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# Paleoproterozoic Cordilleran-style accretion along the south eastern margin of the eastern Dharwar craton: Evidence from the Vinjamuru arc terrane of the Krishna orogen, India

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ABSTRACT

Accretion along continental or island arcs at cratonic margins was responsible for most Paleoproterozoic crustal growth. For the development of the Krishna orogen, India, at the southeastern margin of the Eastern Dharwar craton (EDC), two contrasting models, one by long-lived accretion between ~1.85 Ga and 1.33 Ga terminating in continental collision with the Napier Complex and the other involving continental collision with the Napier Complex at ~1.6 Ga have been proposed. Here we report the geology and geochemistry of the granitoid rocks grouping them into the Vinjamuru arc terrane. These comprise biotite ± hornblende high-silica granite which are mostly calc-alkaline, weakly metaluminous to peraluminous with normalized trace and rare earth element plots resembling those derived from arc sources as seen by negative Nb, Ti, Zr anomalies, enriched LREE and moderate Eu anomalies. On $(La/Yb)_{CN}$ vs $Yb_{CN}$ and Sr/Y vs Y discrimination diagrams these rocks plot in the field of liquids from mantle-derived melts resembling Cordilleran type granitoids. Petrography, major oxide and trace element concentrations suggest formation in an arc tectonic setting during convergent tectonics at the active continental margin of the EDC with evidence for crustal assimilation. To generate the observed high-silica granite, using selected trace and REE, we modeled 10% aggregate continuous melting of a lower crustal hydrous, high $K_2O$-bearing gabbro yielding a granodiorite magma that underwent fractional crystallization at mid-to lower crust followed by mixing with country rock tonalite and minor assimilation with metasedimentary crustal rocks resulting in the observed heterogeneity in trace elements from the granite. We interpret Paleoproterozoic paleopostions of component Indian cratons leading to their Mesoproterozoic assembly and in that context relate the crustal growth along the southeastern margin of the EDC. In contrast to the existing two models, we propose an alternative Cordilleran-style accretion involving development of an intra-oceanic arc due to ocean-ward migration following the earlier choking of the subduction zone at an active continental margin, caused probably by the North China crustal ribbon that had by ~1.78 Ga accreted to the EDC margin. The formation of the outboard intra-oceanic Ongole arc terrane occurred thereafter and was eventually accreted (and metamorphosed) to the Vinjamuru arc terrane between ~1.63 and 1.55 Ga to form the two arc terranes of the Krishna orogen; we discount any continental collision at this stage as tectonics along this margin, post 1.5 Ga, switched to an extensional regime.



## 1. Introduction

Growth of the continental crust during the Paleoproterozoic driven by steady-state arc magmatism during crustal underplating and terrane collisions are fundamental post-Archean mechanisms of crust formation (Rudnick, 1995; Taylor and McLennan, 1985). Among the several growth models accretion of juvenile material to continental crust along continental or island arcs at cratonic margins, with seaward migration of subduction zones, is considered responsible for most Paleoproterozoic crustal growth (e.g. Cawood et al., 2009, 2013; Hawkesworth et al., 2010) and evolution of regional scale granulite belts (Brown, 2009; Collins, 2002). In contrast to the Andean style orogenesis involving termination by continental collision, the Cordilleran style occurs by subduction of the oceanic crust in a Pacific-type tectonic setting (Busby, 2004; DeCelles et al., 2009; Ducea et al., 2015a; Maruyama, 1997). Characteristic magmatic and metamorphic rock associations and their deformation histories have been proposed to explain accretionary crustal growth from several continents (Bhowmik

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and Dasgupta, 2012; Cawood et al., 2009; Gray and Foster, 2004; Isozaki et al., 2010; Kay et al., 2005; Lee et al., 2007; Petford and Atherton, 1995; Russo and Silver, 1996).

One such Paleoproterozoic belt at the southeastern margin of the Eastern Dharwar craton (EDC) of India is the Krishna orogen (Fig. 1) which has, recently been interpreted as the site of accretionary growth. There are two contrasting models for development of this orogen, one by long-lived accretion (Dharma Rao and Santosh, 2011) between ~1.85 Ga and 1.33 Ga terminating in continental collision with the Napier Complex, a part of the present-day East Antarctica, at ~1 Ga resulting in the Eastern Ghats Belt (reviewed by Dasgupta et al., 2013). In contrast the other model involves continental collision with the Napier Complex at ~1.6 Ga (Vijaya Kumar et al., 2011), utilizing, implicitly, the ~1.9 Ga cratonic rifting at the south EDC margin proposed by Ravikant (2010), thereby allowing for a craton-margin freeboard for a period of ~300 Ma during which accretionary orogenesis could have occurred.

Based on the interpretation of Paleoproterozoic paleopositions of the componental Indian cratons (e.g. Belica et al., 2014; French et al., 2008) leading to their Mesoproterozoic assembly, we have related the crustal growth along the south eastern margin of the EDC to an accretionary process, based on existing information and our geological and geochemical study. Finally we propose an alternative Cordilleran style model for the formation of the Krishna orogen along the Vinjamuru and Ongole arc terranes.

