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Shear-wave splitting in Eastern Indian Shield: Detection of a Pan-African suture separating Archean and Meso-Proterozoic terrains

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ABSTRACT

Based on fast axes orientation (ψ) and delay time (δt) measurements at fifteen broadband stations, the Archean Eastern Indian Craton (EIC) is classified into three main tectonic zones viz. Singhbhum-Odisha craton (SOC) [$\psi = (82 \pm 8)^\circ$ and $\delta t = (1.5 \pm 0.2)$s], Chotanagpur granitic gneissic terrain (CGGT) [$\psi = (63 \pm 9)^\circ$ and $\delta t = (1.4 \pm 0.3)$s] and Eastern Ghats mobile belt (EGMB) [$\psi = (70 \pm 10)^\circ$ and $\delta t = (1.3 \pm 0.2)$s]. The results in the Archean province of EIC depict a moderate to large delay times (1.0–1.9 s) with azimuths that reveals an upper mantle anisotropy with a mean orientation of ($74.5^\circ \pm 5.6^\circ$) sub-parallel to the E-W trending structural grain of the Archean craton, evidencing frozen lithospheric anisotropy. The direction of anisotropy (~N39° E) in northern Meso-Proterozoic CGGT is found to be consistent with the direction of current absolute plate motion of Indian plate. Regional variation of observed orientation of fast axes near the flanking Paleo- and late- Archean orogenic belts is attributed to the tectonic control rather than current plate motion. Nevertheless, estimated large mean delay times (1.41 ± 0.27 s) do also suggest a contribution from the anisotropy associated with asthenospheric mantle flow. Most interestingly, our study detects a transition zone (coinciding with the location of Damodar Graben) separating south (late Archean) and north (Meso-Proterozoic) CGGT across which the fast axes orientation changes from E-W ($\psi = 71^\circ$) to NE ($\psi = 39^\circ$), which could be evidencing the signatures of the eastward extension of Pan African (550–500 Ma) suture as also observed in Antarctica.

1. Introduction

The plate tectonic processes during the Archean or Precambrian were supposed to be different than that of the present day. The geological record of Eastern Indian shield covers more than 2 b.yr. of the Archean (3.6–1.0 Ga) (Misra, 2006). It comprises of the oldest 3.6 Ga Archean nucleus of Indian plate (i.e. Singhbhum-Odisha craton, SOC) in the south and late Archean Chotanagpur Granitic Gneissic terrain (CGGT) of 1.0–2.7 Ga in the north (Meert et al., 2010). It is believed that these two Archean provinces have undergone a subduction event in Archean; where the SOC subducted under the CGGT (Sarkar, 1982). Plate tectonic processes such as the Archean subduction should be manifest as anisotropic fossil fabrics preserved deep within the Indian lithosphere. However, vertical tectonic processes such as crustal delamination (Shalivahan et al., 2014) or plume activity (e.g., Behera et al., 2005) that are sometimes associated with a younger, hotter, more ductile Earth, would not be expected to impart such coherent measurable anisotropic fabric. In this paper, we investigate these different geodynamic models for the formation of eastern Indian shield through a shear wave splitting study of seismic anisotropy using waveform data from a new broadband seismic experiment in eastern Indian shield, which covers both Archean Singhbhum-Odisha craton (SOC) and Proterozoic Chotanagpur Granite Gneissic Terrain (CGGT), which occupies an area of 240,000 km^2 of the eastern Indian shield (Fig. 1a).

Shear wave splitting method using SKS/SKKS phases has been used to study the mantle anisotropy underlying continental and oceanic regions (Vinnik et al., 1984, 1992; Silver and Chan, 1988; Ando et al., 1983). In this method, splitting parameters are calculated from horizontal recordings of shear waves through searching for an azimuth of the fast shear phase and splitting time delay of the slow shear phase wherein the fast shear wave is assumed to be associated with the “fast” olivine axis of a peridotite mantle model with a horizontal orientation of the symmetry axis. Numerous studies showed that the estimated splitting parameters strongly depend on the back azimuths of arriving waves, which has been modeled as a model of a multi-layer approximation of upper mantle anisotropy (Silver and Savage, 1994). Several other techniques have also been proposed to model anisotropy (Babuska et al., 1993; Šílený and Plomerová, 1996). Studies through shear-wave splitting

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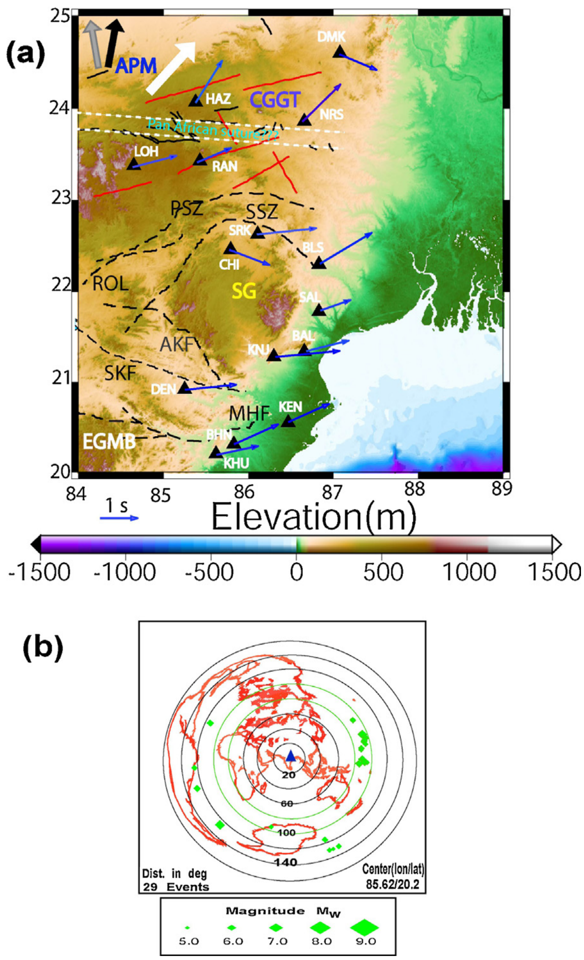

