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Three-dimensional lithospheric mapping of the eastern Indian shield: A multi-parametric inversion approach

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ABSTRACT

We analyzed satellite gravity and geoid anomaly and topography data to determine the 3D lithospheric density structure of the Singhbhum Protocontinent. Our density model shows that distinct vertical density heterogeneities exist throughout the lithosphere beneath the Singhbhum Protocontinent. The crustal structure identified includes a lateral average crustal density variation from 2800 to 2890 kg/m^3 as well as a relatively flat Moho at 35–40 km depth in Singhbhum Protocontinent and Bastar Craton. A similar Moho depth range is found for the Mahanadi, Damodar, and Bengal basins. In the northern part of the area, Moho undulates between more than 40 km under the confluence of Mahanadi–Damodar Gondwana basins and the Ganga foreland basin, and 36–32 km under the Eastern Ghats Mobile belt and finally reaches 24 km in the Bay of Bengal. The lithosphere–asthenosphere boundary (LAB) across the Singhbhum Protocontinent is at a depth of about 130–140 km. In the regions of Bastar Craton and Bengal Basin, the LAB dips to about 155 ± 5 km depth. The confluence of Mahanadi and Damodar Gondwana basins toward the north-west and the foreland Ganga Basin toward the north are characterized by a deeper LAB lying at a depth of over 170 and 200 km, respectively. In the Bay of Bengal, the LAB is at a shallower depth of about 100–130 km except over the 85 ^{0}E ridge (150 km), and off the Kolkata coast (155 km). Significant density variation as well as an almost flat crust–mantle boundary indicates the effect of significant crustal reworking. The thin (135–140 km) lithosphere provides compelling evidence of lithospheric modification in the Singhbhum Protocontinent. Similarities between the lithospheric structures of the Singhbhum Craton, Chhotanagpur Gneiss Complex, and Northern Singhbhum Mobile Belt confirm that the repeated thermal perturbation controlled continental lithospheric modification in the Singhbhum Protocontinent.

1. Introduction

Cratons are generally considered to be stable tectonic units and underlain by thick (~200 km) lithospheric roots that are chemically and physically distinct from the surrounding mantle. Buoyancy, as well as the refractory nature of Archaean sub-continental lithospheric mantle (SCLM), offers a simple explanation for thickness and longevity of the Archaean lithospheric keels (Jordan, 1988; O'Reilly et al., 2001). In contrast, recently discovered significantly shallower lithosphere–asthenosphere boundary (LAB) in several cratons such as the North China Craton (Zhu et al., 2012; Wang et al., 2014), the western Wyoming Craton (Lee et al., 2000), the western Brazilian Craton (Beck and Zandt, 2002), the Saharan Metacraton (Abdelsalam et al., 2011), and the southern Granulite Terrane of Dharwar Craton (Kumar et al., 2013a) open the question whether the SCLM had a notably thinned root since the time of its stabilization or if subsequent tectonic events have modified it (Lee et al., 2011). Mapping, with reasonable accuracy, the present-day structure of the lithosphere and hence the depth to the LAB is for that reason a critical factor for understanding the tectonic processes responsible for the evolution of cratons. Geological proxies such as xenoliths and xenocrysts may offer complimentary constraints on lithospheric modification mechanism.

The eastern Indian shield is one of the critical examples in the current debate (Fig. 1). The Singhbhum Craton, one of the oldest nuclei (~3.6 Ga old) of the eastern Indian shield that stabilized at about 3.0 Ga (e.g., Roy and Bhattacharya, 2012), possibly amalgamated into a reasonably compact, large continental mass including Chhotanagpur Gneiss Complex by Proterozoic time and remained a coherent entity throughout the Phanerozoic (e.g., Sharma, 2009). This triangular amalgamated large continental region is referred to hereafter as the Singhbhum Protocontinent. Major tectonic and magmatic events of the region include Palaeoproterozoic thermal perturbations in Singhbhum Craton (Mazumder, 2005), sandwiching of the Northern Singhbhum Mobile Belt, and hence welding of the two terranes, Singhbhum Craton and Chhotanagpur Gneiss Complex (Meert et al., 2010), Mesoproterozoic mafic as well as ultramafic intrusions in Singhbhum Craton (Bose, 2009) and extrusion of large-scale Rajmahal Traps in north-eastern part of the Chhotanagpur Gneiss Complex and lamproites in Damodar Gondwana Basins at around 117±2 Ma

