continent subduction processes provide important evidence for distinct episodes of crust-generation and continental lithospheric evolution. Rhyolites constitute an integral component of the tholeiitic to calc-alkaline basalt–andesite–dacite–rhyolite (BADR) association and contribute to crustal growth processes at convergent plate margins. The evolution of the Dharwar Craton of southern peninsular India during Meso- to Neoarchean times was marked by extensive development of greenstone belts. These granite-greenstone terranes have distinct volcano-sedimentary associations consistent with their geodynamic setting. The present study deals with geochemistry of rhyolites from the Chitradurga-Shimoga greenstone belts of western (WDC) and the Gadwal-Kadiri greenstone belts of eastern (EDC) sectors of Dharwar Craton to compare and evaluate their petrogenesis and geodynamic setting and their control on the continental lithospheric evolution of the Dharwar Craton. At a similar range of $SiO_2$, $Al_2O_3$, $Fe_2O_3$, the rhyolites of WDC are more potassic, whereas the EDC rhyolites are more sodic and less magnesian with slight increase in $TiO_2$. Minor increase in MgO content of WDC rhyolites reflects their ferromagnesian trace elements which are comparatively lower in the rhyolites of EDC. The relative enrichment in LILE (K, Rb) and depletion in HFSE (Nb, Ta, Zr, Hf) marked by negative Nb–Ta, Zr–Hf and Ti anomalies endorse the convergent margin processes for the generation of rhyolites of both the sectors of Dharwar Craton. The high silica potassic rhyolites of Shimoga and Chitradurga greenstone belts of WDC showing prominent negative Eu and Ti anomalies, flat HREE patterns correspond to Type 3 rhyolites and clearly point towards their generation and emplacement in an active continental margin environment. The geochemical characteristics of Gadwal and Kadiri rhyolites from eastern Dharwar Craton marked by aluminous compositions with low and fractionated HREE patterns and minor negative Eu anomalies are in conformity with Type 1 rhyolites and suggest that they were erupted in an intraoceanic island arc system. The overall geochemical systematics of the rhyolites from both the sectors of Dharwar Craton suggest a change in the geodynamic conditions from intraoceanic island arc of eastern Dharwar Craton and an active continental margin of western Dharwar marked by ocean–ocean subduction and migration of oceanic arc towards a continent followed by arc-continent collision that contributed for the evolution of continental lithosphere in the Dharwar Craton.

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## 1. Introduction

The Earth is the only planet in the solar system which possesses a well-developed, felsic continental crust (Maruyama et al., 2013). This crust was progressively extracted from the Earth's mantle over the last 4.0 billion years and although it represents only 0.6% of the mass of the silicate Earth, it contains up to 70% of the Earth's budget of highly incompatible elements (Rudnick and Gao, 2003; Rollinson, 2008). The origin and growth of continental crust through geological time is very significant as the evolution of Archean continental crust records a spectrum of tectono-magmatic activities which controlled progressive and episodic crust generation processes (Santosh, 2013). Understanding the geological and tectonic processes involved in the generation of continental crust provides one of the fundamental aspects of global crustal evolution and continental growth (Condie and Aster, 2013). Phanerozoic continental crust formed mainly along subduction

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zones by tectonic accretion and emplacement of juvenile magmatic rocks (Sengör et al., 1993; Polat, 2012; Xiao and Santosh, 2014). However, the nature of petrogenetic and geodynamic processes that generated the Archean continental crust still remains one of the most challenging problems in Earth science (Foley et al., 2002; Rapp et al., 2003; Hawkesworth et al., 2010). It has been estimated from various crustal growth models that at least 60% of the existing continental crust separated from the mantle before 2.5 Ga (Belousova et al., 2010; Hawkesworth et al., 2010), and the Archean–Proterozoic era is the most important period of accelerated crustal growth on Earth, with a peak at 2.7 Ga (Condie, 1992, 1998; Tarney and Jones, 1994; Albarede, 1998; Isley and Abbott, 1999; Polat, 2012; Zhai, 2014).

Archean continental growth has been dominantly controlled by arc magmatism, accretion of oceanic crust (ophiolites) and arc-related sediments at convergent plate boundaries, basaltic underplating of the crust and plume-related intra-plate magmatism (hotspot magmatism; Taylor and McLennan, 1995; Fleidner and Klemperer, 2006; Santosh et al., 2013). Records of continental growth by arc magmatism and subduction–accretion processes at both an oceanic arc (formed on older oceanic crust) and a continental arc (formed on older continental crust) across the ocean–continent transition are preserved in many terranes, and these processes have periodically punctuated the geological record on continents by addition of juvenile crustal materials onto cratonic areas. Phases of felsic magmatism show strong association with subduction related tectonic activities in terms of both ocean–ocean and ocean–continent convergence and their emplacements provide evidence for distinct episodes of crust-generation (Ahmad et al., 2008, 2009; Reagan et al., 2008; Stern, 1991; Dostal et al., 1994).

Rhyolites constitute an integral component of the tholeiitic to calc-alkaline basalt–andesite–dacite–rhyolite (BADR) association of convergent margin setting. The active continental margins are the most important sites of generation of rhyolitic magmas in the ancient and modern subduction systems (Manikyamba et al., 2007; Khalifa et al., 2011; Eyuboglu et al., 2013; Praveen et al., 2013). A combination of magmatic processes such as influx of slab-derived fluids and melts into mantle wedge, wedge melting, assimilation of crustal materials by arc magma and magma mixing play a very significant role in the petrogenetic evolution of tholeiitic to calc-alkaline mafic to felsic magmas (Gao et al., 2012; Guan et al., 2012; Qi et al., 2012; Yang et al., 2013). The Dharwar Craton of southern peninsular India records geological history spanning 3.4–2.5 Ga involving several episodes of crustal development.

