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Teleseismic receiver functions modeling of the eastern Indian craton

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ABSTRACT

We estimate receiver functions (RFs) through the time-domain deconvolution using three-component broadband data of 100 teleseismic events ($30° \leqslant \wedge \leqslant 90°$) from 15 seismographs in the eastern Indian craton. Estimated radial RFs show a positive phase at 4.6–5.8 s delay time corresponding to the crustal thicknesses of 37–46 km. Through the differential evolution (DE) waveform inversion modeling of radial receiver functions, we delineate the crustal structure at 15 broadband stations. On an average, the Archean Singhbhum Odisha Craton (SOC) is characterized by a thick crust of 43 ± 3 km in comparison to a relatively thin crust of 41 ± 1 km underlying the Proterozoic Chotanagpur Granite Gneissic terrain (CGGT). While, a thin crust of 38 ± 1 km characterizes the younger Eastern Ghats Mobile Belt (EGMB). The main results of our modeling reveal a 46 km thick Archean crust underlying the Singhbhum granite (SG) of 3.6 Ga, which is characterized by a 3 km crustal thickening probably resulted from the Archean subduction process. Our modeling also detects a 2–3 km crustal thinning with the thinnest crust of 37 km below the region near South Singhbhum Shear Zone, which could be attributed to the 1.6 Ga plume activity associated with Dalma volcanic. Our modeling also led to the delineation of a crustal thinning of 2–3 km underlying the region in EGMB, which was influenced by a much younger (~117 Ma) Rajmahal magmatism associated with the Gondwana break-up episode. However, our study could not detect any age-dependent variation of crustal thicknesses in the eastern Indian craton. The main result of our modeling suggests a two-phase crustal evolution process for the SOC viz. older E-W crustal thickening due to E-W plate compression and later crustal thinning episodes associated with the Dalma volcanism in the north and the Rajmahal volcanism in the South.

1. Introduction

The stable cratonic lithosphere is the upper layer that moves mechanically and coherently with plate motions, which, in general, consists of crust and upper mantle. It has been suggested that crustal thickness is directly proportional to age, excepting young mountain belts, with oldest and coldest Archean crust being the thickest (Pavlenkova, 1987; Zuber et al., 1989; Nelson, 1991). On the contrary, a global review of seismic studies revealed that Archean crust (~27–40 km) is thinner than Proterozoic crust (~40–55 km) (Durrheim and Mooney, 1992). On another note, Archean crust (~40–55 km) is found to be thicker than Proterozoic crust (~30 km) in the Karelian Province of Baltic Province (Gaal and Gorbatschev, 1987). Thus, presently there is an ongoing debate regarding the validity of above two crustal evolution models for different cratons in the world, which are of Archean and Proterozoic ages. The Indian lithosphere has a long history of interaction with deep mantle processes that resulted, for example, in the formation of rifts, sutures, and mega lineaments (Naqvi and Rogers, 1987). Naqvi and Rogers (1987) proposed that the Indian peninsular shield (2.0–3.6 Ga) is consisting of six widespread Archean–Early Proterozoic cratons, which provides a unique opportunity to study the characteristic differences between the Archean and Proterozoic cratonic crust. With an objective to search for the crustal evolution model of the Indian craton, our present study focuses on studying the crustal structure associated with a region, which covers both Archean Singhbhum Odisha Craton (SOC) and Proterozoic Chotanagpur Granite Gneissic Terrain (CGGT) that occupies an area of 240,000 km^2 of the eastern Indian shield (Fig. 1a).

