Reviewing the characteristics of slip behaviour for megathrust earthquake at Sumatera using vertical derivative of GOCE satellite gravity field

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Abstract. The review of the seismogenic zone characteristics associated with the earthquake rupture process in the Sumatra Subduction Zone has been carried out by various methods. This zone has experienced several major earthquakes; Aceh 2004 Mw=9.1, Nias-Simeulue 2005 Mw=8.6, Bengkulu 2007 Mw=8.5, and Enggano 2000 Mw=7.9. This study focuses on the relationship between density contrast analysis based on gravity data from the GOCE satellite and the slip distribution in four major earthquake rupture zones. Satellite gravity data processing is carried out to obtain data for Gravity disturbance (Gd) and vertical gravity derivatives (Tzz), corrected by topography and sediment effects with different spectrum decomposition to get gravity maps with different depths. Based on the Tzz analysis, the maximum slip of the earthquake rupture is correlated with the minimum Tzz pattern and low-density contrast. In contrast, the rupture ends at the maximum Tzz pattern and high-density contrast. Tzz pattern and Gravity disturbance can describe the barrier and asperity of the Sumatra subduction zone. The schematic maps portray the seismic segmentation of Sumatra Subduction, which have asperities zone along the subduction strike associated with the minimum Tzz and associated with the forearc zone, as well as the barrier related to the maximum Tzz, which is a manifestation of structures (fracture zone and seamount) that are subducted to the oceanic plate.

1. Introduction

The characteristic review of the seismogenic zone associated with the rupture process during an earthquake has been carried out from various studies. Bilek and Lay (1999) previously studied the attributes in the depth-to-depth rupture process and the spatial heterogeneity, and Lay et al. (2012) introduced four-character domains with different seismic radiation characteristics by focusing on variations in the energy drop in a short time along with the dip [2][10]. This model is the main framework in determining the risk for large megathrust earthquakes [14]. Mapping this heterogeneity (along strike and dip) with the density structure in the seismogenic zone will help as a proxy to study the differences in asperity and barrier behavior during the rupture propagation process.

Further research on the probable area and the estimated spread of large earthquake slip in subduction zones will be very useful for risk level analysis. Several authors (e.g., Chlieh et al., 2008, Moreno et al., 2010) estimated that the variation in coupling in subduction zones can provide information about areas that are likely to experience large slip [3][13]. High-coupled sections are fault areas that have the potential to release most of the seismic strain during large earthquakes. Chlieh et al. (2008) found that the Nias-Simeulue earthquake in 2005 originated from a strongly coupled rupture in the megathrust and
found a relationship between this coupling and seismic asperity [3]. Métois et al. (2016) found that 5 out of 6 high coupling zones correlated with coseismic asperities in the Chile-Peru subduction zone [11]. Alvarez et al. (2019) shows correlation between relatively low/high Tzz and megathrust slip behavior in Peru-Chilean margin [1]. Low Tzz are related to regions with a high slip, higher degree of seismic coupling and to marginal basins, while high Tzz otherwise.

Figure 1. Cross-section schematic explaining the domain to the megathrust rupture characteristics [10]. References: ellipses with grey shading in domain A represent sediment and pore fluids at shallow depths. Dark shaded bodies labelled as seismic areas is the location of unstable shear plane friction. Domain A located close to the trench where tsunami earthquakes or aseismic deformation and stable sliding happen. Domain B is the megathrust center where high slip occurs with short-term energy and is a relatively unstable shear friction (asperity) property. Domain C is the downdip location where moderate slip occurs in small-scale areas of stable shear areas and surrounded by relatively stable areas in earthquake conditions. The transition domain D is the location of slow slip events, low-frequency earthquakes, and seismic tremors.

