Gondwana Research 29 (2016) 105–135

Contents lists available at ScienceDirect

Gondwana Research

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

Oldest rocks from Peninsular India: Evidence for Hadean to Neoarchean crustal evolution

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ARTICLE INFO

Article history:
Received 20 August 2014
Received in revised form 29 October 2014
Accepted 2 November 2014
Available online 21 November 2014

Handling Editor: S.J. Liu

Keywords:
Petrology and geochemistry
Zircon U–Pb geochronology
Lu–Hf isotopes
Early Earth
Southern India

ABSTRACT

The evolution of continental crust during Hadean and Archean and related geodynamic processes provides important clues to understand the early Earth history. Here we report evidence for Hadean and Eoarchean crust from the fringe of the Coorg Block, one of the oldest crustal blocks in Peninsular India. We present geological, petrological, and geochemical data, together with zircon U–Pb ages and Lu–Hf isotopes from a suite of metaigneous (granitoids, diorite, charnockite, metavolcanics) and metasedimentary (quartz mica schist, calcareous schist, ferruginous quartzite and BIF) rocks. Petrological and geochemical studies indicate that the igneous suite formed from subduction-related arc magmatism, and that the sedimentary suite represents an imbricated accretionary package of continental shelf sequence and pelagic components. Mineral thermometry suggests metamorphism under temperatures of 710–730 °C and pressures up to 8 kbar. Magmatic zircons in the metaigneous suite show oscillatory zoning and high Th/U contents (up to 3.72) and record multiple pulses of magmatism at ca. 3.5, 3.2, 2.7 and 2.5–2.4 Ga. The metasedimentary rocks accreted along the margins of the Coorg Block show multiple zircon population with mean $^{207}Pb/^{206}Pb$ ages at 3.4, 3.2, 3.1, 2.9, 2.7, 2.6, 2.5, 2.2, 2.0, and 1.3 Ga, and overprinted by younger thermal event at ca. 0.8–0.7 Ga. Zircons in the 3.5 Ga dioritic gneiss show positive $\varepsilon Hf_{(t)}$ values ranging from 0.0 to 4.2 and Hf crustal model ages (T_{DM}^{C}) of 3517 to 3658 Ma suggesting that the parent magma was derived from Eoarchean juvenile sources. The zircons in the 3.2 Ga charnockite display $\varepsilon Hf_{(t)}$ values in the range of −3.0 to 2.9 and Hf crustal model ages (T_{DM}^{C}) of 3345 to 3699 Ma. The Neoarchean metagranites, diorites and felsic tuff show both positive and negative $\varepsilon Hf_{(t)}$ values and a range of T_{DM}^{C} values from 2904 to 3609 Ma suggesting magma derivation from Meso- to Eoarchean juvenile and reworked components. The T_{DM}^{C} values of the dominant zircon population in the metasedimentary suite range from 3126 to 3786 Ma, with the oldest value (4031 Ma) recorded by zircon grain in a ferruginous quartzite. The $\varepsilon Hf_{(t)}$ values of detrital zircons also show both positive and negative values, with a dominant crustal source. Our zircon U–Pb and Lu–Hf data suggest vestiges of Neohadean primordial continental crust in Peninsular India with episodic crustal growth during Eoarchean, Mesoarchean and Neoarchean building the continental nuclei. The results contribute to the understanding of crustal evolution in the early history of the Earth.

1. Introduction

The formation and evolution of continental crust in the early Earth have been topics of prime interest among geoscientists, with potential clues in earlier studies provided by continental sediments (Allègre and Rousseau, 1984; Taylor and McLennan, 1995). Episodic crust formation events on the globe have been addressed in several recent studies from the ages of magmatic rocks which show peaks at 3.3–3.2, 2.7, 2.5, 1.9 and 1.2 Ga (McCulloch and Bennett, 1994; Condie, 2000; Kemp et al., 2006; Zhai and Santosh, 2011; Condie and Kröner, 2012; Condie and Aster, 2013; Santosh et al., 2014). However, the volume and composition of the Hadean crust during early Earth history, and the nature of source as depleted or enriched mantle remain contentious (Amelin et al., 1999; Davis et al., 2005; Bennett et al., 2007). Popular hypotheses include the basaltic “protocrust” (Kamber et al., 2005) or voluminous recycled felsic crust (Armstrong, 1981; Harrison et al., 2005). Some models consider that silicate Earth differentiation during the Hadean generated the same volume of continental crust as that of present day, but that the older crust was recycled back into the mantle by the onset of Archean, as argued from evolved isotopic signature (Bennett et al., 2007; Kemp et al., 2010). Prolonged subduction of continental crust is speculated to have generated stagnant ‘second continents’ in the mantle transition zone (Kawai et al., 2013).

