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Crustal shear-wave velocity structure beneath Sumatra from receiver function modeling

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ABSTRACT

We estimated the shear-wave velocity structure and Vp/Vs ratio of the crust beneath the Sumatra region by inverting stacked receiver functions from five three-component broadband seismic stations, located in diverse geologic setting, using a well known non-linear direct search approach, Neighborhood Algorithm (NA). Inversion results show significant variation of sediment layer thicknesses from 1 km beneath the backarc basin (station BKNI and PMBI) to 3–7 km beneath the coastal part of Sumatra region (station LHMI and MNAI) and Nias island (station GSI). Average sediment layer shear velocity (Vss) beneath all the stations is observed to be less (~1.35 km/s) and their corresponding Vp/Vs ratio is very high (~2.2–3.0). Crustal thickness beneath Sumatra region varies between 27 and 35 km, with exception of 19 km beneath Nias island, with average crustal Vs ~3.1–3.4 km/s (Vp/Vs ~1.8). It is well known that thick sediments with low Vs (and high Vp/Vs) amplify seismic waves even from a small-magnitude earthquake, which can cause huge damage in the zone. This study can provide the useful information of the crust for the Sumatra region. Since, Sumatra is an earthquake prone zone, which suffered the strong shaking of Great Andaman–Sumatra earthquake; this study can also be helpful for seismic hazard assessment.

1. Introduction

The Sumatra region, one of the most seismically active zones on earth, has produced three of the largest mega-thrust earthquakes in the past decade along different segments, the 26th December 2004, devastating Andaman–Sumatra earthquake of Mw ~9.1; the 28th March 2005, Nias earthquake of Mw ~8.7 (Ammon et al., 2005; Lay et al., 2005; Konca et al., 2007; Lange et al., 2010; Harmonn et al., 2012) and the 12th September 2007, Benkulu earthquake of Mw ~8.5 (Konca et al., 2008). These great earthquakes have ruptured most of the segments of the fault that have produced earthquakes of similar magnitude over the past 300 years, except one remaining segment of the fault, centered on Siberut Island. This segment produced an earthquake of Mw > 8.7–8.9 in 1797 but has not ruptured since (Chlieh et al., 2008).

Many of the techniques for quantifying seismic hazards, such as ground-motion simulations and earthquake locations, require realistic earth models as an input (Magistrale et al., 2000). However, very little is known about the crustal and upper mantle shear wave velocity structure of the whole region from global surface wave studies with very poor resolution (Ritzwoller et al., 2002).

For the Sumatra region, velocity data is available in the form of low-resolution global data sets such as CRUST1.0 (Laske et al., 2013). In recent years extensive reflection seismic studies in the region were carried out by different researchers, namely, Kopp et al. (2001), Singh et al. (2008), and Franke et al. (2008) to image the uppermost crust (10–20 km) of offshore Sumatra, the previously published receiver function study by Kieling et al. (2011), Macpherson et al. (2012), and ambient noise study by Harmonn et al. (2012). In addition to these studies, an effort has been made for details investigation of shear-wave velocity structure beneath the Sumatra region by applying Receiver Function (RF) analysis to the new data set recorded at five broadband seismographs (Fig. 1). The additional dataset presented in this paper provides new information constraining shear-wave velocity structure beneath the study region.

2. Geologic and tectonics

The island of Sumatra lies along the southwestern boundary of the Sunda Craton (Sundaland), forming an Andean continental margin (Fig. 1) (Milsom, 2005). The geology of the region is characterized by forearc and backarc basins associated with the subduction front. These basins are filled primarily with sedimentary and volcanic material of Tertiary age (Barber et al., 2005). Pre-