Research on the structure of the interplate zone has significantly increased using potential methods. Satellite gravity data has the advantage of being able to map the entire megathrust zone without the limitations of terrestrial counting systems (such as GPS, seismological stations) and other satellite systems that only provide earth surface data. In the last 2 decades, Sumatra has experienced several megathrust earthquakes with Mw> 7.5. The use of GOCE satellite data is expected to be an effective method in studying the geodynamics in Sumatra arc system. The advantages by the Gravity Satellite data have made research focused on analyzing and modeling gravity data to reveal the density structure along the megathrust to be compared with the slip behavior of the Sumatra megathrust earthquakes in the last two decades.

2. Methodology

2.1. GOCE Satellite Gravity Data
The most recent GOCE satellite model used in this study is GO_CONS_GCF_2_DIR_R6 (Bruinsma et al., 2013), a combination of GOCE-SGG (Satellite Gravity Gradiometer), GOCE-SST (Satellite-to-Satellite Tracking), GRACE (Gravity Recovery and Climatic Experiment) and LAGEOS (Laser
GEOdynamics Satellite. Anomaly Potential (T) was obtained by reducing the normal potential field with reference ellipsoid (WGS84) with observed potential [7], then reduced by topographic effects to reduce density differences within the crust (Hofmann-Wellenhof and Moritz, 2006, Molodensky et al., 1962):

\[
Gd = \delta g (h, \lambda, \phi) = g_{\text{obs}} (h, \lambda, \phi) - \gamma (h, \phi) - g_t (h, \lambda, \phi) [\text{mgal}]
\]  

(1)

where Gd is the Gravity Disturbance, \( g_{\text{obs}} \) is the observed gravity, \( g_t \) is the mass effect of the topography over the ellipsoid, \( \gamma \) is the reference gravity potential. By direct modeling of satellite-only GOCE data, from spherical harmonic coefficients (Janak and Sprlak, 2006) of a grid cell size of 0.05°, Gravity Disturbance (Gd) and Vertical Derivative of Gravity (Tzz) are obtained. Gravity Disturbance data are downloaded directly from the ICGEM (International Center for Global Earth Model) website.

2.2. Topography and Sediment Correction of GOCE Satellite Gravity Data

To eliminate the relation between gravitational signals and topography, topographic effects must be removed from satellite observations (Forsberg and Tscherning, 1997). Topography removal calculations were carried out using a model of the Earth's surface, which also included bathymetry (ETOPO1 data). The calculation also considers the shape of the Earth's curvature to avoid misinterpretation due to the wide area of the study. A topographic density of 2.67 g / cm\(^3\) is used for the mass above sea level, while 1.03 g / cm\(^3\) is used to correct the effects of seawater. Sediment effect reduction was carried out, with a density of 2.4 g / cm\(^3\). Sediment thicknesses were obtained from the National Geophysical Data Center - NOAA data (Whittaker et al., 2013).

2.3. Derivative of GOCE Satellite Gravity Data

Vertical Derivative of Gravity (Tzz) is obtained as the second radial derivative of Gravity Disturbance (Rummel et al., 2011):

\[
Tzz = \frac{\partial^2 T}{\partial^2 r} \quad \text{(unit : 1 Eötvös = 10}^{-4}\text{mgal/m)}
\]  

(2)

Tzz is expressed in Eötvös, in theory has a better resolution than the gravitational vector itself for detecting density variations in the Earth's crust (Li, 2001), especially shallow structures with high-density contrast. It is possible to determine the edges of the anomaly of a mass with detailed and accurate accuracy. Gradiometers are better than gravimeters at detecting anomalies of shorter wavelengths (higher frequency) and the gradient anomaly more localised to the source than the gravity anomaly.

