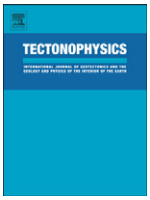
Tectonophysics 592 (2013) 175–186

Contents lists available at SciVerse ScienceDirect

Tectonophysics

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



Heterogeneous lithosphere and the underlying mantle of the Indian subcontinent

G.L. Kosarev [a], S.I. Oreshin [a], L.P. Vinnik [a,*], S.G. Kiselev [a], R.S. Dattatrayam [b], G. Suresh [b], P.R. Baidya [b]

[a] Institute of Physics of the Earth, B. Grouzinskaya, 10, 123995, Moscow, Russia
[b] India Meteorological Department, Ministry of Earth Sciences, Lodi Road, New Dehli-110003, India

ARTICLE INFO

Article history:
Received 12 October 2012
Received in revised form 8 February 2013
Accepted 14 February 2013
Available online 24 February 2013

Keywords:
Receiver functions
Crust
Upper mantle
Transition zone
Lithosphere–asthenosphere boundary,
Deccan Traps

ABSTRACT

P and S receiver functions (PRFs and SRFs, respectively) for 21 broad-band seismograph stations of the India Meteorological Department (IMD) illuminate lithosphere and the underlying mantle of some previously poorly sampled regions of the Indian sub-continent. Our analysis demonstrates that the Archean and Early Proterozoic lithospheric keel of the Indian shield has been reworked by younger processes. We find very low S-wave velocities in the uppermost mantle (from 4.0 to 4.3 km/s) to the north of the Deccan Volcanic Province (Kutch region and Aravalli Craton) (1), in the south (Southern Granulite Terrain and Sri Lanka) (2) and in the north-east (Gangetic Plane, Bengal Basin and Singhbuhm Craton) (3). The anomalies 1 and 2 may extend into the transition zone. Early arrivals of the S410p seismic phase are indicative of anomalously high Vp/Vs ratio (~1.9) in the upper mantle of the low-velocity regions, whereas late arrivals in the western Himalaya, Ladakh and western Tibet are consistent with the previously found indications of anomalously low Vp/Vs ratio. A transition from the high-S-velocity mantle lid to a layer of slightly lower velocity is seen in part of the data but a straightforward interpretation of this transition as the lithosphere–asthenosphere boundary is problematic. A mafic S velocity in the upper crust and a pronounced low-S-velocity layer in the lower crust beneath the eruptive center is practically the only specific feature in the lithosphere that may be linked to the Deccan Traps. A separation in depths between the 410-km and 660-km discontinuities varies laterally in a range from 240 to 270 km. The largest uplift of the 410-km discontinuity (up to 390 km) is observed beneath the foothills of the Himalaya where it is caused by cooling of the transition zone by the ongoing continental collision.

1. Introduction

The present-day Peninsular India is the result of a long and complex tectonic evolution. The Indian shield of the Archean and Early Proterozoic age is a mosaic of Precambrian tectonic provinces up to 3800 Myr old (Goodwin, 1991; Mahadevan, 1994). Archean rocks are dominant in the Aravalli, Dharwar, Singhbhum, Bundelkhand and Bastar cratons (Fig. 1). The cratons are separated by numerous grabens. Most of the grabens were formed in Precambrian time, activated in the Permian and continued to subside in the Cretaceous (Kumar, 1985). The breakup of Gondwana at about 150 Myr resulted in the creation of two continents: Africa in the west and Madagaskar, the Seychelles, India, Antarctica, Australia in the east. As the dispersal of Gondwana progressed, Antarctica and Australia rifted from the other sub-continents at 128–130 Myr (Holmes and Watkins, 1992), and Madagaskar rifted from India at about 90 Myr. From 80 Myr to 55 Myr India drifted to the north with a speed reaching ~20 cm/year (McKenzie and Sclater, 1971; Negi et al., 1986). At 65 Myr it experienced Deccan volcanism which continued for about 1 Myr (Duncan and Pyle, 1988). The Deccan Traps occupy an area of 500,000 km^2 (Fig. 1) which makes them one of the largest provinces of continental flood basalts (Jay and Widdowson, 2008). The eruptive center was located to the northeast of Bombay (near seismograph station MUM in Fig. 1), where the accumulation of flood basalt is up to 3000 m (Hooper, 1990). The basalts were also accumulated at the bottom of the Arabian Sea, to the west of the Indian coast. The origin of the Deccan Traps is usually attributed to the passage of India over the Reunion hotspot (Morgan, 1981). At 55 Myr India collided with Eurasia (Rowley, 1996), but its northward motion is continuing at a lower speed.

