Precambrian Research 258 (2015) 260–277

Contents lists available at ScienceDirect

Precambrian Research

journal homepage: www.elsevier.com/locate/precamres

Petrogenesis of basalt–high-Mg andesite–adakite in the Neoarchean Veligallu greenstone terrane: Geochemical evidence for a rifted back-arc crust in the eastern Dharwar craton, India

Tarun C. Khanna [a,*], V.V. Sesha Sai [b], Michael Bizimis [c], A. Keshav Krishna [a]

[a] CSIR – National Geophysical Research Institute, Hyderabad 500 007, India
[b] Geological Survey of India Training Institute, Bandlaguda, Hyderabad 500 068, India
[c] Department of Earth and Ocean Sciences, University of South Carolina, Columbia, SC 29208, USA

ARTICLE INFO

Article history:
Received 23 October 2014
Received in revised form
29 December 2014
Accepted 5 January 2015
Available online 13 January 2015

Keywords:
Back-arc basalt
High Mg-andesite
Adakite
Neoarchean
Veligallu greenstone belt
Dharwar craton

ABSTRACT

The ~2.7 Ga Veligallu greenstone terrane in the eastern Dharwar craton is one of the least studied Neoarchean greenstone belts in India. To our knowledge, there is no published dataset that provides a detailed account of the petrogenetic processes, which culminated into the evolution of this greenstone belt. This paper presents a comprehensive account of field, petrography and geochemistry of the basalt–high-Mg andesite–adakitic volcanic rock association in the Veligallu greenstone belt.

The basalts are tholeiitic in nature and are characterized by primitive geochemical compositions with ~49 wt% SiO_2, ~9 wt% MgO, Mg# 54, Cr ~ 197 ppm, Ni ~ 122 ppm, Y ~ 27 ppm, Yb ~ 2.7 ppm; Zr/Y < 3 and Ce/Yb < 5. They do not plot on a mixing line between Mesoarchean TTG and N-MORB, therefore, inconsistent with any interaction with the upper continental crust. Accordingly, they are interpreted to have erupted in an oceanic setting. On the basis of Nb/Th ratio the Veligallu basalts are divided onto two groups. The basalts with Nb/Th > 8 display systematically flat to light-REE depleted chondrite normalized REE patterns (La_N/Yb_N = 0.76–1.0), in contrast to the samples with Nb/Th < 8, which display slight enrichments in light-REE (La_N/Yb_N = 1.0–1.6). The depleted basalts are characterized by primitive mantle normalized Nb concentrations lower than La but equal to Th, in contrast to the enriched basalts, which are characterized by slight depletions of Nb relative to both La and Th. Collectively, as a group, they display Nb/Yb ratio higher than the N-MORB. The enrichment in Nb is attributed to moderate to low degree (~10%–4%) partial melting of a depleted MORB source. The trace, REE and their interelement ratios in the Veligallu basalts exhibit transitional characteristics between the average N-MORB and the typical Phanerozoic island arc basalts. Overall, the geochemical characteristics of the Veligallu basalts are identical to basalts erupted in the Phanerozoic back-arc basins.

The Veligallu high-Mg andesites are orthopyroxene-bearing calc-alkaline andesites and are characterized by moderate SiO_2 (~56 wt%), high MgO (~8 wt%), Mg# (61–67), Cr (174–330 ppm) and Ni (173–242 ppm) contents; low Y (~13 ppm) and Yb (~1.2 ppm) concentrations, relative to typical island arc andesites. They exhibit light-REE enriched (La_N/Sm_N ~ 1.7) and heavy-REE depleted (Gd_N/Yb_N ~ 1.9) fractionated REE patterns. On a primitive mantle normalized trace element variation diagram they exhibit negative Nb and Ti, and contrasting positive Zr anomalies relative to the neighboring REE. The La–Yb systematics suggest that these high-Mg andesites were generated by hydrous partial melting of a slab-melt metasomatized mantle wedge in the sub-arc mantle. The felsic volcanic rocks are characterized by high SiO_2 ~ 73 wt%, Na_2O ~ 4.5 wt%, and significantly low concentrations of MgO (~0.72 wt%), Cr ~ 19 ppm, Ni ~ 23 ppm, Y ~ 5.9, and Yb ~ 0.44 ppm; strongly fractionated chondrite normalized REE patterns (La_N/Yb_N ~ 30) with occasionally minor positive Eu anomaly, and primitive mantle normalized negative Nb and Ti, and contrasting positive Zr anomaly. The geochemical attributes of the Veligallu felsic volcanic rocks are analogous to the Cenozoic high silica-type adakites that are produced by partial melting in the sub-arc mantle, and presumably without any significant interaction of the slab-melts with the overlying mantle wedge.

