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Possible magmatic underplating beneath the west coast of India and adjoining Dharwar craton: Imprint from Archean crustal evolution to breakup of India and Madagascar

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ABSTRACT

The shear wave velocity of the crust along a ~660 km profile from the west to the east coast of South India is mapped through the joint inversion of receiver functions and Rayleigh wave group velocity. The profile, consisting of 38 broadband seismic stations, covers the Archean Dharwar craton, Proterozoic Cuddapah basin, and rifted margin and escarpment. The Moho is mapped at a depth of ~40 km beneath the mid-Archean Western Dharwar Craton (WDC), Cuddapah Basin (CB), and the west and east coasts formed through the rifting process. This is in contrast with a thin (~35 km) crust beneath the late-Archean Eastern Dharwar Craton (EDC). Along the profile, the average thickness of the upper, middle and lower crust is ~4 km, 12 ± 4 km and 24 ± 4 km respectively. Above the Moho, we observe a high-velocity layer (HVL, $Vs > 4$ km/s) of variable thickness increasing from 3 ± 1 km beneath the EDC to 11 ± 3 km beneath the WDC and the CB, and 18 ± 2 km beneath the west coast of India. The seismic wave velocity in this layer is greater than typical oceanic lower crust. We interpret the high-velocity layer as a signature of magmatic underplating due to past tectonic processes. Its significant thinning beneath the EDC may be attributed to crustal delamination or relamination at 2.5 Ga. These results demonstrate the dual signature of the Archean Dharwar crust. The change in the geochemical character of the crust possibly occurred at the end of Archean when Komatiite volcanism ceased. The unusually thick HVL beneath the west coast of India and the adjoining region may represent underplated material formed due to India–Madagascar rifting, which is supported by the presence of seaward dipping reflectors and a 85–90 Ma mafic dyke in the adjoining island.

1. Introduction

The growth of continental crust and its deformation history through time are recorded in the chemical and physical properties of the crust. Most of our present understanding of the nature of the deeper portion of the continental crust is derived normally based on the velocities of seismic waves. Global compilations of seismic velocity structure with depth show significant variability in the composition of continental crust with tectonics and thermal regimes (Christensen and Mooney, 1995; Rudnick, 1995). The continental crust with a global average thickness of 34 km to 40 km is usually divided into upper, middle and lower crust with characteristic shear wave velocity of <3.5 km/s, 3.5–3.8 km/s and greater than 3.8 km/s respectively. The thickness of the layers is approximately 11–12 km each. Compositionally the upper crust is felsic with over 66% SiO_2 dominated by granite/granodiorite. The middle crust contains rocks in the amphibolite facies with lower SiO_2 and K_2O and higher FeO, MgO than the upper crust. It is widely agreed that felsic to mafic granulites of igneous origin dominate the lower crust with the corresponding mean SiO_2 varying from 69 to 48% and the P-wave velocity from 6.7 to 7.2 km/s (Rudnick and Fountain, 1995). By contrast, Rudnick and Gao (2003) and Hacker et al. (2011) demonstrate that the lower crust might not be mafic.

The composition and physical properties of the upper and middle crust are better understood, but the nature of lower crust and its seismic signature are more difficult to determine and have been the subject of numerous studies (Rudnick and Fountain, 1995; Rudnick and Gao, 2003; Hacker et al., 2011; Huang et al., 2013). Although, the average velocity of crust increases with the depth, the increase is primarily confined to the lower crust. The average velocity of the upper crust does not vary with the crustal thickness (Drummond and Collins, 1986). It is, therefore, a reasonable proposition that the lower crust participates in the processes responsible

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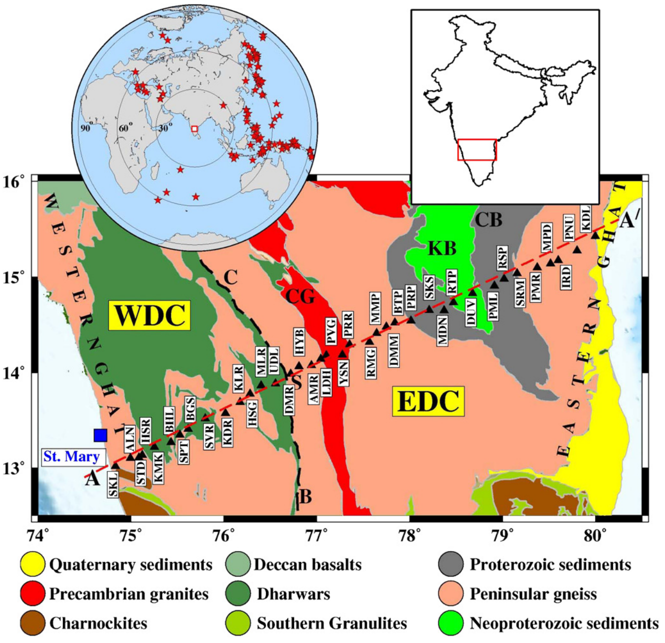

Fig. 1. Geological map showing major features along the profile AA/: WDC – Western Dharwar Craton, EDC – Eastern Dharwar Craton, CB – Cuddapah Basin, CSB – Chitradurga Schist Belt (marked by a dashed black line), CG – Closepet Granite. Seismic stations are shown as black triangles with a three letter code. The upper-right inset is a map of India showing the study region and the upper-left map shows the distribution of earthquakes (red star, Mag. ≥5.5) used for the receiver function analysis. The red square denotes the approximate location of the seismic array. Blue filled in square at 13.37°N, 74.67°E above the westernmost station represents the approximate location of St. Mary Island. This figure is modified from the paper of Saikia et al. (2016). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

for the making of the continental crust. Quantitative characterization of lower crust could, therefore, provide a constraint to understand the mechanism for Earth's continental crust evolution.