Indian crust and upper mantle were investigated with all kinds of seismic techniques: wide-angle P-wave reflections (e.g., Kaila and Krishna, 1992), surface waves and surface-wave tomography (e.g., Bhattacharya, 1992; Mitra et al., 2006; Mohan et al., 1997; Priestley et al., 2006), P-wave tomography (e.g., Kennett and Widiyantoro, 1999; Van der Voo et al., 1999) and receiver functions (e.g., Gaur and Priestley, 1997; Gupta et al., 2003; Julia et al., 2009; Kumar and Mohan, 2005; Rai et al., 2003). The data on crustal thickness are generally compatible in different studies, but the models of the upper mantle are controversial. The uncertainty is so large, that, as noted by Oreshin et al. (2011), estimates of the S-wave velocities at the same geographic location and in the same depth range may differ by up to 20%, in a range between 4.8 km/s and 4.0 km/s.

---

* Corresponding author. Tel.: +7 499 2549325.
E-mail addresses: vinnik@ifz.ru, lpvinnik@gmail.com (L.P. Vinnik).

0040-1951/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.tecto.2013.02.023

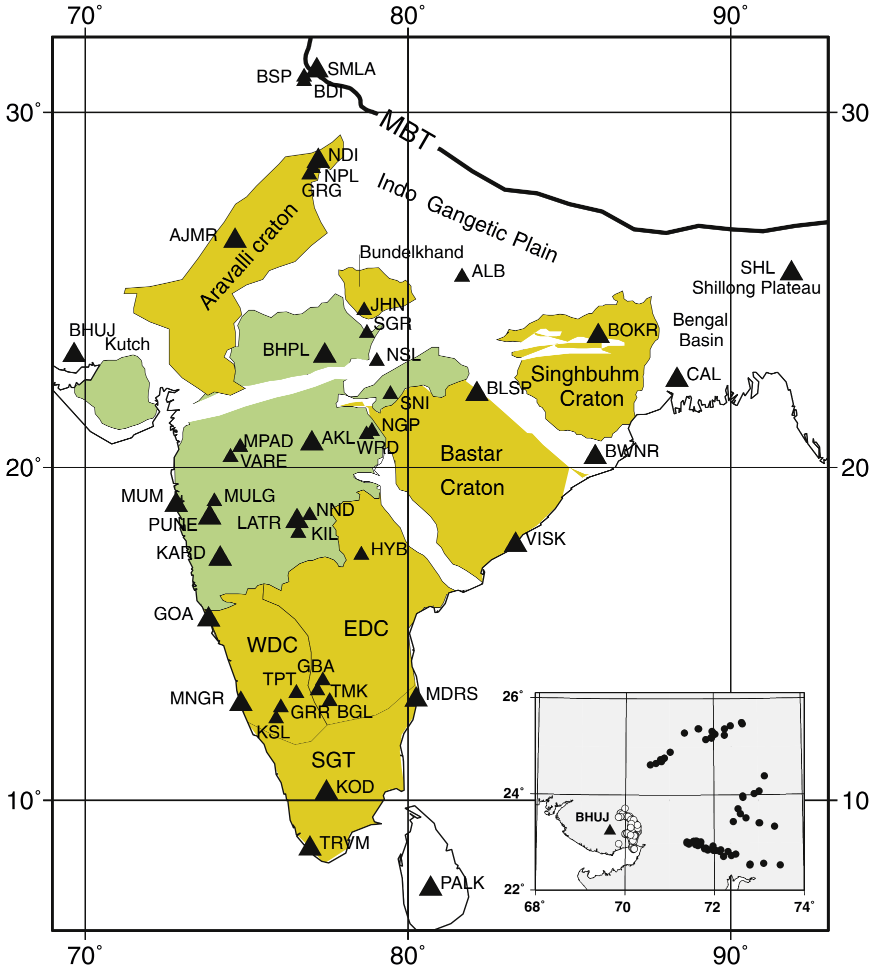


Fig. 1. Tectonics of the study region and seismograph stations. Cratons are brown; the Deccan Volcanic Province is green. MBT is the Main Boundary Thrust of the Himalaya. Stations, the records of which are processed in the present study and in previous studies are shown by large and small triangles, respectively. Inset: piercing points of PRFs (open circles) and SRFs (black circles) at a depth of 200 km for station BHUJ.

Seismic S-wave velocities in the upper mantle beneath the central and southern Indian shield are known to be anomalously low relative to those in typical shields of comparable age. An early indication of this anomaly was obtained by Chevrot et al. (1999) from the travel times of Ps converted phases from the transition-zone 660-km and 410-km discontinuities: these phases arrive to seismograph station Hyderabad (HYB) in southern India with a delay of 1.5 s relative to other cratons of comparable age. Relatively low S-wave velocities, ~4.4 km/s in a depth range from the Moho to ~180 km versus 4.7 km/s for a typical craton were obtained in the later receiver functions studies (Kiselev et al., 2008; Oreshin et al., 2011) mostly at the stations in a corridor between approximately 