* Corresponding author. Tel.: +91 4027012488; fax: +91 4027171564.
E-mail address: khannangri@gmail.com (T.C. Khanna).

http://dx.doi.org/10.1016/j.precamres.2015.01.004
0301-9268/

The juxtaposed occurrence of basalts with the banded iron formations, and their close spatial association with the high-Mg andesites, in the Veligallu greenstone belt, indicates that the petrogenesis of these volcanic rocks is consistent with their eruption in an intraoceanic setting. The close proximal association of the back-arc type basalts, and the high-Mg andesites and adakites within the Veligallu greenstone belt potentially suggests that this greenstone belt represents a rifted back-arc crust. This event appears to have significantly contributed to the peak of crustal growth activity in the eastern Dharwar craton at 2.7 Ga.

1. Introduction

The greenstone belts in the eastern Dharwar craton (EDC) are of Neoarchean age (~2.7 Ga; Jayananda et al., 2013; Khanna et al., 2014). Some of the major greenstone belts, for example, Gadwal (e.g. Manikyamba and Khanna, 2007), Hutti (e.g. Ananta Iyer et al., 1980; Sarma et al., 2008; Manikyamba et al., 2009), Sandur (e.g. Manikyamba et al., 2008; Ram Mohan et al., 2013), Kushtagi (e.g. Naqvi et al., 2006), Kolar (e.g. Rajamani et al., 1985; Balakrishnan et al., 1990), Ramagiri (Zachariah et al., 1996), Penakacherla (Manikyamba et al., 2004) and Kadiri (Dey et al., 2013), in this sector have been extensively studied in relation to their geology, mineralization potential, petrogenesis and geodynamic evolution, which provide significant insights into the subduction related arc magmatic processes and growth of continental crust in the eastern Dharwar craton.

The ~2.7 Ga Gadwal greenstone belt (Khanna et al., 2014), which is located to the north-west of the Cuddapah Basin, consists of boninite–adakite association and coeval occurrence of basalt–andesite–rhyolite suite. This lithological association has been interpreted to reflect intraoceanic arc magmatic processes that culminated into the growth of continental crust in this sector of the Dharwar craton (Manikyamba and Khanna, 2007; Khanna, 2013). The arc basalt–high-Mg andesite–adakite association in the Hutti greenstone belt was interpreted in terms of a paired arc–back-arc model, which provide significant insights into the crustal growth processes in the Dharwar craton (Manikyamba et al., 2009). The Kadiri greenstone belt, which is located ~40 km west of the Veligallu greenstone belt in the south-west of Cuddapah Basin, consists of basalt–andesite–rhyolite association that was interpreted in terms of a plume–arc accretion model (Dey et al., 2013). Comparatively, the ~2.7 Ga Veligallu greenstone belt, however, remains one of the least studied greenstone belts in the eastern Dharwar craton. To our knowledge, there is no significant published literature that provides a detailed account of the petrogenetic processes, explaining the evolution of this greenstone belt. Therefore, through this paper, we provide a comprehensive account of field, petrography and geochemistry of the basalt–andesite–adakite volcanic association in the Veligallu greenstone belt, and further relate their petrogenesis to subduction related magmatic processes in a rifted back-arc tectonic setting in the Neoarchean.