## 2. Geologic setting

The EDC is composed of ~2.5 Ga tonalite-trondjhemite-granodiorite (TTG) gneiss containing linear ~2.7 Ga greenstone belts (Chadwick et al., 2000; Jayananda et al., 2000; Moyen et al., 2003). The southern margin of the Dharwar craton preserves evidence of a Neoarchean to early Paleoproterozoic subduction–accretion event (Bhaskar Rao et al., 1996; Raith et al., 1999; Ratheesh-Kumar et al., 2016; Samuel et al., 2016; Santosh et al., 2015). The western margin of the Dharwar craton, before Cretaceous rifting, was contiguous with Madagascar whereas the northern margin is juxtaposed against the Bastar craton along the ~2.5 Ga Karimnagar granulite belt. The Bastar and EDC abut the Eastern Ghats Belt (Fig. 1). Based on structural data Chetty (2001) recognized that the Eastern Ghats Belt was fault-bounded whereas based on Nd model ages and Pb isotopic compositions Rickers et al. (2001) demonstrated this belt to be a collage of crustal domains bounded by major lineaments. The southeastern margin of the EDC was recently interpreted as having developed from a rifted margin with the Nellore greenstone being the easternmost belt of this Archean craton (Ravikant, 2010; Ravikant et al., 2014). Tectonomagmatic events following rifting due to convergent margin processes (Henderson et al., 2014; Ravikant et al., 2013; Sarkar and Schenk, 2014; Sarkar et al., 2014, 2015) formed the mobile belt termed as the Krishna orogen. Dobmeier and Raith (2003) grouped rocks of the southernmost Eastern Ghats Belt (classified as Domain 1A by Rickers et al., 2001) and the previously known Nellore Schist Belt into the Udayagiri, Vinjamuru and Ongole Domains as the Krishna Province; this is referred here as the Krishna orogeny. This reclassification was based on one major observation by Mezger and Cosca (1999) that the southernmost Eastern Ghats Belt rocks preserved imprints of a common Late Mesoproterozoic event and that they were not reworked by the 990–940 Ma event widespread in the Eastern Ghats Belt. The previously known Nellore Schist Belt, therefore has been resolved into a Paleoproterozoic Udayagiri Group, the ~2.7 Ga Nellore greenstone belt (sensu stricto) and the Late Paleoproterozoic Vinjamuru and Ongole Domains. Based on detailed geological mapping of the Krishna orogen, the Udayagiri Group platformal sedimentary succession along with cratonic units were demarcated from the orogenic Vinjamuru and Ongole Domains which are shown to represent accreted arc terranes to the southeastern margin of the EDC (Fig. 2). The magmatic events preserved in these rocks record their protracted history and are described as under cratonic and orogenic units.

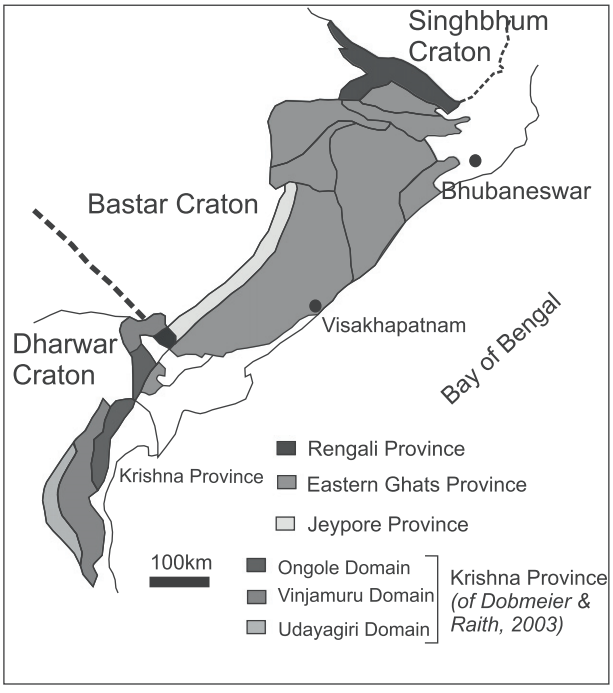


**Fig. 1.** Geological map of the Krishna Province (defined by Dobmeier and Raith, 2003) showing the location of the Vinjamuru Domain and the adjoining areas (modified after Sarkar et al., 2015).

### 2.1. Cratonic units

Arc-type tonalite-granodiorite batholithic plutonic complexes make up the EDC which were emplaced during a major Neoarchean episode of calc-alkaline magmatism. The southwestern contact between granodiorite-tonalite and the Nellore greenstone belt is intrusive, whereas gneissic hornblende-biotite granodiorite containing diorite with synplutonic dykes are exposed north of Podili (all locations are listed in Appendix I). Several intrusions of orbicular granite and granodioritic porphyry are observed within the EDC granitoid. These intrusive rocks are exposed mainly along the eastern margin and were proposed by Ravikant et al. (2014) to represent granitoid emplacement related to a ~2 Ga intra-continental within-plate magmatic event likely related to the major mafic dyke swarm events between 2.2 and 2.1 Ga ago (Belica et al., 2014; French and Heaman, 2010; French et al., 2008; Kumar et al., 2015; Pandey et al., 1997).

The Udayagiri Domain, previously grouped as the westernmost part of the Krishna Province by Dobmeier and Raith (2003), is here given Group status as proposed by Saha et al. (2015). Minor leucocratic variants of the EDC granitoids occur to the southwest of Udayagiri near Bata Peta village and underlie the Udayagiri Group indicating this contact to be an unconformable surface. The rocks comprise a deformed volcanosedimentary succession of greywacke with basal thin beds of oligomictic quartz-pebble conglomerate and interlayered sandstone, siltstone with rare intermediate to mafic rocks, all metamorphosed under greenschisct-facies conditions. From the sparse primary sedimentary structures preserved in these rocks, the depositional environment is inferred to have evolved from early fluvial to stable shallow marine conditions. The schistose rocks are a product of polyphased deformation and the dominant mesoscopic structure present is a well-developed crenulation cleavage axial planar to tightly folded bedding and bedding-parallel cleavage. Exposure of basement granitoid southwest of Udayagiri near Bata Peta indicates the basal status of overlying quartzite. Furthermore, recent total chemical dating