Sediment and Crustal Structure Beneath East Kalimantan and East Java, Indonesia From Receiver Function

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Abstract. We investigate the sediment and Earth's crustal structure beneath the East Kalimantan and East Java by modelling the stacked receiver function from six seismic broadband stations belong to the Meteorology, Climatology and Geophysics Agency of Indonesia (BMKG). The calculation of receiver functions from 60 teleseismic earthquake events using iterative time-domain deconvolution method. Inversion result shows a significant variation in the sediment layer thickness from 1 km to 4 km beneath East Java. It is correlated with the South East Java basinal area (station KRK) and the North East Java Basin (station GRJI and BWJI). The sediment layer of about 5 to 10 km beneath East Kalimantan is associated with the Kutai Basin (station SGKI, SMKI, and BKB). Average Sediment layer shear velocity (Vs) beneath all station is observed to be less than 2.31 km/s. Crustal thickness beneath East Java varies between 20 to 40 km and 34 to 50 km beneath East Kalimantan, with average crustal shear wave velocity, Vs 4.60 km/s.

1. Introduction
Indonesia (Fig. 1) has many basinal areas as a producer of oil and gas fields, such as East Java and East Kalimantan. The basinal area in East Java is located on the Northside and includes a large area encountered with various types of basin areas [4]. Likewise, East Kalimantan is also an abundant hydrocarbon producing region [5]. Geophysical measurements with seismic methods can help to determine the geological conditions below the surface in the area. Although from stratigraphic, seismic, and well drilling data are available in this area, investigations into deeper structures up to the depth of the crust structure are still limited.

Geological mapping for subsurface structures can be done by observing the propagation of seismic waves from earthquakes. When an earthquake signal is recorded at an observation station, this data contains information about the source, the propagation through the Earth's material and the local structures under the seismic station. In this study, we present the use of earthquake data recorded on a single station, known as the receiver function to model the local structure below the station. This method uses the P-wave phase and the S-wave conversion from a distant (teleseismic) earthquake recorded by three components seismometer. Assuming that the vertical component behaves as the wavelets, the reflection coefficient under the observation station can be calculated by deconvolving the rotated horizontal component with the vertical component known as the receiver function method [1][15]. Receiver function studies have been done in several regions of Western Indonesia, i.e. in
Sumatra [10], West Java [3], Central and East Java [2][16]. However, the detailed sediment and crustal structure in East Java and East Kalimantan with the receiver function method needs to be examined further, especially for tectonic studies in the area.

2. Methodology

We use the seismogram records from IA network operated by BMKG with support from GFZ-Postdam from six stations in East Kalimantan and East Java. These stations are located in a different basinal area. The stations BKB, SMKI, and SGKI are associated with the geological environment of the Kutai Basin, while the KRK station is correlated with the South East Java basin area, and the GRJI and BWJI stations are located in the North East Java basin zone. The selection of observational data is in the form of 60 earthquake events with moment magnitude criteria $\geq 6.0$ and epicentre distance of 30°-90° in the 2015-2019 period, as shown in Fig. 1. This large-scale earthquake event can provide a good signal for recording at the observation station.

![Figure 1](image_url)

**Figure 1.** Location of the six IA stations in the East Java and East Kalimantan. Teleseismic events that were used to calculate the receiver functions are shown in the upper right inset. The basinal area are from Geological Agencies [4].

Seismometers have recorded data consists of three components, namely the Z (vertical), N (North-South), and E (East-West). Rotation to the radial component is the first step that must be done before further receiver function calculation. Rotation utilizes a simple 2D rotation of coordinate transformation, converting two horizontal components into radial (R) and transverse (T) components.

We use an iterative time-domain deconvolution technique to calculate the P-wave receiver functions [9]. Then, this study selects the wave signal in radial and vertical components with a window time of 10 seconds before the P-wave onset time and 30 seconds after the P-wave arrival time. This
technique is a way to minimize the difference in observational data of radial components with synthetic data generated from the convolution of vertical components iteratively. This calculation applies a Gaussian filter with a width of 2.5 that filters frequencies of 0.75 Hz. Gaussian selection can eliminate high-frequency noise in seismogram data and can also produce suitable waveforms. Then, the receiver function response in the radial of each earthquake is selected based on the best wave phase response and is made stacking (Fig. 2(a)). Stacking is a way to improve the quality of seismic signals by adding up the signals for each earthquake events. Furthermore, the process of making a medium-velocity model of the Earth in 1-D refers to Herrmann [7]. The initial model of this study used the AK135f velocity model and the observation data in the form of wave stack data generated from each observation station.

![Figure 2](image)

Figure 2. (a) Radial receiver functions plotted with increasing back azimuth for station BKB. Ps Moho is marked by a green dashed line, and PpPs are marked by a blue dashed line. (b) The plot of stacked receiver functions from different stations. Average back azimuth (B in degrees, blue colour) and the number of receiver functions (N, green colour) for each station.