The SOC assumes significance because it is one of the oldest cratonic nuclei of the Indian landmass (Mukhopadhyay, 2001; Mukhopadhyay et al., 2008). The Archean nucleus of SOC consists of Singhbhum granite complex of 3.6 Ga by detrital zircon dating (Naqvi and Rogers, 1987; Sharma et al., 1994) that surrounded by volcano-sedimentary supracrustals and arcuate Proterozoic belt of Chotanagpur (Fig. 1a). The Singhbhum granite body extends more than 150 km in north-south and more than 70 km in an east-west direction between latitude 21°N and 22.75°N and

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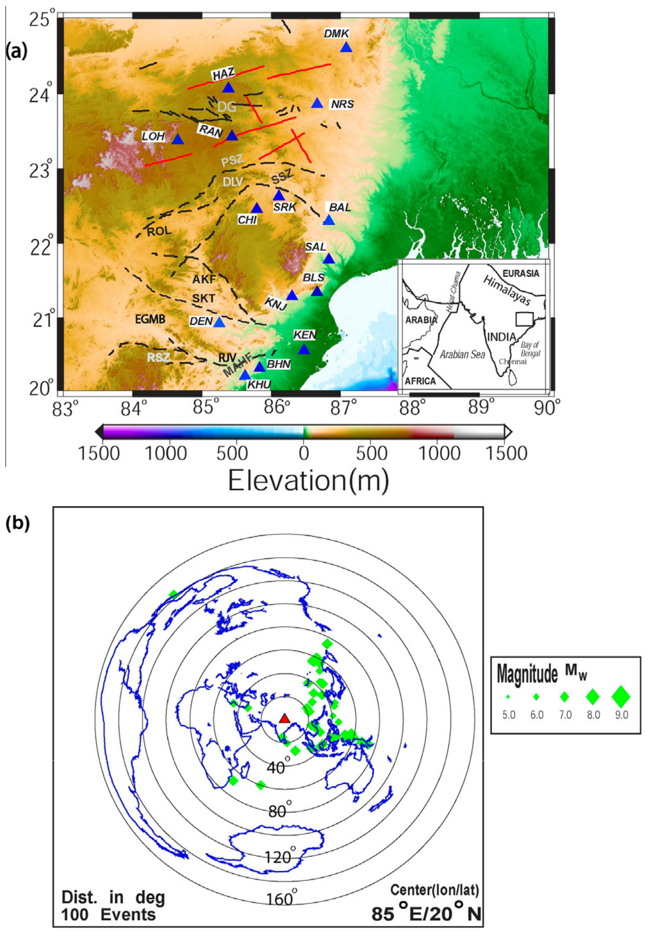

Fig. 1. (a) A plot showing station distribution in the Eastern Indian shield. Blue triangle symbols mark the broadband seismograph stations (KHU-Khurda, BHN-Bhubaneswar, KEN-Kendrapara, DEN-Denkanal, KNJ-Keonjhor, BLS-Balasore, SAL-Salbani, BAL-Balukuria, CHI-Chaibasa, SRK-Saraikela, LOH-Lohardaga, RAN-Ranchi, HAZ-Hazaribagh, NRS-Nirsa, and DMK-Dumka). CGGT, SG and EGMB represent the Chotanagpur Granitic Gnessic terrain, Singhbhum Granite and Eastern Ghats mobile belt, respectively. The black dotted line represents faults; shear zone and lineament, which are written on the map. The red lines represent lineaments, and black lines represent faults in the Chotanagpur plateau (upper part of the map). The inset shows the key map for the area, where the study area is shown by a gray square. (b) The epicentral plot of 100 teleseismic events, whose broadband data from our Singhbhum network, are used for our receiver function study. Red triangle and green diamonds mark the center of our network and epicenters of selected teleseismic events.

