Evidence of subduction zone segmentation: Finite-difference tomography and earthquake relocation along the Java margin

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Abstract

The Java margin is part of the 5600 km long Sunda Arc subduction zone that extends from Sumatra to the Lesser Sunda Islands and is dominated by earthquakes with magnitude less than 7. Although several 7.0 [?] Mw < 8.0 earthquakes have occurred, there has been an absence of Mw>8. Previous earthquake relocation studies have mainly focused on the ml [?] 4 earthquakes, while seismic tomography studies have mainly focused on the volcanic system in Central and East Java. In this study, we aim to image the entirety of Java margin to investigate segmentation along this margin. We use the arrival time dataset from 2009 – 2018 collected from 44 stations in the BMKG national seismic network to relocate earthquakes and invert for seismic velocity structure along the Java margin using a finite-difference tomography algorithm. A total of 6041 earthquakes, 68250 P- and 22795 S-phases, ml 1.9 – 7.5, were included in the inversion, resulting in 4883 high-quality relocations. The distribution of relocated events shows several isolated clusters of seismicity at the trench, which are distributed nearly vertical, from the near-surface to 80 km depth. Feature with Vp/Vs ˜ 1.73, which higher compared to value along the trench, coincides to one of the isolated clusters. Gaps are observed between bands of seismicity at the trench and beneath the forearc region. The seismicity is distributed surrounding or between the high anomalies of residual bathymetry which represent the structure of the subducting slab. Beneath the forearc, bands of seismicity are observed between 30 – 80 km depth and below 100 km depth. Their distribution reveals a steeper slab geometry relative to previously published slab models (Slab 1.0 and Slab 2.0). Several features with Vp/Vs < 1.70 and higher Vp and Vs than the surrounding area coincides with the bands of seismicity observed between 30 – 80 km depth. Shallow structure is also well defined by the earthquake relocations outlining three major faults (Cimandiri, Kencana-Rakutai faults, and an unnamed fault located east of Opak fault). The relocation results and velocity structure show that the distribution of seismicity along the subduction zone is segmented. This segmentation is likely related to the structure of the subducting plate.

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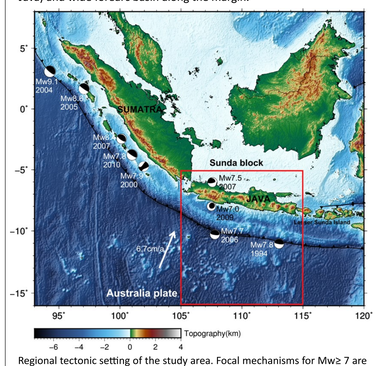
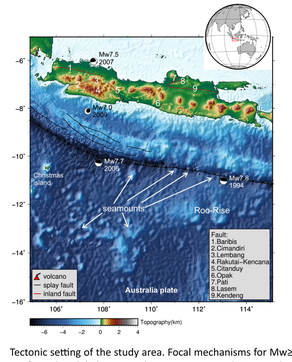
1.Regional Tectonic Setting of Java

- Java margin is part of 5600 km of the Sunda Arc subduction zone that extends from Sumatra to the Lesser Sunda Island. The Australia plate converges to the Sunda block from N11°E off the western Java to almost normal to the trench in central and eastern Java.
- Rough subducting plates consist of seamounts and Roo-Rise, accompany the incoming of Australian plate to the Java trench affecting the deformation in trench and the forearc, and seismicity of the margin.
- The deformation includes frontal erosion, shortening and steepening of the frontal slope, uplift of forearc ridge, landward retreat of accretionary wedge create faults and features along the margin (e.g. splay faults on the outer forearc along the western and central Java) and wide forearc basin along the margin.



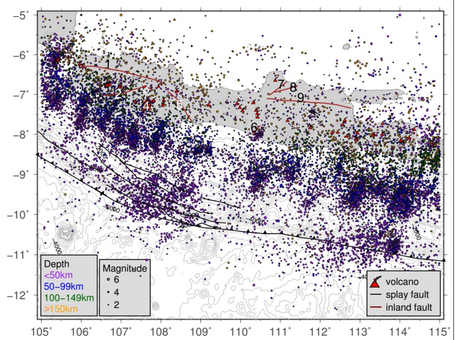
Regional tectonic setting of the study area. Focal mechanisms for Mw≥ 7 are from the Global CMT catalog. The area in the red box is enlarged in the next figure.