75° and 80°E, but higher velocities (up to 4.75 km/s) were reported in surface-wave studies (Mitra et al., 2006; Priestley et al., 2006). There are significant discrepancies in images of lateral velocity variations for the P waves (Kennett and Widiyantoro, 1999) and multi-mode surface waves (Priestley et al., 2006). These discrepancies may present a combined effect of differences in the wave types, methodologies and resolution. Structure of the transition zone displays some regularities apparently related to the presence of cold subducted lithosphere (e.g., Oreshin et al., 2011), but within the Indian shield the analysis so far was confined mainly to the stations in the corridor between 75° and 80°E.

Our study is an attempt to better understand the state of the Indian lithosphere and underlying mantle through accurate mapping of their seismic parameters with receiver functions. P receiver functions (PRFs) were used in a number of studies in India. S receiver functions (SRFs) present a relatively new technique. Application of this technique for mapping the lithosphere/asthenosphere was pioneered by Oreshin et al. (2002), and it has been demonstrated that, though the inversion of either P or S receiver functions is non-unique, the range of non-uniqueness is greatly reduced by simultaneous inversion of PRFs, SRFs and teleseismic travel-time residuals (Vinnik et al., 2004). The results of the simultaneous inversion are better constrained, more stable and more informative than separate inversions, and here we continue the series of studies in India based on these techniques (Kiselev et al., 2008; Oreshin et al., 2008, 2011; Vinnik et al., 2007).

Our results are obtained from the recordings of the IMD (India Metheorological Department) seismograph network of 21 stations (Fig. 1 and Table S1): (AJMR, AKL, BHPL, BHUJ, BLSP, BOKR, BWNR, CAL, GOA, KARD, KOD, LATR, MDRS, MNGR, MUM, NDI, PUNE, SHL, SMLA, TRVM, VISK). We also processed recordings of GSN station PALK in Sri Lanka. These data are complemented by previously published results of application of similar methods at other stations.

2. P receiver functions

Our methodology of calculations of P and S receiver functions (PRFs and SRFs, respectively) was described in detail elsewhere (e.g., Vinnik et al., 2007) and here we present it shortly.