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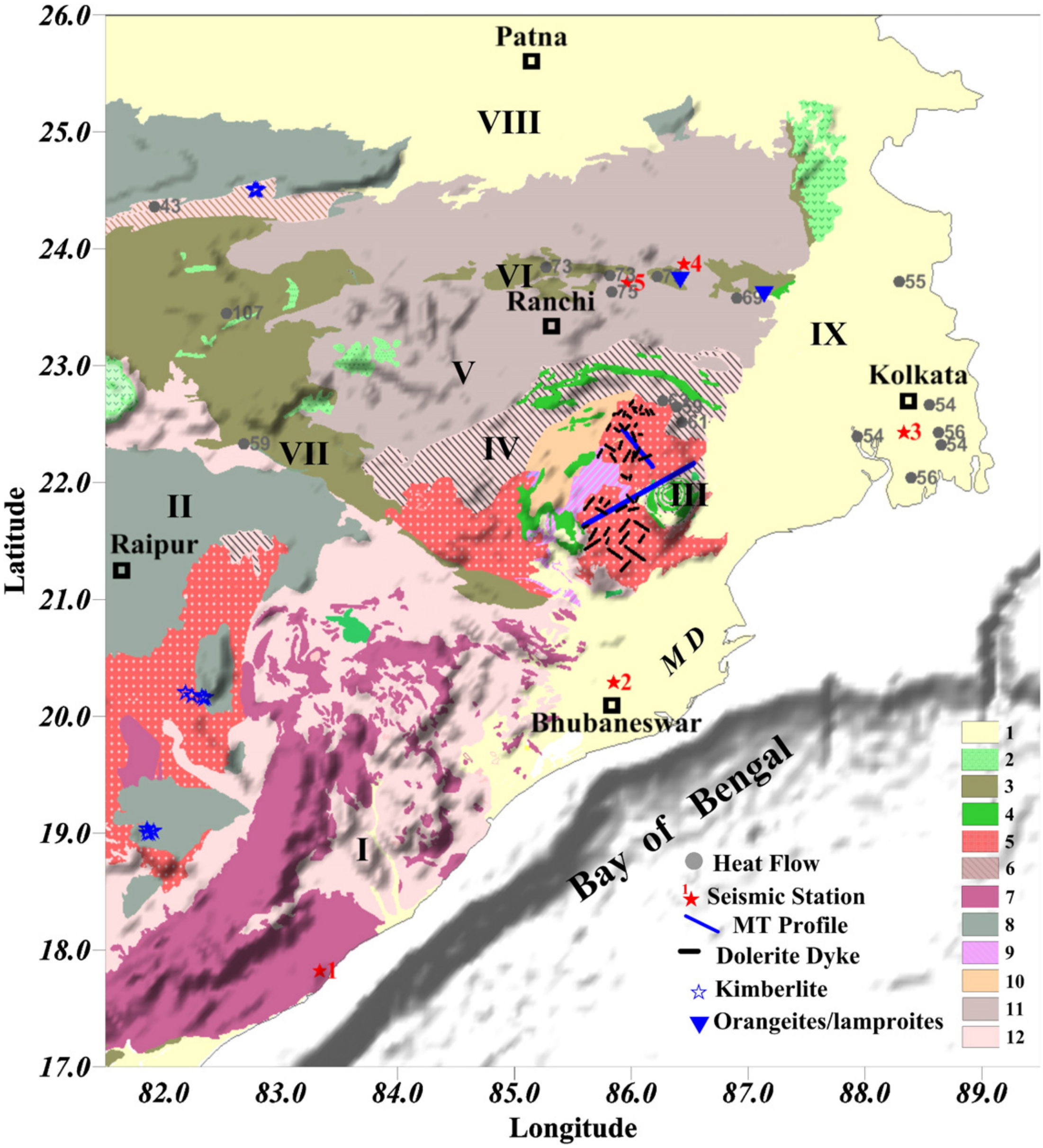