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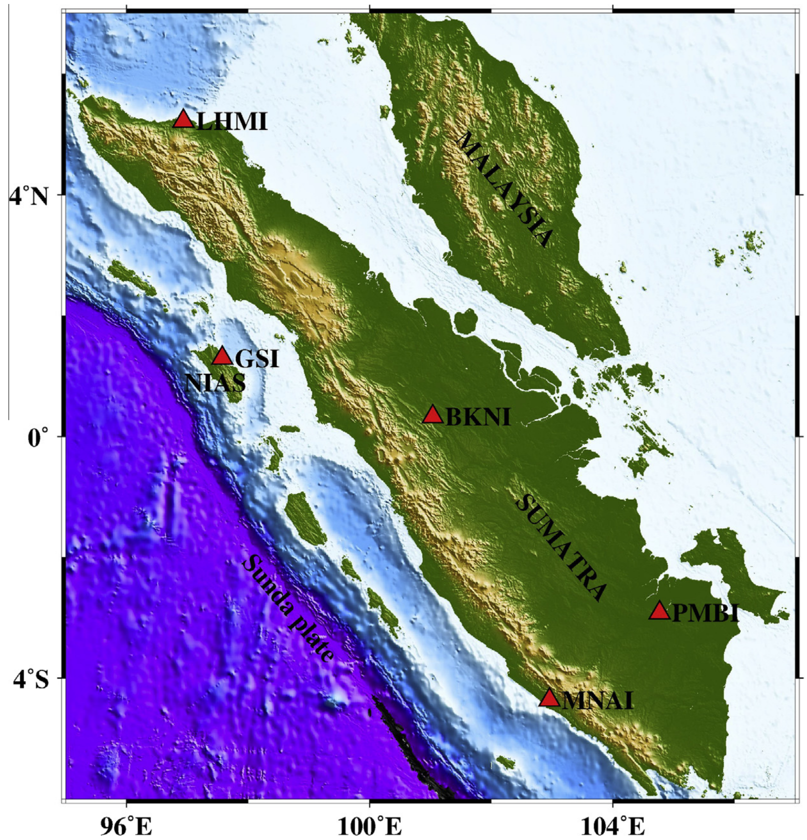

Fig. 1. Map of the study region. Red triangles denote the location of the station. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Tertiary basement crops-out in the Barisan mountains, where it is often overlain by recent volcanic deposits.

The seismotectonics of the Sumatra region are dominated by the Sunda megathrust, caused by subduction of the oceanic Indo-Australian plate underneath the Sunda plate, which started during the Cretaceous (~100 Ma) (Hamilton, 1979). It extends about 6000 km from the Andaman Islands in the north-west to the Lesser Sunda Islands in the south-east. Continuing subduction is attested by a Wadati-Benioff Zone (WBZ) that extends to depths of the order of 200 km (e.g., Newcomb and McCann, 1987; Milsom, 2005), and by volcanic activity in the Barisan mountains, the peaks of which generally lie within a few tens of kilometers of the coast. Convergence vectors vary considerably along the Sumatran portion of the Sunda arc due to the east African location of the pole of rotation as indicated by geographic positioning system data (Larson et al., 1997). The strike-slip component of motion induced by this oblique convergence is accommodated by the great Sumatran fault, a right lateral fault running the length of Sumatra along the spine of the Barisan Mountains (Sieh and Natawidjaja, 2000). The complex Sumatran platelet, or sliver, between the trench and the great Sumatran fault contains the forearc basins and forearc ridge, and is considerably deformed. Another trench-parallel right-lateral fault system, the Mentawai fault, whose trace runs along the outer edge of the forearc basins, accommodates additional strike-slip motion and may delineate the boundary between the accretionary complex and continental backstop (Diament et al., 1992).

3. Data analysis

In this study, we use seismological data recorded by five seismic stations on the island of Sumatra (LHMI, BKNI, MNAI and PMBI) and one (GSI) on the island of Nias (Fig. 1) during the period 2014. These five broad-band stations are part of the GEOFON network GE, operated by GFZ-Potsdam and they occupy diverse geologic environments, with station GSI being located on the forearc ridge while stations PMBI, BKNI and LHMI sit atop backarc basins. The coastal station MNAI is situated on the edge of a forearc basin. Details of the stations and their locations are presented in Table 1.

In our study, over 100 three-component seismograms are used from earthquakes of magnitude ⩾5.5 with epicenter distance between 30° and 95°, and have clear P-wave arrivals. However, many of these recordings contained low signal to noise ratios, and were discarded if the deconvolution did not produce a reasonable receiver function. In receiver function computation waveform are filtered using Butterworth high pass filter with a corner frequency of 0.02 Hz and then decimated to 20 samples per second. The waveform data are then cut to a length of 150 s (30 s prior to P-wave arrival and 120 s post length) and the mean (D.C. effect) and the trend (tilt in the base line) are removed from the waveform. Those waveforms are used to calculate receiver function. Fig. 2 shows the earthquakes (red star) recorded by the seismic stations (black triangle), used in our study to find the crustal structure beneath Sumatra.

Table 1
Location of all the seismographs used in this study.

Station code	Longitude (°E)	Latitude (°N)	Elevation (m)
GSI	97.58	1.30	107
BKNI	101.04	0.33	51
LHMI	96.94	5.22	3
MNAI	102.96	−4.36	154
PMBI	104.77	−2.92	30