2.4. Topography and Sediment Correction of GOCE Satellite Gravity Data

Spectral analysis is performed by cutting the degree of harmonic expansion to obtain a clearer picture of the body at a certain depth. This spectrum analysis results will lead to response of Tzz's to the mass of the anomaly source at various depths in this study. Featherstone (1997) conducted a spectral analysis of geoid and gravity anomalies and found that cutting the degree/order of the harmonic expansion would decompose the straight-line gravimetric signal with increasing mass causing the gravity signal [4]. Álvarez et al. (2017) derive the formula relating the depth of the signal-causing mass to the various degrees of harmonic expansion for Tzz and find the various depths according to the degree of harmonic expansion cut.

\[
Z = \frac{(R_E + H_c)(N - 1)}{(N + 2)(N + 1)}
\]  

(3)

where \( R_E = 6371 \) km is the radius of the Earth, \( H_c \) is the height calculation for Tzz and \( N \) is the degree/order of the harmonic expansion. Higher orders are associated with shallower sources, while lower orders are associated with deeper sources. The processing result of this harmonic decomposition will be a tool to analyse the increase in-depth with the mass causing the gravity signal in various cases in this study. Table 1 explains the difference in degree/order with the resulting Z depth and its spatial resolution (Álvarez et al., 2017).
Table 1: Depth of the causative mass in the spherical harmonic expansion formula on Tzz.

| Degree/Order N | Spatial resolution $\frac{\lambda}{N} = \pi R / N_{\text{max}}$ | $Z_l[\text{km}]$ for $\Delta_g$ (Featherstone, 1997) | $Z_l[\text{km}]$ for Tzz ($H_c = 7 \text{ km}$) |
|----------------|---------------------------------------------------------------|--------------------------------------------------------|-------------------------------------------------|
| 300            | 66.72                                                        | 21.31                                                  | 20.98                                           |
| 275            | 72.78                                                        | 23.251                                                 | 22.86                                           |
| 250            | 80.06                                                        | 25.581                                                 | 25.11                                           |
| 225            | 88.95                                                        | 28.441                                                 | 27.85                                           |
| 200            | 100.07                                                       | 32.011                                                 | 31.26                                           |
| 175            | 114.37                                                       | 36.611                                                 | 35.62                                           |
| 150            | 133.43                                                       | 42.76                                                  | 41.4                                            |

3. Results and analysis

3.1. Aceh Andaman Earthquake 2004 (Mw = 9.1)

The Aceh-Andaman earthquake occurred on 26 December 2004 with Mw = 9.1, and the epicenter was located at 3.295 ° N 95.982 ° E with an estimated hypocenter depth of 30 km \[6\]. This earthquake occurred along a thrust fault between the Eurasian Plate and the Australian Plate. Within 500 seconds, this fault emitted elastic strains accumulated over centuries due to the subduction of the Indian and Burmese microplates. The 2004 Aceh earthquake had a rupture of more than 1300-1500 km length towards the northwest and a width of c. 150 km \[3\][6]. Early models of mainshock fault distribution vary in detail. However, they consistently imply that the rupture moves northwestward from the epicenter and substantial fractures occur hundreds of km northwest of the epicenter. The strike of this rupture is N 40° W with a dip of 11° towards the northeast \[6\].

3.1.1 Rupture behavior based on Tzz

In general, there is a geometrical similarity between the maximum slip along the strike rupture and the minimum Tzz value (<-20 Eötvös) in marine forearc. The negative anomaly values continue as the depth increases, as shown by the Tzz map with various depths. The main earthquake rupture points to the northwest with the end of the downdip rupture correlated with positive Tzz anomaly values in the northwest and south of the rupture area. The Fault Zone investigator intersecting the fore bulge is seen at a gravity gradient that divides the higher value Tzz (> +20 Eötvös) with, the lower value Tzz (<+15 Eötvös). According to Robinson et al. (2006), a Fracture Zone Investigator intercepted the trench in a position where there was a halt from the rupture of the 2004 Aceh (south) and 2005 Nias (north) earthquakes, and no foreshocks were recorded in that position. This allows the fracture zone, which subducts the Sumatra trench and affects the earthquake rupture area, and acts as a barrier.