Fig. 1. Location map of the principal structural units of the eastern Indian shield and adjoining Bay of Bengal. I: Eastern Ghats Mobile Belt, II: Baster Craton, III: Singhbhum Craton, IV: Northern Singhbhum Mobile Belt, V: Chhotanagpur Gneiss Complex, VI: Damodar Basin, VII: Mahanadi Basin, VIII: Ganga Basin, IX: Bengal Basin. [1] Phanerozoic sediments; [2] Rajmahal/Deccan Traps; [3] Gondwana sediments (of E-W trending Damodar and NW-SE trending Mahanadi basins); [4] Proterozoic volcanics (Dalma, Dhanjori, and Simlipal) / Alkaline rocks; [5] Archaean / Proterozoic Granite / Granitoid; [6] Schist belts; [7] Charnockites and khondalites; [8] Proterozoic Basins; [9] Older Metamorphic Group; [10] Iron Ore Group; [11] Chhotanagpur Gneiss Complex; [12] Archaean Granite gneiss. Location of MT profiles, Heat flow (in mW/m^2) observations, Kimberlites/Orangeites and Proterozoic dolerite dykes are also given for the ready reference. The broad-band seismic stations are *1 VISK: Visakhapatnam, *2 BWNR: Bhubaneswar, *3 CAL: Kolkata, *4 DHAN: Dhanbad, and *5 BOKR: Bokaro. MD stands for the Mahanadi Delta.

(Kumar et al., 2003). Several competing geodynamic scenarios have been proposed to explain the tectono-magmatic evolution of the Singhbhum Protocontinent, starting from a sequence of collision tectonics (e.g., Sarkar, 1982; Saha, 1994; Rekha et al., 2011) inducing subcrustal metasomatism (Banerjee, 1981; Chalapathi Rao et al., 2013) and resulting in EMI-type mantle (Roy et al., 2004). Most of these competing geodynamic scenarios rely on models of uncertain lithospheric structure derived mostly from geological proxies.

Geophysical observations provide high-resolution data that can be used to obtain refined images of the lithospheric structure. The few isolated geophysical studies undertaken in the Singhbhum Protocontinent, however, show ambiguous lithospheric structure due to their own set of assumptions and limitations. Published estimated thermal lithospheric thicknesses is ~65 km (Pandey and Agrawal, 1999), electrical lithosphere varies from 58 to 95 km (Roy et al., 1989; Shalivahan et al., 2014), and lithospheric estimates using S-wave receiver functions range between 100 and 115 km (Kumar et al., 2007, 2013b). In contrast, the regional-scale estimates of the lithospheric thickness derived from shear-wave velocity as a function of depth indicate a 180–220 km thick continental lithosphere under the Singhbhum Protocontinent (Priestley and McKenzie, 2006). Global seismic data demonstrate that the 95 ± 4 km interface likely represents a boundary in composition, melting, or anisotropy, the LAB being otherwise expected to be much deeper in cratonic regions (Rychert and Shearer, 2009). Owing to scanty data and large uncertainty in resolution of the individual geophysical proxies, the delineated LAB structure of Singhbhum Protocontinent seems elusive and the argument that the lithospheric mantle is modified and recycled needs to be ascertained. In view of this, we make an attempt to delineate a simplified 3D lithospheric density structure encompassing the Singhbhum Protocontinent and adjoining part of the Bay of Bengal combining three distinct geophysical proxies, namely, gravity, geoid, and topography data