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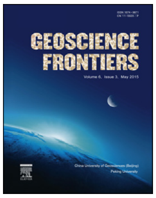

Research paper

Geochemistry and petrogenesis of Rajahmundry trap basalts of Krishna-Godavari Basin, India

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ABSTRACT

The Rajahmundry Trap Basalts (RTB) are erupted through fault-controlled fissures in the Krishna-Godavari Basin (K-G Basin) of Godavari Triple Junction, occurring as a unique outcrop sandwiched between Cretaceous and Tertiary sediments along the east coast of India. Detailed geochemical studies have revealed that RTB are mid-Ti (1.74–1.92) to high-Ti (2.04–2.81) basalts with a distinct quartz tholeiitic parentage. MgO (6.2–13.12 wt.%), $Mg^{\#}$ (29–50) and Zr (109–202 ppm) suggest that these basalts evolved by fractional crystallization during the ascent of the parent magma along deep-seated fractures. Moderate to high fractionation of HREE, as indicated by $(Gd/Yb)_N$ ratios (1.71–2.31) of RTB, suggest their generation through 3–5% melting of a Fe-rich mantle corresponding to the stability fields of spinel and garnet peridotite at depths of 60–100 km. Low K_2O/P_2O_5 (0.26–1.26), high TiO_2/P_2O_5 (6.74–16.79), La/Nb (0.89–1.45), Nb/Th $>$ 8 (8.35–13), negative anomalies at Rb reflect minimum contamination by granitic continental crust. $(Nb/La)_{PM}$ ratios (0.66–1.1) of RTB are attributed to endogenic contamination resulted through recycling of subducted oceanic slab into the mantle. Pronounced Ba enrichment with relative depletion in Rb indicates assimilation of Infra- and Inter-trappean sediments of estuarine to shallow marine character. Geochemical compositions such as Al_2O_3/TiO_2 (3.88–6.83), medium to high TiO_2 (1.74–2.81 wt.%), positive Nb anomalies and LREE enrichment of these RTB attest to their mantle plume origin and indicate the generation of parent magma from a plume-related enriched mantle source with EM I signature. Ba/Th (46–247), Ba/La (3.96–28.51) and Th/Nb (0.08–0.13) ratios suggest that the source enrichment process was marked by recycling of subduction-processed oceanic crust and lithospheric components into the mantle. Zr/Hf (37–41) and Zr/Ba (0.51–3.24) indicate involvement of an asthenospheric mantle source. The Rajahmundry basalts show affinity towards FOZO (focal zone mantle) and PSCL (post-Archaean subcontinental lithosphere) which reflect mixing between asthenospheric and lithospheric mantle components in their source. Origin of RTB magma is attributed to plume-lithosphere interaction and the upward movement of melt is facilitated by intrabasinal deep-seated faults in the K-G Basin.

1. Introduction

The late Cretaceous–early Tertiary Rajahmundry Trap Basalts (RTB) of the Krishna-Godavari Basin extends ~60 km on either side of the Godavari River, north of the city of Rajahmundry in Andhra Pradesh, India (Baksi et al., 1994; Baksi, 2001; Sen and Sabale, 2011). The RTB have been considered as the eastward continuation of Deccan Traps thus representing an example of long distance lava transport spanning over 1500 km across India and about 70 km into the Bay of Bengal (Jay, 2005; Jay and

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Widdowson, 2008; Keller et al., 2008; Self et al., 2008). These traps are the only known outcrops of basalt flows along the east coast of India, coeval with the Deccan Traps. Recent work by Lakshminarayana et al. (2010) has brought to light the stratigraphic framework, flow morphology and volcanological features of the Rajahmundry Trap lava flows. In quarries of the Pangidi-Rajahmundry area, three distinct basalt flows interbedded with two Intertrappean sedimentary horizons are observed, which are in turn underlain by the late Cretaceous fossiliferous limestone bed (Infratrappean) and overlain by the Cenozoic Rajahmundry Formation (conglomerate/sandstone). The fossiliferous Infratrappean bed represents a marker zone of K-Pg (Cretaceous–Paleogene) boundary mass extinction. Ar-Ar geochronological data have established that the RTB (~64 Ma) are contemporaneous with the Deccan Traps (65–66 Ma) that records voluminous volcanic activity on the Indian subcontinent marking the catastrophic events at K-T boundary (Baksi et al., 1994; Allegre et al., 1999; Pande et al., 2004; Sheth, 2005). However, detailed petrological and geochemical studies of the RTB are lacking till date to appraise their genesis and mode of emplacement. This paper presents new geochemical (major, trace and rare earth elements) data for the RTB in order to elucidate (i) the petrogenetic processes associated with their evolution and (ii) implications on their emplacement in terms of regional tectonic framework.