3.1.2 The direction of movement of the rupture and asperity according to Tzz

A study conducted by Hayes et al. (2016) and Chlieh et al. (2008) showed a coseismic slip rupture started from the hypocenter (asperity) in the southeastern part of the fault segment and spread northwest to hundreds of kilometers from the epicenter. The minimum Tzz value appears to be related to the geometry of the maximum slip and is the main asperity area of the 2004 Aceh earthquake rupture area. The epicenter of the earthquake is nucleated close to the high Tzz anomaly, and the increased slip to the northwest of the epicenter is limited by the high Tzz anomaly to the northeast and southwest of the rupture area. Analysis of Tzz with different depths up to N = 225 shows a continuity of low Tzz to the northwest of the epicenter, which differs from degrees N = 200 to N = 150. The continuity of the low Tzz shows the path of propagation (direction) and amplification of the 2004 Aceh-Andaman earthquake. According to the Hayes et al. (2016), the hypocenter depth is 30 km close to the downdip rupture, with the updip being northwest of the strike rupture \[6\].
3.1.3 Seismic barrier at the SE area of the rupture

Observations show that the fault rupture did not propagate significantly to the southeast. However, the slip magnitude is quite large in the southeastern part of the rupture, thus suggesting a seismic barrier at this location. In the 2005 Nias earthquake, the maximum slip was about 100 km from this barrier between the 2004 and 2005 earthquake ruptures, pointing to important physical properties of this barrier. The existence of a fracture zone that is predicted to affect rupture has been proposed by Chlieh et al. (2008), Lange et al. (2010) and studied by the British Oceanographic Data Center (2008). In this area, also very little seismic activity indicates a possible seismic gap. Based on the analysis of the Tzz map, there is a relatively high Tzz value at the tip of the rupture spread in the southeast and a narrow minimum.

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**Figure 2.** Vertical Derivative of Gravity (Tzz) and Gravity disturbance (Gd) that have been corrected by topography and sediment thickness around Aceh (north Sumatra) to Nicobar Island from the GO_CONS_GCF_2_DIR_6 model (Bruinsma et al., 2013). Figure A) shows Tzz with N = 300, Figure B) shows Tzz with N = 250, Figure C) shows Tzz with N = 200, and Figure D) shows Gd with N = 300-10. Black line is the trench location from Hayes et al. (2016), red star is the epicenter, slip distribution pattern map (5-meter contour) from Chlieh, 2006 from inversion of coseismic slip far-field displacement, Fracture Zone with a black dotted line from Kopp, 2008. SIM: Simeulue, N: Nias. The black arrow line on A) indicates the minimum depreciation of the Tzz value at the end of the rupture. The white arrow line on B) shows the direction of propagation of the 2004 Aceh-Andaman earthquake. The black arrow near Australian Plate represents the subduct direction of Australian Plate.
Tzz pattern in this area. The relatively maximum Tzz in the southeast of the 2004 Aceh earthquake rupture area is predicted to be a seismic barrier. Relatively maximum Tzz is usually associated with various types of oceanic plate roughness (such as seamounts, aseismic ridges) and control seismic segmentation along the margins. Lange et al. (2010) confirmed the existence of a fracture zone that was subducted at a longitude of 96° E and can be regarded as a seismic barrier.

3.1.4 Gravity disturbance
Gravity disturbance that has been corrected for topography and sediment thickness from GOCE data up to N = 300 shows that the minimum anomaly correlates with the maximum slip area. The pattern produced by the gravity anomaly is relatively minimum along the trench, similar geometrically to the pattern of the maximum slip distribution. Low-density contrast is at the maximum slip region, whereas high contrast is at the end of the rupture. Gravity disturbance that is relatively minimum and correlates with maximum slip is associated with low density and can reflect the forearc basin.