In this study, we present the shear wave velocity structure at 38 locations with an average spacing of 10–15 km across the South India from its west to the east coast through the joint inversion of Rayleigh wave group velocity calculated from ambient noise and the teleseismic receiver functions. The main aim of the present study is to investigate the lateral variability in the thickness and the composition of the Earth's lower crust and its role in the formation and evolution of the diverse continental crust through the ages.

2. Geological framework and geophysical studies

Along the seismological profile (Fig. 1), the most prominent geological units are Archean Dharwar Craton, Proterozoic Cuddapah Basin (CB) and, the Eastern and Western continental margins. The western end of the profile comprises of the coastal plain and the adjoining Western Ghat (WG) mountain range believed to have been formed due to the rifting of India from Madagascar at ∼85 Ma (Storey et al., 1995). To the east of the western Ghat, there is the Dharwar craton, divided into Western (WDC) and Eastern (EDC) domains. The WDC dominantly contains Mesoarchean (3.4–2.7 Ga) volcano-sedimentary successions with the most significant period of juvenile crustal addition during 3.35–3.0 Ga. The geochemical data suggest significantly depleted mantle beneath the WDC as early as 3.35 Ga (Boyet and Carlson, 2005). In contrast, in the EDC extensive juvenile magmatism occurred during 2.7–2.5 Ga which is later than the global 2.7 Ga peak of crustal growth (Dey, 2013). The eastern segment of EDC is wrapped by the Proterozoic Cuddapah Basin (CB) and the Eastern Ghat (EG). The EG was formed due to processes (Assembly and breakup of Rodinia and assembly of Gondwana) operating from ca. 2.6 to 1.2 Ga and has most recently been affected by India–Antarctica rifting (Naqvi and Rogers, 1987).

The broadband seismic profile closely follows the wide-angle refraction/reflection profile from the west to the east coast of south India executed in the 1970s (Kaila et al., 1979). Except toward the edges, the profile passes through an almost flat country with an average elevation of ∼600 m. The Bouguer gravity field over most part of the terrain is -75 ± 5 mgal, except over the western part of craton and the western Ghat, where it is -110 mgal. In the proximity of the coast, where the gravity field is -10 to -40 mgal. Along the seismic profile, Kaila et al. (1979) and Roy Chowdhury and Hargraves (1981) inferred 7 crustal-scale faults that offset the Moho by ∼7 km. The average Moho depth varies from about ∼36 km in EDC to ∼41 km beneath the WDC. Wide-angle seismic data was subsequently digitized and modeled through travel time analysis (Mall et al., 2012; Chandrakala et al., 2015). These studies argue for the presence of high-velocity layer (HVL, $V_p > 7.0$ km/s) at the base of the crust in a few segments of the profile, specifically beneath the WDC, CB and the EG. Due to inherent data quality limitation and inadequate ray coverage it is difficult to place the constraint on the thickness and velocity of layers. Saikia et al. (2016) presented the Moho depth variation along the profile through H-k analysis and common conversion point migration of receiver function. The Moho depth along the profile varies smoothly between 34 and 41 km, except beneath the western Ghat and at the contact of WDC and EDC, where it is offset by up to ∼8 km.

3. Data and methodology

To map the shear wave velocity structure with depth, we perform a joint inversion of receiver function measurements (Langston, 1979) with the Rayleigh wave group velocity dispersion data. The group velocities are extracted from the ambient noise tomography (Das and Rai, 2016) and the receiver functions computed from the teleseismic waveforms recorded at seismic stations operated during January 2012 to April 2014. These waveforms recorded at 50 Hz samples by seismographs that include REFTEK 130 data acquisition system and Guralp CMG 3T/3ESP broadband sensors. Details of station network are presented in Saikia et al. (2016). We briefly describe the ambient noise and receiver function analysis methodology.

3.1. Ambient noise data processing and group velocity construction

For ambient noise data processing, seismograms records are analyzed from 57 broadband seismograph sites (includes PALK from Sri Lanka) (Fig. 2a). These stations operated in phases with duration from 6 months to over 2 years, a majority of them having data for over a year. The empirical Green's function (EGF) between pairs of the station is computed from the cross-correlation of ambient seismic noise recorded at these stations following Bensen et al. (2007). At each station data is resampled to 10 s/s and split into one-day segments, followed by removal of mean, trend and instrument response. The resulting waveform is then tapered, band-pass filtered between 1 and 60 s period followed by time domain normalization and spectral whitening. Finally, the cross-correlation between each of the resulting day segment is computed and stacked. Fig. 3 shows Rayleigh wave cross correlations centered at station SUP.

Automated frequency-time analysis (e.g Levshin and Ritzwoller, 2001; Bensen et al., 2007) with a phase matched filter is then applied to each noise correlation function to compute Rayleigh wave group velocity. For each station pair, phase match filtering