2. Regional geology

The Dharwar craton is divided into two tectonic regions, viz. the western and the eastern Dharwar cratons (Swami Nath and Ramakrishnan, 1981; Naqvi and Rogers, 1987). The NNW-SSE trending shear zone extending all along the eastern margin of the Chitradurga greenstone belt separates the eastern greenstone belts from those in the western block (Swami Nath and Ramakrishnan, 1981; Naqvi and Rogers, 1987). The study area (Fig. 1A), the Neoarchean Veligallu greenstone belt, is in the eastern Dharwar craton and it is situated towards the south of the southwestern part of the Cuddapah Basin. The northern tip of the belt abruptly ends at the contact with the overlying Proterozoic sedimentary cover of the Cuddapah Basin, and the southern end tapers into the surrounding granite-gneisses.

The Veligallu greenstone belt (Fig. 1B) broadly exhibits N–S trend with an approximate strike length of ~60 km, and a maximum width of ~8 km in the central part (Srinivasan, 1990). The belt is surrounded by granitoids and intruded by younger mafic dikes. The magmatic intrusions are dolerite, pyroxenite and gabbro. The belt was subjected to deformation and metamorphosed in greenschist to lower amphibolite facies conditions. Basalt is the predominant volcanic rock type in the study area (Fig. 2A). The andesites occur as linear bands, proximal to the basalts (Fig. 2B). About 100 meters west of the andesite outcrop, banded iron formations (BIF) are exposed. Discrete exposures of adakitic rocks occur in the central part of the belt (Fig. 2C). The felsic volcanic rocks, sampled from elsewhere in this belt, yielded a SIMS U-Pb zircon age of 2.7 Ga (Jayananda et al., 2013), which endorses a Neoarchean age for the volcanic rocks in the Veligallu greenstone terrane.

3. Sampling and analytical techniques

The volcanic rocks sampled for this study were collected from relatively fresh portions of the outcrop devoid of quartz veins and secondary mineralization. Petrographic screening was performed for secondary carbonate and sulphide mineralization, intense mineralogical alterations, and the preservation of igneous textures. Subsequently, the rocks were further screened for loss on ignition (LOI). The petrographic observations, however, do not show any discernible mineralogical difference between the samples with high and low LOI. A representative subset consisting of 34 samples with LOI <2 wt.% (e.g. Polat and Hofmann, 2003), was then selected for further detailed petrological studies.

For bulk-rock geochemistry, rocks were powdered manually using an agate mortar and pestle. All the geochemical analyses were performed at the CSIR–National Geophysical Research Institute, Hyderabad, India. Ten major element oxides, Cr, and Ni were analyzed using pressed powder pellets, on a Philips MagiX PRO PW2440; microprocessor controlled, wavelength dispersive sequential XRF. The relative standard deviation for the major element oxides is <3%. Trace elements including large ion lithophile elements (LILE), high field strength elements (HFSE) and rare earth elements (REE) were determined by quadruple inductively coupled plasma mass spectrometry (ICP-MS, Perkin Elmer SCIEX ELAN DRC II). The dissolution method practiced at the University of South Carolina (Sen et al., 2011), was adopted at NGRI. A freshly prepared mixture of ultrapure grade acids ($HF + HNO_3$) taken in 3:1 ratio was added to 50 mg rock powder in screw top Teflon “Savillex” vessels and kept on the hot plate at 160 °C for 5 days. Subsequently, the acid mixture was evaporated to dryness. To the dry sample, 10 ml of 50% (v/v) HNO_3 was added and again evaporated to dryness. This procedure was repeated to ensure that the solution does not contain any traces of precipitate. Then 20 ml of freshly prepared 1:1 HNO_3 was added to the dry sample and left on the hot plate at ~60 °C for 10–15 min to obtain a clear solution. Then the sample solution was cooled to the room temperature and spiked with