3.2. Nias-Simeulue Earthquake 2005 (Mw = 8.6)
The Nias-Simeulue earthquake occurred on March 28, 2005, with Mw = 8.6, and the epicenter was located at 2,085° N 97,108° E with an estimated depth of 30 km. The earthquake relates to the activity of a northeast dipping thrust fault at the junction of the Australian and Sunda plates. The rupture area of this earthquake is approximately 340 x 125 km (length x width). This earthquake was most likely triggered by changes in stress due to the 2004 Aceh earthquake. This earthquake occurred about 160 km southeast of the 2004 Aceh earthquake rupture zone. The penultimate earthquake with an Mw = 8.6 occurred in 1861 in this region, which caused a tsunami with a magnitude similar to that of 2005 Nias-Simeulue earthquake. Rupture initially points to the north, then rupture points to the south based on seismogram analysis from Walker et al. (2005).

3.2.1 Rupture behavior based on Tzz
The rupture area of the Nias-Simeulue earthquake resulting from GPS inversion (Briggs et al., 2006) shows two patterns of maximum slip to the northeast and southeast. In detail, this pattern is different from the slip distribution produced by Hayes et al. (2016). In general, there are similarities between the maximum slip geometry and the minimum Tzz value in the northeast and southeast of the rupture area. The two ruptures to the northeast and southeast are bounded by the relative maximum Tzz at the minimum Tzz constriction ends in both directions. The negative anomaly values continue as the depth increases, as shown by the Tzz map with various depths. The FZ investigator that cuts the fore bulge is seen from the gravity gradient, which divides the higher Tzz value (> 15 Eötvös) by, the lower Tzz (<15 Eötvös). The map of Lange et al. (2010) shows the existence of a fracture zone at a longitude of 98° E, which extrapolated divided the rupture area of the Nias-Simeulue earthquake.

3.2.2 Asperity identification
The Nias-Simeulue earthquake was the result of 2 different simultaneous earthquake rupturing event: Mw = 8.2 to the north of the epicenter and Mw = 8.5 to the south. Most of the coseismic slip occurred about 150 km from the trench and was in a locked fault zone (Hsu, 2006). The maximum slip of this earthquake occurred in the northeastern sector of Nias and the southeast part of Simeulue (Qiang Qiu, 2019). The slip data correlates with the minimum Tzz value found in the rupture zone following the coastline geometry along the continental forearc. The best geometric correlation between minimum Tzz and maximum slip is found at a Z = 31 km depth using the N = 200 model. This is consistent with Hayes et al. (2016) observations, which state high slip (maximum slip = 9 meters) at a depth of 28-40 km. The minimum Tzz continuity at this depth suggests the movement of the Nias-Simeulue earthquake rupture. The positive Tzz pattern and high slip distribution correlate with the high coupling pattern, which is the asperity of this earthquake.
3.2.3 **Barrier identification**

Based on the coupling data, it seems that the seismic barrier zone correlates with the low coupling segment, which functions as a barrier and effectively captures/becomes the final stop of the rupture propagation; this is also found in Metois et al. (2016), Loveless and Meade (2011). The isolated seamount in the southern part may control the slip of earthquakes and may prevent major earthquake events characterized by relatively high Tzz values in the southeastern rupture area.

3.2.4 **Gravity disturbance**

The minimum gravity pattern has a geometrical similarity to the maximum slip pattern from the slip distribution data. The density contrast in the area with low maximum slip, and vice versa at the boundary of the rupture, occurred a significant density change based on the gravity disturbance data. The minimum gravity associated with the northeast maximum slip is dominated by low-density material filling the basin.