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http://dx.doi.org/10.1016/j.gr.2014.11.003
1342-937X/

Although debates surround the nature and timing of initiation of plate tectonics on Earth, the formation of early Achaean tonalite–trondhjemite–granodiorite suites (TTG) and greenstones, and the interleaving of arc–plume sequences as observed in many ancient terranes are considered to indicate that subduction initiation events might have been common in the early Hadean–Eoarchean Earth (O'Neill and Debaille, 2014). In a review addressing the role of detrital zircon in Hadean crustal evolution, Nebel et al. (2014) noted that regional scale TTG suites mark granitoid-generating processes in the Eoarchean, along with the first appearance of low-Ca (s-type) granites at around 3.9 Ga. The global detrital zircon record also coincides with the first addition of juvenile crust and that this age might probably mark the onset of Archean-style tectonics which was likely associated with subduction activity. Only limited information is available on Hadean crust from zircons with ages over 4.0 Ga that include reports from the Jack Hills of the Yilgarn Craton in Western Australia (Wilde et al., 2001; Valley et al., 2014), and the Acasta gneisses in the Wopmay orogen, Canada (Iizuka et al., 2006). Detrital or xenocrystic grains in some of the Proterozoic and Phanerozoic orogenic belts also carry rare ancient zircons (e.g., He et al., 2011; Cui et al., 2013; Diwu et al., 2013). Although these reports suggest that the primodial continental crust might have formed in the Hadean, its extent of preservation remains unknown. A recent study combining Hf and O isotopes of Eoarchean zircons from Jack Hills suggests simultaneous loss of ancient crust accompanied by juvenile crust addition suggesting that subduction tectonics operated at this time, similar to the process on modern Earth (Bell et al., 2014).

The growth of continental crust through time is debated with endmember models on episodic growth versus continuous growth. Crustal evolution history as studied in detail from one of the largest Phanerozoic orogens on the globe, the Central Asian Orogenic Belt, shows substantial addition of juvenile crust and continental building through arc–arc and arc–continental collision with ancient micro-continents caught in between (Xiao and Santosh, 2014 and references therein). Rino et al. (2008) reported detrital zircon data from sediments in major river mouths of the globe and provided robust evidence for the episodic growth of continental crust through time. Although their zircon population covers a wide time range from 4.2 Ga to the present, the data clearly identify discontinuous and episodic growth of continental crust during four peaks at 2.6–2.7 Ga, 2.0–2.2 Ga, 1.0–1.2 Ga, and 0.5–0.8 Ga. They also noted that the minor peaks in some cases, such as in the Mesoarchean, are possibly due to data bias arising from the lack of adequate information on these terranes.

Peninsular India assembles a collage of continental blocks which were part of various supercontinents in Earth history starting from Ur at 3.0 Ga through Columbia at 1.9 Ga, Rodinia at 1.0 Ga and Gondwana at 0.54 Ga (Rogers and Santosh, 2003; Meert et al., 2010; Nance et al., 2014). The Southern Granulite Terrane (SGT) to the south of the Dharwar Craton is composed of continental blocks ranging in age from Mesoarchean (3.2 Ga; Santosh et al., 2014) through Neoarchean and Paleoproterozoic to late Neoproterozoic–Cambrian (Santosh et al., 2003, 2009; Plavsa et al., 2012; Collins et al., 2014; Kröner et al., 2015; Praveen et al., 2014; Samuel et al., 2014; Shaji et al., 2014). In a previous study, our group reported Mesoarchean juvenile crust formation in the Coorg Block, an exotic crustal block that does not bear any imprints of the later Neoarchean, Paleoproterozoic and Neoproterozoic tectonothermal events that are widely represented in the surrounding crustal blocks in the SGT (Santosh et al., 2014). In this study, we focus on the margins of the Coorg Block, and the bounding suture zones where we carried out detailed field investigations and sample collection (Fig. 1). We present systematic geologic, petrologic, geochemical and zircon U–Pb and Lu–Hf data from a suite of metaigneous and metasedimentary rocks which provide new insights into Neohadean and Eoarchean crustal evolution history in Peninsular India as well as multiple magmatic pulses and episodic continental growth through the Archean Earth history.