2. Geological setting

The RTB are located along the southeastern part of the Godavari Triple Junction (Fig. 1A). The NW–SE trending Godavari Rift and the NNE–SSW to NE–SW oriented K-G Basin represents a tectonic junction known as Godavari Triple Junction. This terrane preserves a geological record spanning Mesoproterozoic to Neogene and provides evidences for Gondwana break-up, Cretaceous continental rifting and drifting (Lakshminarayana, 1996, 2002; Lakshminarayana et al., 2010). A series of NE–SW trending mounds present between Duddukuru and Rajahmundry, covering an area of ~100 km^2, represent the RTB (Fig. 1A) in the Krishna-Godavari Basin (K-G Basin). The development of K-G Basin has been controlled by a phase-wise uplift of the basement (Eastern Ghat Mobile belt) during Phanerozoic. Lakshminarayana (1995a) suggested that a series of NE–SW step faults controlled the development of east coast basins since Mesozoic. From west to east, these blocks are the Mailaram high, Dammapeta Basin, Raghavapuram Basin and Pangidi-Rajahmundry Basin (Fig. 1A). The Mailaram high was uplifted first during early Mesozoic and controlled the sedimentation pattern in the Dammapeta Basin. Due to post Jurassic uplift, the Mailaram high became a watershed and resulted in the development of short headed fan delta streams flowing towards east (Lakshminarayana, 1997) for the first time. RTB is exposed in three separate areas, namely Nallajerla, Pangidi and Rajahmundry separated by younger sediments (GSI, 1996). The occurrence of prominent outcrops is recorded in Pangidi and Rajahmundry and the Rajahmundry Trap lava flows occur as a single unit (Lakshminarayana, 1995b). The Pangidi-Rajahmundry area of K-G Basin exposes coastal Gondwana sediments (Cretaceous), RTB (K-Pg boundary), Rajahmundry Formation (Paleogene) and the Quaternary sediments (Table 1) (Fig. 1B). The uppermost horizons of the Tirupati Formation, forming the basement of the RTB, are represented by sandstone, clay and limestone and are known as the 'Infratrappean beds' which in turn are unconformably overlain by the RTB (Lakshminarayana et al., 1992). The RTB are bounded by a prominent NE–SW fault along the northwestern margin and overlain by the Cenozoic Rajahmundry Formation and Quaternary sediments in the east. NW–SE lineaments/faults traverse the traps at Duddukuru and Pangidi (Fig. 1B). The entire succession of RTB is preserved between these two faults.

Our present work deals with the well-exposed succession of RTB from the Gowripatnam (17°1′55.8″N, 81°37′41″E) and Duddukuru (17°2′2.2″N, 81°35′33.3″E) quarries, located west of the Godavari river. The RTB units here comprise of three distinct basaltic lava flows (lower, middle and upper) separated by two Intertrappean sedimentary horizons identified as Intertrappean I and II. The 20–30 m thick lower flow unconformably overlies the Maastrichtian-Danian Infratrappean bed (Fig. 2A). The lower basalt flow is characterized by the presence of physical volcanological features such as rootless cones, tumuli and dyke like forms along with prominent development of single to multi-tier columnar (Fig. 2B) and radial jointing (Fig. 2C). Intertrappean I consists of ~2–3.5 m thick clay, marl and limestone intercalations which is sandwiched between the lower and middle flows of RTB (Fig. 2A). Several invertebrate fossils have been collected from this limestone horizon at Pangidi and Rajahmundry areas and this palaeontological evidence has received great attention in view of their similarity with the Intertrappean beds of western and central India (Lakshminarayana et al., 2010; Malarkodi et al., 2010). The middle flow represents 6–10 m thick, greenish grey vesicular basalt resting unconformably over the clay and limestone of Intertrappean I. This flow is 1–2 m thick and appears to be massive. The middle flow is overlain by Intertrappean II which is made of red clay/red bole. The upper flow (5–17 m thick) unconformably overlies the Intertrappean II and is made of fine-grained vesicular basalt.

3. Petrography

The lower, middle and upper flows of RTB are characterized by phenocrysts of plagioclase and clinopyroxene. Groundmass is generally marked by tiny plagioclase, granular pyroxene, opaque minerals and glass. Plagioclase phenocrysts are dominant and are mostly lath-shaped (Fig. 3A). Clinopyroxene phenocrysts are mostly prismatic and occur as individual medium-sized subhedral grains, and clusters of microphenocrysts. These clustered clinopyroxene microphenocrysts have been designated as tecoblast (Pattanayak and Srivastava, 1999; Ganguly et al., 2012). Euhedral olivine phenocrysts are minor and are partially or completely altered to palagonite and iddingsite. These are secondary constituents derived mostly by the hydrous alteration of the primary mafic minerals. The lower and middle flows exhibit vesiculation features containing abundant vug infillings and a greater proportion of groundmass glass, whereas the upper flow is massive with lesser vesicles. Devitrification is also observed at some places. The overall textural pattern is intersertal and intergranular (Fig. 3B). Distinct development of clustered plagioclase phenocrysts represents glomeroporphyritic texture (Fig. 3A). Some sections have the presence of secondary carbonates.

4. Analytical techniques

Least altered samples of trap basalts, collected from three lava flows, were selected for detailed geochemical studies. Forty-two samples were analyzed for major, trace and rare earth elemental compositions. Rocks were powdered using an agate mortar. Major elements were analyzed by XRF (Phillips MAGIX PRO Model 2440), with relative standard deviations <3%. For rare earth elements (REEs), HFSE and other trace elements, powders were dissolved in reagent grade HF and HNO_3 in Savillex screw top vessels, using the procedure of Manikyamba et al. (2012), and determined by ICP-MS (Perkin Elmer SCIEX ELAN DRC II) at the National Geophysical Research Institute (NGRI), Hyderabad. Certified reference materials JB-2 and BHVO-1 were run as standards along with the samples given basaltic compositions of major, trace elements and REE. The analyses and RSD values of JB-2 and BHVO-1 are given in Table S1.