Tectonic setting of the study area. Focal mechanisms for Mw≥ 7 are from the Global CMT catalog. Seamounts and Roo-Rise locations are from Masson et al 1990 and Kopp et al 2006.

2. Seismicity of Java

- Seismicity along the Java margin is dominated by M <7 earthquakes and no Mw ≥ 8 earthquakes for the last 300 years. There are several 7.0 ≤ Mw < 8.0 earthquakes located either shallow than 50 km depth or deeper than 75 km depth.
- Seismicity along the Java margin appears to be segmented along the margin. Seismic events at or near the trench separates from seismicity at the forearc region.
- Stripping-lines seismicity pattern along the coastline followed by less-intense seismicity area. A wide less-intense seismicity area is observed off the coast of central Java. This seismic pattern is likely caused by a complex structure along the trench and forearc associated with a rough subducting plate and/or southern volcanic chain in the island arc.
- Seismicity on the island arc outlined crustal faults or features near the faults.



Seismicity of Java from 1921—2018 from ISC and BMKG (local permanent network) catalogs. Fault names refer to fault legends on the map in the upper panel. Seismicity is sized by the magnitude and colored based on depth.

3. Finite-Difference Tomography

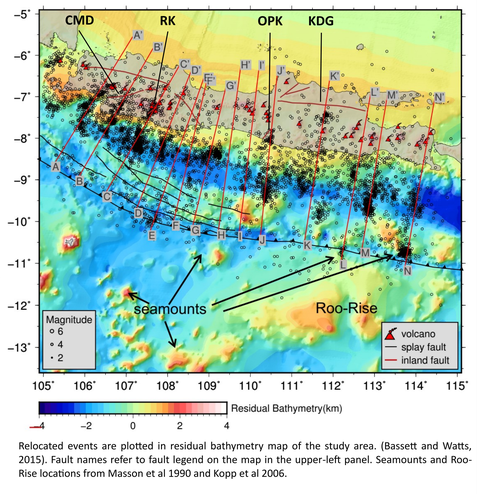
FDtomo algorithm employs arrival time data set and a 1D velocity starting model to iteratively create a 3D velocity model and updating earthquakes hypocenters.

- Using arrival time data recorded by 44 stations from 2009—2018 BMKG catalog, a total of 4942 seismic events (54796 P-phase and 22269 S-phases) within 400 km depth with a range of magnitude of ML 1.9—7.5.
- FD tomography process is done for 6 iterations in fine grid spacing of 5km cube, consisting of 203 x 153 x 84 nodes.
- A 1D P—velocity model of 0—400km depth (Kaulakov et al 2007, Kenneth and Engdahl, 1991, Wagner et al 2007) with constant Vp/Vs = 1.77 is used as a starting model.

- Total of 4782 seismic events are successfully relocated and their distribution refines the seismicity pattern along the margin.
- Few isolated clusters are observed at the trench (e.g. transect E, L and N) and this isolation appear to be associated to subducting seamounts or Roo-Rise south of the trench (represent as high residual bathymetry (up to 1.5 km heights)).
- High residual bathymetry (1—2 km heights) associated with complex forearc structures separates seismicity at the trench to seismicity at the forearc region.

- Stripping pattern of seismicity along the coastline (e.g. transect A, B, D,G, M) likely related to the variation of near-coastline structures caused by complex forearc deformation and/or southern volcanic chain in island arc. A wide less-intense seismicity area off the coast of central Java is likely associated with the southern volcanic chain in island arc.

- Seismicity on the island arc outlines several faults (Rakutai-Kencana (RK) fault, an unnamed fault located east of Opak (OPK) fault) and features near the Cimandiri (CMD) and Kendeng (KDG) faults.

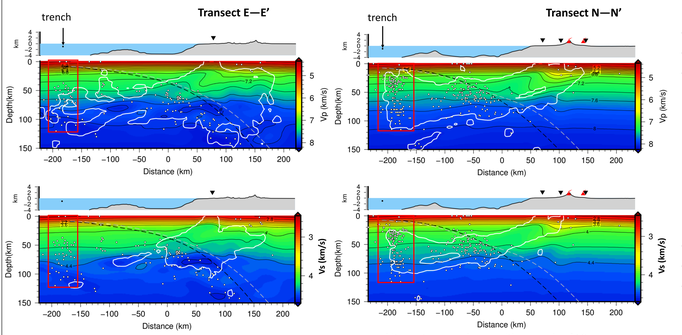


Relocated events are plotted in residual bathymetry map of the study area. (Bassett and Watts, 2015). Fault names refer to fault legend on the map in the upper-left panel. Seamounts and Roo-Rise locations from Masson et al 1990 and Kopp et al 2006.