3. Result and Discussion

The receiver function response from each station is shown in Fig. 2(b). The difference in the results of these waveforms reflects the variation of the geological conditions beneath each station. First, we examined stack receiver function at station KRK, GRJI, and BWJI located in East Java. The stacked receiver function for the KRK station shows two distinct conversions at 1.5 s and (5.5-7.5) s. The positive phase observed at 1.5 s is the P-to-S conversion from the sediment layer (Pss), which suggests a thick sediment layer beneath the South East Java basin. The observed 4.5 s phase may according to the P-to-S (Ps) conversion from Moho and multiple (PpPs) is visible near 15.0 s. At station GRJI, the stacked waveform shows complex shapes that correspond to the converted signals at 0-3.5 s and 5.5 s, due to the presence of a low-velocity layer near the surface North East Java Basin. A large amplitude at 1.5 s signal corresponds to the phase of the Pss as the conversion from the sediment layer. The signal at 13.0 s dan 15.0 s could be the PpPs multiple of Ps at 3.5 and 5.5 s, respectively. Receiver function at station BWJI show complex waveform with a P-wave phase with a low amplitude and the Pss sediment phase with a large amplitude at the 1.0 s. Similar characteristics of low amplitudes and complex waveforms the first few seconds are also observed at stations GRJI because this station is also located in the North East Java basin area. Then, the Ps Moho phase is seen in the signal at 5.0 s, and multiple PpPs are found from 12.5 s. The receiver function for station BKB shows a peculiar characteristic of the large-amplitude P phase, with Ps-wave arrival is separated from the first arrival by a very deep trough. The receiver function shows prominent conversions at 3 s and a large amplitude at 7.5 s. The signal at 11.5 and 13 s could be the PpPs multiple of Ps at 3 and 7.5 s. At station SMKI, the receiver function response generates a phase wave with a signal of 8.5 s and 12.0 s which correspond to PpPs wave conversion and Ps at 4.0 s and 6.5 s, respectively. For station SGKI, show the PpPs multiple signals at 10.5 s and Ps at 2.5 s. The signal at 15.5 s could be the PpPs multiple of Ps at 5.5 s. Station BKB, SMKI, and SGKI are located in the Kutai Basin, which shows the same waveform...
characteristics, and we speculate that the large negative amplitude excursions, as well as the broadness of the arrivals, indicates the presence of a near-surface low-velocity layer in above the Kutai Basin.

Figure 3. The inversion results obtained for all six stations. (a) station SGKI, (b) station SMKI, (c) station BKB, (d) station BWJI, (e) station GRJI, and (f) station KRK. Left panel: the observed and calculated receiver functions are plotted in the blue and red lines, respectively. Right panel: red is the initial model, iteration model, the blue is the final model, sediment thickness (H1), and crustal thickness (H2).

S-wave velocity model for stations in East Kalimantan and East Java are shown in Fig. 3. The velocity characteristic for the sediment layer is represented by a low shear-wave velocity from the surface. Interpretation suggests the crustal thickness by observing a sudden change in the shear velocity, and we limit to a value of Vs 4.5 km/s for the mantle velocity. Inversion result for receiver function in station SGKI indicates the sediment thickness of about 10 km with sediment layer has Vs of 2.13 km/s and crustal thickness of about 34 km corresponding with Vs 4.47 km/s. At station SMKI, the S-wave velocity is 2.42 km/s down to about 5 km depth, and the crustal layer is estimated at a depth of 50 km with the Vs of 4.40 km/s. At station BKB, We obtained low-velocity layer to ~2.12 km/s indicating sediment layer of about 10 km and characteristics of gradual increase of velocity 4.57 km/s indicating crustal layer at thick of about 46 km. Modelling for station BWJI on the island of
Bawean show about 2 km thick sediment layer with Vs 1.71 km/s and followed high-velocity layer from the depth of 8 to 18 km of Vs > 4.5 km/s. We suggest this high velocity is related as the intrusion rock below from old volcanism below the Island [11]. Crustal thickness is estimated at 40 km, with velocity Vs of 4.50 km/s. Inversion results for station GRJI show a 4 km layer thickness of Vs 2.10 km/s and followed by a gradation of Vs 4.60 km/s at 22 km indicating crustal layer. At station KRK, we obtained low-velocity layer Vs 3.40 km/s of 1 km thick near the surface indicate a sedimentary layer and estimated crustal thickness to be about 20 km with Vs of 5.0 km/s.

Fig. 4 is the result of interpretation under the territory of East Java and East Kalimantan. This model shows the relationship of sedimentary layers with relatively shallow thickness from the South direction and getting thicker towards the North, while the crust layer shows relatively thin thickness from the South and thickened in the middle (station BWJI, BKB, and SMKI), and thinning back towards North or below the SGKI station. Satyana et al. [13] published his study that estimated thickness of tertiary sediments in the Kutai basin with a range of 10-11 km. Other research, the tomography method shows the suspected sedimentary layer in the southern Mount zone which is associated with the South East Java basin is dominated by higher Vs, and the Rembang zone which is correlated with the North East Java basin is dominated by moderate Vs [12]. In addition, the CRUST 1.0 model shows sediment thickness for the Kutai basin area with a thickness of ~ 8 km, the North East Java basin area ranges from ~ 4 km and the South East Java basin around 1 km, while the crust layer shows a relatively shallow thickness around 28 km from the south side Java island to the North of Borneo island is getting thicker around 30 km [8]. So, the results of the present study show results that are consistent with previous studies.

![Figure 4](image)

**Figure 4.** Interpretation of the subsurface model obtained from this study in the area of East Java and East Kalimantan. Red curves show the 1-D shear wave velocity profile obtained from inversion receiver function at IA global network stations.

### 4. Conclusions

We estimate the thickness for the sedimentary layer beneath East Java to be around 1-4 km with an average velocity of Vs ~2.40 km/s and crustal layer with an average velocity of Vs 4.70 km/s at a thickness of 20-40 km. While the sedimentary layer for East Kalimantan is the thickness of 5-10 km thick with an average velocity of Vs ~ 2.22 km/s and thickness crust is at 34-50 km with an average of Vs 4.48 km/s.

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