2. Geological setting and sampling

2.1. Geological background

The Coorg Block is bound to the north by the E–W trending Mercara Shear Zone (MRSZ) and to the south by the WNW–ESE trending Moyar Shear Zone (MOSZ) (Figs. 1, 2a) (Chetty et al., 2012; Santosh et al., 2014). The Mercara Shear Zone welds the Coorg Block with the Dharwar Craton to the north and is marked by steep gravity gradients (Sunil et al., 2010) interpreted to suggest the presence of underplated high-density material in the lower crust. The Coorg–Nilgiri–Biligiri Rangan–Salem–Madras Blocks were previously grouped together, and considered to have witnessed a common Neoarchean (ca. 2500 Ma) granulite facies metamorphism (Bernard-Griffiths et al., 1987; Raith et al., 1990; Bhaskar Rao et al., 1992; Peucat et al., 1993; Janardhan et al., 1994; Raith et al., 1999; Bhaskar Rao et al., 2003; Devaraju and Janardhan, 2004; Ghosh, 2004; Clark et al., 2009; Sato et al., 2011). Our recent geochronological and isotopic studies (Santosh et al., 2014) revealed that the Coorg Block is an exotic crustal domain within the SGT, in the absence of any records of the 2.5 Ga pervasive regional metamorphism widely represented in the surrounding blocks.

Mesoarchean charnockites and TTG are the dominant rock types in the Coorg Block. Mafic–ultramafic rocks are volumetrically less abundant, and occur as the dismembered and altered tremolite–actinolite schists. Metasedimentary units such as the psammites, pelites and carbonates are rare or absent within the central domain, but several tens of meters thick bands of granulite facies metapelites (khondalites) occur along the northern and northeastern peripheries of the block. The depositional and metamorphic ages of these rocks (our unpublished data) indicate that these passive margin sediments developed in Proterozoic continental rifts and were metamorphosed during latest Mesoproterozoic. From the dominant lithological constituents comprising charnockite–mafic granulite–TTG–porphyritic syenogranite suites, the Coorg Block can be considered as an eroded continental arc. In this study, we carried out field investigations and sampling in the southern and south eastern margin of the Coorg Block along the Irikkur–Thalipararmba–Nadukani–Periya sector of Kannur district and Tirunelli–Appapara–Manandavadi sector of Wyanad district. The WNW–ESE trending Moyar Shear Zone, extending from Payyannur in the west to Sulthan Bathery in the east for about 150 km marks the southern suture of the Coorg Block. This zone merges with the northern Mercara Suture Zone around Padamala, Kartikulam, Tirunelli areas (Fig. 2).

Many workers have studied the geology and structure of the Waynad–Kannur sector (Rao and Varadan, 1967; Nair et al., 1975; Vidyadharan, 1981; Nambiar, 1985; Naha and Srinivasan, 1996; Nambiar et al., 1997; Kurian et al., 1999; Meißner et al., 2002; Jain et al., 2003; Pillay and Bhutia, 2010; Asoka Kumar and Soney Kurien, 2011; Pillay and Khipra, 2012; Soney Kurien and Behera, 2012; Praveen, 2013). These studies have classified the rock types in the region into four groups, namely the Archean Wyanad Group (equivalent to the Sargur Group of Dharwar Craton), the Peninsular Gneissic Complex (PGC), the Charnockite Group, and the younger basic and acid intrusives. The Wyanad Group comprises older supracrustals represented by the metasedimentary and metaultramafic units occurring as enclaves and rafts within the PGC and the Charnockite Group. The PGC comprises hornblende–biotite gneiss and granite gneiss. The Charnockite Group is represented by charnockites and mafic granulites. The Neoproterozoic younger intrusives are mainly granitoids.

Previous studies contended that the Sargur equivalent rocks (low-grade schists and associated quartzites, and the high-grade metasedimentary-metaultramafic rocks) lie unconformably over the Wyanad gneissic complex. Based on lithostratigraphy and grade of metamorphism, these units were correlated with the Neoarchean Lower Bababudan Group of the Dharwar Supergroup (Nair et al., 1975). The gneiss-supracrustal association in the region is comparable to those