4. Result:

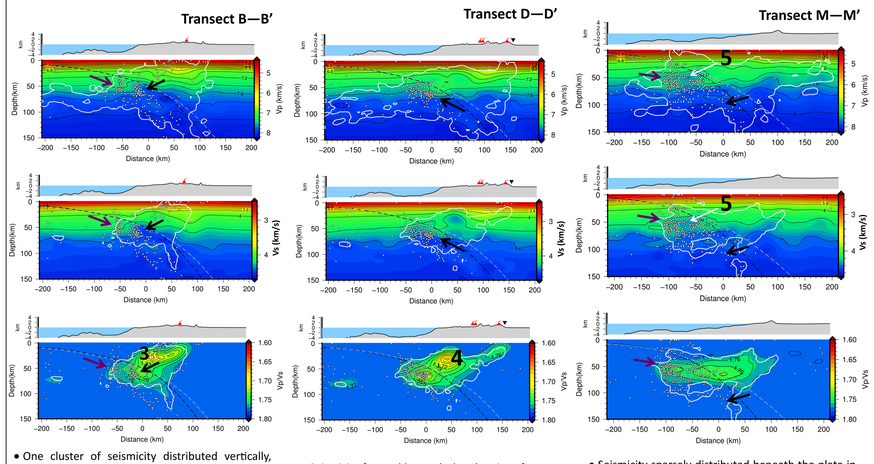
a. Cluster of seismicity at the trench

- Seismicity is distributed nearly vertical, from the near surface to ~120 km depth (red boxes in the cross-sections).
- The seismicity collocated with feature of Vp/Vs > 1.75, where the seamounts (feature 1) and Roo-Rise (feature 2) observed.
- Seismicity at trench is separated to seismicity in the forearc region.
- Subduction of seamounts and Roo-Rise appears to influence this particular seismicity distribution.



- white contours mark area with a sample of 10 or more rays

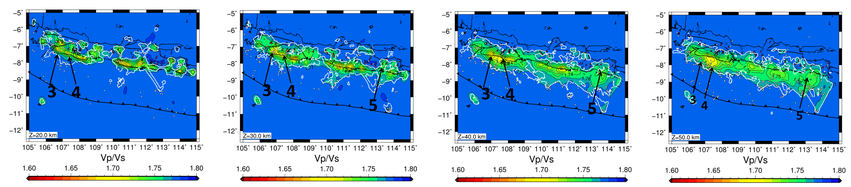
4b. Seismicity beneath the forearc region



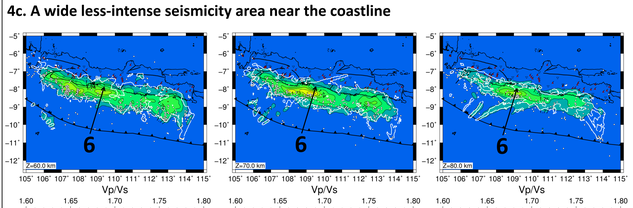
- One cluster of seismicity distributed vertically, from 20 to 60 km depth (purple arrow).
- Another cluster (black arrow) collocated with a feature of high Vp, Vs and higher Vp/Vs than surrounding. This feature is associated with subducting slab structure.
- Seismicity at 40—120 km depth reveal a steeper slab geometry compared to Slab 1.0 and Slab 2.0 models.
- Feature on the upper plate (a lower Vp/Vs than surrounding—feature 3) separate seismicity at the plate interface to shallow seismicity beneath the coastline.

- Seismicity focused beneath the plate interface mode (black arrow), from 30 to 80 km depth.
- Seismicity below 80 km depth reveals a steeper slab geometry compared to Slab 1.0 and Slab 2.0 models.
- Feature with high Vs and lower Vp/Vs than surrounding (feature 4) limit the distribution of seismicity toward shallow depth. This feature represents structure on the overriding plate.