Several recent papers have addressed the geochemistry of volcanic units in different greenstone terranes of the eastern and western sectors of the Dharwar Craton and interpreted that they were either erupted from mantle plume or at convergent margin settings. Eruption of mantle plume through oceanic/continental or continental margin has been identified through the geochemical characteristics of mafic–ultramafic sequences (Manikyamba et al., 2008, 2013; Manikyamba and Kerrich, 2011). Present work deals with the geochemical characteristics of felsic volcanic rocks from Gadwal and Kadiri greenstone belts of eastern and Chitradurga and Shimoga greenstone belts of western Dharwar Craton to evaluate the geodynamic evolution of the Dharwar Craton. These studies provide constraints on the (1) nature of felsic magmatism in these two sectors of Dharwar Craton, (2) petrogenetic processes involved in their origin and (3) tectonic setting of the rhyolites of eastern and western Dharwar Craton. These studies reflect the role of intraoceanic subduction processes in the eastern Dharwar Craton and active continental margin setting in the western Dharwar Craton which resulted in the growth of continental lithosphere during Neoarchean in the Dharwar Craton.

## 2. Geological setting of Dharwar Craton

The Dharwar Craton of southern peninsular India preserves excellent exposures of granite-greenstone belts ranging in age from 3.4 to 2.5 Ga, with associated granitoid intrusions. This craton is divided into western (WDC) and eastern (EDC) sectors by the Closepet granite dated at 2518 Ma (Fig. 1; Naqvi and Rogers, 1987; Jayananda et al., 2000; Moyen et al., 2003; Ramakrishnan and Vaidyanadhan, 2010). The different volcano-sedimentary associations present in greenstone terranes of the WDC and EDC are consistent with distinct geodynamic settings, as endorsed by geochemical studies (Jayananda et al., 2013a,b; Ram Mohan et al., 2013; Peucat et al., 2013; Manikyamba et al., 2004a,b, 2005, 2008, 2009, 2012, 2013; Manikyamba and Kerrich, 2011, 2012). Recent studies on U–Pb zircon ages and Nd isotope data, indicate that the Dharwar Craton as a whole can be divided into the western (3.4–3.2 Ga), central (3.4–3.2 Ga and 2.56–2.52 Ga), and eastern (2.7–2.52 Ga) provinces (Peucat et al., 2013). The western and eastern provinces are composed of older and younger crustal rocks, respectively, whereas the central province consists of a mixture of older and younger lithologies (Dey, 2013; Jayananda et al., 2013a,b). Geological, geophysical, and structural studies record systematic differences in lithological associations of the western and eastern greenstone terranes (Table 1). The former are characterized by >3.0 Ga basement of tonalite–trondhjemite–granodiorite (TTG) gneisses, with interlayered older Sargur Group rocks which is unconformably overlain by 2.9–2.6 Ga Dharwar Supergroup greenstone sequences including komatiites, basalts, andesites, dacites, rhyolites, banded iron formation (BIF), conglomerates and sandstones (Ramakrishnan and Vaidyanadhan, 2010) whereas the latter are ~2.7 Ga greenstone belts, present within TTG intruded by younger granites (2.55–2.52 Ga). According to Dey (2013), the main crust building period in the western Dharwar Craton is between 3.35 and 3.0 Ga whereas the major crust forming geological events in the eastern Dharwar Craton took place between 2.7 and 2.5 Ga. Lithologies of the western Dharwar Craton comprise of two generations of greenstone belts viz. namely older Sargur Group and younger Dharwar Supergroup, late calc-alkaline to potassic plutons and TTG-type peninsular gneisses (Naqvi, 2005; Naqvi and Rogers, 1987; Manikyamba et al., 2012, 2013; Jayananda et al., 2013b). The Sargur Group greenstone belts consist of dominant komatiite-basalt association with occasional felsic volcanic rocks and interlayered sediments like quartzite, pelites, carbonates and BIFs. Sm–Nd whole rock isochron age of komatiites of Sargur Group yield 3352 ± 110 Ma while SHRIMP U–Pb dating of zircons from felsic volcanic represent an age of 3298 ± 7 Ma (Peucat et al., 1995; Jayananda et al., 2013a). The volcano-sedimentary rocks of Dharwar Supergroup, underlain by the peninsular gneisses and Sargur Group, consist of two stratigraphic units. The lower Bababudan Group comprises of oligomictic conglomerate, quartzite, phyllite, mafic–felsic volcanics, tuffs and thick BIFs. Sm–Nd whole rock isochron of mafic volcanic rocks yield 2.9–2.8 Ga age (Kumar et al., 1996) and zircons from upper felsic volcanic tuffs suggest 2.2 Ga (Trendall et al., 1997a,b). The Bababudan Group is overlain by the Chitradurga Group comprising of polymictic conglomerate, greywackes, argillites and limestones with intercalations of mafic to felsic volcanic rock and BIFs (Seshadri et al., 1981; Viswanatha and Ramakrishnan, 1981; Chadwick et al., 1991; Ramakrishnan and Vaidyanadhan, 2010).

### 2.1. Chitradurga and Shimoga greenstone terranes of WDC

The Chitradurga and Shimoga greenstone terranes are located in the western Dharwar Craton where extensive preservation of greenstone belt sequences has been recorded. The greenstone belt

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