Fig. 1. (a) Splitting parameters superimposed on elevation map of Eastern Indian Shield. First anisotropic direction and delay times are marked by arrows. The big white and gray arrow indicate the direction of absolute plate motion (APM) of the Indian plate as obtained from the NUVEL1A global plate model in a no rotation frame and with a fixed Eurasian plate, respectively (DeMets et al., 1990) while the big black arrow marks the APM of Indian plate as predicted by the HS3-NUVEL1A global plate model (Gripp and Gordon, 2002). Solid black triangles mark the location of broadband seismograph stations. The inferred location of the eastward extension of the Pan-African suture is shown by white dotted lines. SKF, AKF, MHF, ROL, SSZ and PSZ represent Sukinda thrust, Ankul fault, Mahanadi fault and Roulkela lineament, Singhbhum shear zone and Purulia shear zone, respectively. (b) Epicentral locations of used events (marked by filled diamond symbols) relative to the center of the study area (shown by a filled triangle). The size of the diamond symbols depends on the magnitude of the events.

measurements have been reviewed by Silver (1996), Savage (1999), Park and Levin (2002) and Vecsey et al. (2008). Modified methods are also proposed for estimating splitting parameters from noisy data through stacking of misfit functions (Wolfe and Silver, 1998) or fitting of observed waveforms and anisotropic models (Menke and Levin, 2003). Vinnik et al. (1992) and Šílený and Plomerová (1996) proposed a generalized method to estimate splitting parameters in 3-D, using LQT coordinate system. Vecsey et al. (2008) have also used both cross-correlation (Bowman and Ando, 1987) and minimum energy (Silver and Chan, 1991; Vinnik et al., 1992) methods, using LQT coordinate system, for estimating splitting parameters in 3-D. Additionally, Vecsey et al. (2008) proposed the transverse minimization (TM) method for estimating robust and stable splitting parameters. However, the cross-correlation (Bowman and Ando, 1987) and minimum energy (Silver and Chan, 1991; Vinnik et al., 1992) are most popular and widely used methods for estimating upper mantle anisotropy until today. Thus, here we study the upper mantle anisotropy in the eastern Indian shield by estimating splitting parameters in 3-D, through both cross-correlation (Bowman and Ando, 1987) and minimum energy (Silver and Chan, 1991; Vinnik et al., 1992) methods, using LQT coordinate system.

2. Geological setting of Eastern Indian Shield

The Singhbhum Craton assumes significance because it is one of the oldest cratonic nuclei of the Indian landmass (Mukhopadhyay, 2001; Mukhopadhyay et al., 2008). The E-W elongate Archean nucleus of SOC consists of Singhbhum granite complex of 3.6 Ga that surrounded by volcano-sedimentary supracrustals and arcuate Proterozoic belt of Chotanagpur (Naqvi and Rogers, 1987; Sharma et al., 1994; Fig. 1a). The Singhbhum granite body extends more than 150 km in north-south and more than 70 km in east-west direction between latitude 21° N and 22.75° N and longitude 85.5° E and 86.5° E (Mukhopadhyay, 2001). In the south, SOC is bounded by more recent (∼117 Ma) Eastern Ghats mobile belt where the regional NE–SW to N–S structural trend rotates to an overall WNW–ESE to E–W orientation along the transition zone between the Singhbhum Craton and Eastern Ghats mobile belt (Crowe et al., 2003). This regional trend within the northern EGMB is evidenced by a second-generation foliation (Halden et al., 1982; Dobmeier and Raith, 2000). The regional features like North Singhbhum mobile belt (SMB), Sukinda fault, Dalma volcanic (2.8 Ga) and Purulia mobile belt also show an E-W orientation (Ghosh and Sengupta, 1990). Thus, it is apparent that the dominant trend of regional Archean features in SOC is E-W.

The region lies in the northern part of SMB is known as the late Archean CGGT consisting 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 Singhbhum Craton range from 900 Ma to 3.3 Ga while the age constraints for the CGGT vary from 1500 to 800 Ma on the basis of 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 Eastern 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 supracrustal 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 volacanism viz. Dalma and Dhanjori groups. Following subsequent major metamorphism at 2.5 Ga, the crustal growth of the CGGT took place mostly between >2.3 Ga and 1.0 Ga. Thus, the center of crustal growth in Singhbhum-Chotanagpur area gradually migrated from the Singhbhum Craton to northwards from Paleoarchean to Mesoproterozoic period (Misra, 2006).

It has been inferred, based on the recent reconstructions of the Early Cambrian architecture of East Gondwanaland, that the Pan African (550–500 Ma) Prydz Bay suture in Antarctica extends in the eastern Indian Precambrian Shield (Boger et al., 2001; Powell and Pisarevsky, 2002; Harley, 2003; Fitzsimons, 2003). From Fig. 1a of Maji et al. (2008), we notice that this inferred suture line passes through a region that located north of Ranchi in CGGT. Further, Chatterjee et al. (2007) suggested that this suture has some vestigial signatures in northeastern India. Thus, some signatures of this suture should be present in Eastern India, in general and CGGT, in particular. However, thermo-chronological data from the eastern fringe of CGGT (Maji et al., 2008) and central Indian tectonic zone (CITZ), located to the west of the CGGT (Roy et al., 2006), rules out any possibility of Pan African high-grade metamorphism in this areas. Nevertheless, we feel that some signature of this Pan-African