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**Figure 3.** Vertical Derivative of Gravity (Tzz) and Gravity disturbance (Gd) that have been corrected by topography and sediment thickness around Aceh (north Sumatra) to Nias from the GO_CONS_GCF_2_DIR_6 model (Bruinsma et al., 2013). Figure A) shows Tzz with N = 300, Figure B) shows Tzz with N = 250, Figure C) shows Tzz with N = 200, and Figure D) shows Gd with N = 300-10. Reference: black trench location line triangular pattern from Hayes et al. (2016), red star is the epicenter, Slip distribution pattern map (5-meter contour) from Chlieh, 2006 from inversion of coseismic slip far-field displacement, Fracture Zone with black dotted line from Kopp, 2008. SIM: Simeulue, N: Nias, PB = Pulau Batu. The white arrow line at B) represents the direction of propagation of the rupture, the white arrow line at C) represents the minimum shrinkage of Tzz at the end of the rupture. The black arrow near Australian Plate represents the subduct direction of Australian Plate.
### 3.3. Bengkulu Earthquake 2007 (Mw = 8.5)

On 12 September 2007 the Bengkulu earthquake occurred with Mw = 8.5 and the epicenter at 4,438° S 101,367° E. A thrust fault at the boundary between the Australian Plate and the Sunda plate was activated. At the earthquake location, the Australian plate is moving northeast towards the Sunda plate converging about 60 mm / year. The thrust fault was continuous with a rupture area of about 300 x 110 km (length x width), the hypocenter was located at a depth of about 20 km with a slip depth at a depth of 16-36 km [5]. The 2007 earthquake did not result in the rupture that occurred in the 1833 earthquake [6].

![Figure 4](image)

**Figure 4.** Vertical Derivative of Gravity (Tzz) and Gravity disturbance (Gd) that have been corrected by topography and sediments around Bengkulu (central Sumatra) from the GO_CONS_GCF_2_DIR_6 model (Bruinsma et al., 2013). Figure A) shows Tzz with N = 300, Figure B) shows Tzz with N = 250, Figure C) shows Tzz with N = 200, and Figure D) shows Gd with N = 300-10. Black stripped line = trench location line from Hayes et al. (2016), red star is the epicenter, slip distribution pattern map (5-meter contour) from Chlieh (2006) from inversion of coseismic slip far-field displacement, fracture zone with black dotted line from Kopp (2008). SB: Siberut, SP: Sipura, PU: North Pagai, PS: South Pagai, E: Enggano. The black arrow near Australian Plate represents the subduct direction of Australian Plate.

#### 3.3.1 Asperity identification

The 2007 Bengkulu earthquake had a rupture with a length of about 300 km, with a maximum slip between the epicenter and Pagai Island, with large coseismic displacement. The upper boundary of the rupture is located on the west coast of the island belt and caused a large uplift on Pagai Island. The lower boundary of the earthquake rupture points westward away the coastline of Sumatra Island. The geometry of the maximum slip based on the slip distribution data correlates with the minimum Tzz value (<-20 Eötvös) and is parallel to the trench. The geometric correlation between minimum Tzz and maximum continuous slip is up to N = 200. This correlates quite well with slip distribution modeling, which explains large slip at a depth of 16-36 km [5]. The geometry of the maximum slip and minimum Tzz also correlates with the large interplate coupling.
3.3.2 Barrier identification
The Asperity of the Bengkulu earthquake correlates with the minimum Tzz, which laterally spreads to
the northwest and is bounded by the relative maximum Tzz at the end of the minimum Tzz. In the
northwestern direction of the rupture, the narrowing of the minimum Tzz correlates roughly with the
end of the earthquake rupture area, although the values are barely different. The existence of a seismic
barrier is thought to be due to the fracture zone, which occurs at longitudes of 99° E and 102° E [9] and
is geometrically at the lateral ends of both sides of the Bengkulu 2007 fault zone.

3.3.3 Gravity disturbance
The maximum slip generated by the slip distribution map is similar in geometry to the high coupling
and minimum gravity anomaly value patterns. The density contrast is low in the maximum slip region
due to the uniform gravity anomaly pattern in this pattern. In contrast, the high contrast is at the end/tip
of the rupture. Gravity disturbance that is relatively minimum and correlates with maximum slip is
associated with low density and may reflect forearc basin.