longitude 85.5°E and 86.5°E (Mukhopadhyay, 2001). A major east-west striking Singhbhum mobile belt (SMB) passes through the Singhbhum Group of rocks close to the northern extremity of the Singhbhum granite (Ghosh and Sengupta, 1990). The region lying in the northern part of SMB is known as the Proterozoic CGGT, which consists of granitic gneisses, quartzo-feldspathoids, and intermittent mafic intrusives (Mahmoud et al., 2008). Recently, Meert et al. (2010) based on dating of igneous events proposed that the radiometric age constraints for the SOC range from 900 Ma to 3.3 Ga while the age constraints for the CGGT vary from 1500 to 800 Ma by K-Ar dating (Naqvi and Rogers, 1987). On another note, it is believed that the SOC, SMB, and the CGGT together constituted a single crustal block in the East Indian shield, which grew in sequence between 3.6 and 1.0 Ga (Sarkar, 1982; Misra, 2006). The SOC forming the nucleus of this crustal block grew during 3.6–3.12 Ga, through two supra crustal granite cycles. This was followed by crustal growth of SMB supra-crustals between 3.12 and 2.50 Ga, through syn-rift setting deposition and subsequent folding, which was followed by formation of Simlipal volcano-sedimentary basin (~3.12–3.09 Ga) and major mafic volcanism e.g. Dalma and Dhanjori groups. Following subsequent major metamorphism at 2.5 Ga, the crustal growth of the CGGT took place mostly between >2.3 and 1.0 Ga. Thus, the center of crustal growth in Singhbhum-Chotanagpur area gradually migrated from the SOC toward north during Paleoarchean to Mesoproterozoic period (Misra, 2006). Therefore, it is quite apparent that there could be evidence of age-dependent crustal growth between SC in the south and CGGT in the north. In the present paper, we have made an effort to explore this through modeling of P-wave receiver functions for estimating crustal thicknesses.

Two-dimensional modeling of magnetotelluric data delineates a thick cratonic crust of 46 ± 6 km and a thin lithospheric thickness of 95 km underlying the Singhbhum granitic complex, which has been attributed to the important role played by the Himalayan orogeny in delamination of the lithospheric roots of the SOC (Bhattacharya and Shalivahan, 2002; Shalivahan et al., 2014; Kent, 1991; Roy et al., 1989). The south-western side of the study area occupies the much younger (~120 Ma) Eastern Ghats Mobile Belt (EGMB), which has undergone episodes of rifting and subsidence followed by uplift during Late Jurassic (Sastri et al., 1974; Fox, 1934; Thakur et al., 1993). Recent modeling of seismic and gravity data revealed a thinner crust (35–37 km) and a thick high velocity (7.5 km/s) and high density (3.05 g/cm^3) basaltic underplated lower crust underlying the rift zone or EGMB, which have been attributed to the 117 Ma Rajmahal volcanism associated with the Gondwana break-up episode (Behera et al., 2005; Lisker and Fachmann, 2001). This crustal thinning model gets further support from the available high surface heat flow values ranging from 49 to 109 mW/m^2 (Rao and Rao, 1983). However from the inversion modeling of receiver functions, the crustal thickness has been estimated to be 41 km below the CGGT (Kayal et al., 2011), while the crustal thickness is estimated to be 38 km underlying the neighboring region in West-Bengal (Mitra et al., 2008). Thus, available estimates of Moho depths in the region depict a very heterogeneous distribution of crustal thickness underlying the study region covering SOC and CGGT. However, no attempt has been made to map the fine crustal structure beneath this geologically complex region, which would lead to a much better understanding of the crustal evolution processes during Archean-Proterozoic periods that might have shaped this oldest cratonic block of Indian subcontinent.

Receiver function waveforms are a composite of P-to-S [or S-to-P] converted waves that reverberate within the structure near the seismometer (Langston, 1979). Modeling the amplitude and timing of those reverberating waves can supply valuable constraints on the underlying geology (Owens and Zandt, 1985; Ammon, 1991; Cassidy, 1992). Recent techniques for receiver function analysis include more detailed modeling of receiver function arrivals from sedimentary basin structures (Clitheroe et al., 2000), anisotropic structures (Savage, 1998), estimation of Poisson's ratio (Zandt et al., 1995; Zhu and Kanamori, 2000) and joint inversions (Julia et al., 2000). Recently, Li et al. (2006) have applied the differential evolution (DE) algorithm, which is a population-based Monte Carlo method (Storn and Price, 1997; Růžek and Kvasnička, 2001), to inversion for one-dimensional crustal structure from teleseismic receiver function. The stochastic and population-based nature impart DE the capacity of avoiding local optimum solutions and finding out the global optimum solution in multimodal problems. It has only three controlling parameters that are easy to adjust, making it very simple to implement. The convergence of DE is quite fast, and it takes just seconds to solve the nonlinear inversion of receiver function for delineating 1-D crustal structure. DE algorithm has also been used to solve the problem of hypocenter determination (Růžek and Kvasnička, 2005) and minimal representation