- Seismicity sparsely distributed beneath the plate interface mode (black arrow), from 10 to 100 km depth.
- Seismicity below 100 km depth reveals a steeper slab geometry compared to Slab 1.0 and Slab 2.0 models.
- Feature with lower Vp/Vs and higher Vp and Vs than surrounding (feature 5) limit the distribution of seismicity toward the coastline. This feature represents structure on the subducting plate.

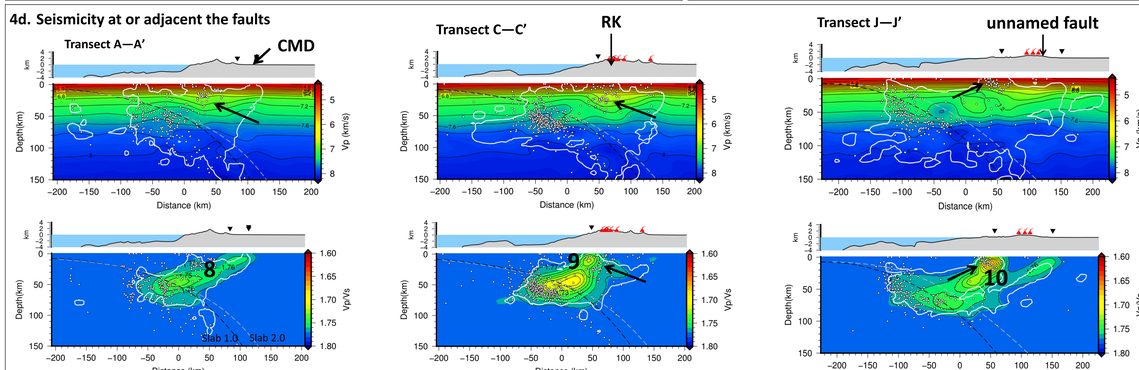


4c. A wide less-intense seismicity area near the coastline



- Less-intense seismicity area characterized with high Vp/Vs value, ranges between 1.75 – 1.77 (feature 6).
- Seismicity starts to appear at the southern boundary, coincides with lower Vp/Vs feature.
- The high Vp/Vs features likely limit the seismicity toward the inland area. This feature is likely associated with the southern volcanic chain in the island arc which continued to the northern edge of Java basin.

4d. Seismicity at or adjacent the faults



- Seismicity outlines a feature west of the Cimandiri (CMD) fault. Seismicity distributed from above plate interface toward shallow depth with range of magnitude ML 2.1—4.8.
- It coincides with a feature of Vp/Vs < 1.70 and higher Vp than the surrounding (feature 8) which represents an upper plate structure.

- Seismicity outlines the Rakutai—Kencana fault. Seismicity distributed from near surface to ~40 km depth with range of magnitude ML 2.4—5.2.
- A feature with Vp/Vs > 1.70 and lower Vp than the surrounding (feature 9) separate this seismicity to the plate interface seismicity. This feature represents an upper plate structure.

- Shallow seismicity outlines an unnamed fault east of Opak fault.
- Seismicity distributed from near surface down to 20 km depth with range of magnitude ML 2.5—3.6
- This shallow seismicity crossing a Vp/Vs < 1.70 feature (feature 10).

- A nearly vertical seismicity outlines a feature south of the Kendeng (thrust) fault (black arrows). It distributed from near surface down to ~70 km depth with a range of magnitude ML 2.4—4.0.
- A feature of Vp/Vs > 1.70 and lower Vp than surrounding (feature 11), south of this seismicity separates shallow seismicity to seismicity at the plate interface.

Conclusion

- The relocation results and velocity structure show seismic segmentation along the strike. Seismic segmentation observed between trench and forearc region, and along the coastline.
- Seismicity at the trench related to the rough subducting plate (e.g. seamounts and Roo-Rise). The seismicity near the trench is separate to the forearc seismicity by complex forearc structure as a result of deformation by the rough subducting plate.
- Seismic distribution along the coastline caused by the variation of near-coastline structures as the result of complex forearc deformation and/or southern volcanic chain in island arc.
- The upper plate structures separate the shallow seismicity and bands of seismicity adjacent to the plate interface and/or beneath the forearc.
- Several bands of seismicity beneath the forearc are distributed nearly vertical and seismicity deeper than 50 km depth reveals a steeper slab geometry compared to Slab 1.0 and Slab 2.0 models.
- Inland seismicity outlines crustal faults and features near the faults.

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