3.4. Enggano Earthquake 2000 (Mw = 7.9)
The 2000 Enggano earthquake occurred on 4 June 2000 with Mw = 7.9 close to Enggano Island. This
earthquake happened in the Sumatra subduction zone in the final southeastern position of the rupture
area of the M> 8 subduction earthquake in 1833 (Hayes et al., 2016) and was fully coupled (Zachariasen
et al., 2000). Based on the broadband modeling, the rupture moved to the southeast of the epicenter up
to 100 km from the hypocenter.

3.4.1 Asperity and barrier identification
Based on the distribution of Tzz and aftershock values from the earthquake, it is hypothesized that the
asperity zone is southeast from the epicenter to about 150 km to the southeast, where the narrowing of
the Tzz value is minimum. This adapts to minimum Tzz spread and interseismic coupling, which is
moderate and has a similar geometry to minimum Tzz. The Enggano 2000 earthquake barrier is located
at the tip of the lateral distribution in the northwest and southeast. The barrier is predicted to be due to
the subduction of the fracture zone mapped at a longitude of 102° E by Lange et al. (2010). The
southeastern part of the rupture end may also be caused by the fracture zone and become a seismic
barrier. The in-depth Tzz map shows that minimum expansion of Tzz to a smaller (deeper) degree.

4. Conclusions
Vertical gravity derivative (Tzz) and gravity disturbance (Gd) can help explain the slip behavior of
megathrust earthquakes that occur along the Sumatra subduction zone by correlating slip distribution
data, coupling and geological structures. Previous studies have successfully linked high or low coupling
properties with the high and low slip rupture distribution patterns of earthquakes. This research mapped
the slip rupture zone of the earthquake and the slip magnitude using Tzz data. The minimum Tzz value
is closely related to high slip in the rupture zone and correlates well with high coupling. The maximum
Tzz value is closely related to decreased earthquake slip at the end of the rupture zone and correlates
with low coupling. Rupture propagation can also be explained by looking at the minimum Tzz dispersion
pattern, which is confirmed by the direction of the earthquake rupture analyzed. Tzz can provide
information on seismic zones, the presence of asperities and barriers along the Sumatra subduction zone.
Seismic barrier is clearly visible on the Tzz map, the barrier located on Simeulue Island and Batu Island.
Meanwhile, there are two more barriers that are being questioned, those located in the Mentawai Islands
and on Enggano Island. Tzz's data shows that in the Mentawai Islands, there is a minimum narrowing
of Tzz in the center of the archipelago, but there is no clear boundary. Meanwhile, the barrier on Enggano
Island shows a minimum narrowing of Tzz and an increase in the value of Tzz, however, due to the
absence of a detailed slip distribution record and this zone having experienced a major earthquake in
1861, it cannot be ascertained that this area is a persistent barrier. This methodology is able to provide
information about the physical properties along the roundup of Australian and Eurasian Plates, so as to
map the risk level of the study area. The minimum Tzz distribution along the marine forearc correlates with the maximum slip and can be used to consider the seismicity hazard along the coastline to avoid disaster on high population zones.

Figure 5. Interpretation of Tzz in Sumatra's subduction with the asperity sites associated with minimum Tzz and the barrier associated with Tzz is relatively maximum and its relationship to the rupture zone. The red star is the epicenter of the 2004 Aceh-Andaman earthquake. The white star is the 2005 Nias-Simeulue earthquake epicenter. The black star is the 2007 Bengkulu, and the light blue color is the Enggano 2000 earthquake epicenter. Minimum Tzz near the oceanic plate is a zone with high slip and high coupling and interpreted as asperity and located in the forearc basin. This zone, according to the subduction domain by [10], is zone B. The minimum Tzz value closer to the Sumatra coastline are in the zone C in Lay et al. (2012).

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