The seismogenic source on the deep lateral ramp of Sumatra accretionary wedge inferred from the source model of the 2009 mw 7.6 Padang, Indonesia, earthquake

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Abstract. The 2009 Mw 7.6 Padang earthquake has been inferred as an intraslab event because it locates at approximately 80 km depth which is within the oceanic slab with maximum curvature. However, the major trench-parallel-striking normal faulting event usually occurs at this tectonic environment but not the trench-normal-striking reverse event like this 2009 Padang earthquake. To solve this enigma, the coseismic displacements were estimated based on the analysis of daily coordinate time series calculated by GAMIT software from 15 continuous GPS stations along the Sumatra region. The maximum horizontal displacement is approximately 58.3 mm toward SW at the MSAI station while the maximum vertical displacement reaches 16.1 mm. The optimized geometry parameters of the source fault were determined by the Markov Chain Monte Carlo using the uniform-slip dislocation model. The optimized strike and dip of fault plane are 80° and 57°, respectively. The coseismic slip distribution was then estimated using the distributed-slip dislocation model in terms of optimized fault geometry. The geodetic moment of 1.35 x 10²⁷ dyne-cm in our best-fit model is equivalent to Mw 7.39. The coseismic slip mainly ranges 28-70 km in depth with the maximum slip of 2000 mm. The optimized source fault plane is also comparable to the relocated aftershock distribution. Comparing to the location of interface, our source fault is mainly located at the place above the interface. We therefore proposed that this 2009 Padang earthquake occurred in the deep part of accretionary wedge, but not with the slab. In addition, we also proposed this 2009 event as a lateral ramp event because its strike is normal to the trench, such as the 2010 Jaishian earthquake in Taiwan. Finally, we proposed that a thick-skinned deformation may be also represented in the prism of Sumatra subduction zone.

1. Introduction

A current study purposed by [1] shows that their joint analysis of geodetic and seismic waveform data initiated the Padang earthquake was an intraslab event and ruptured primarily downdip and to the southwest. In the previous study, the depth sections emphasize the agreement between the larger magnitude aftershock locations between 74 and 97 km depth. However, [2] and [3] define a shallow portion of a slab as a depth range 20 - 60 km and judge either is intraslab by observing the focal mechanism and depths. Generally, intraslab earthquakes
are divided into two groups based on the focal depth. Events shallower than 300 km are defined as intermediate depth earthquake and those deeper than 300 km are considered deep-focus earthquake. Intermediate depth earthquakes form a double seismic zone in the depth range of 40 - 80 km, which occur only at locations where hydrous minerals are present, and are particularly concentrated along dehydration reaction boundaries [4]. [5] and [6] proposed the location of the Moho at the plate interface is corresponding to depths between 21 and 55 km which is the sign of a path to hydration.

The major trench-parallel-striking normal faulting event usually occurs at this tectonic environment but not the trench-normal-striking reverse event like this 2009 Padang earthquake. To reveal and describe a tectonic ramp that is parallel to the transport direction of regional thrust sheet, relocated aftershock provided by [7] is essential for us to explain what kind of deformation that occurred in Padang Earthquake. The aftershock distribution (Figure 1) shows only 19 reliably aftershocks from the main shock until 30 December 2009. About 70% of aftershocks occurred within one month after the main shock. The geodetic observation such as GPS observation provided by EOS Singapore is adopted to measure the displacement in Padang Earthquake. On that account, the Mw 7.6 Padang Earthquake provides a good chance to characterize the deformation of Padang Earthquake from the coseismic source model associated with geodetic observation, fault geometry and slip distribution.

For these reasons, we want to re-visit the coseismic source model derived from GNSS observation simultaneously and identify the characteristics of the Mw 7.6 Padang Earthquake event.

Figure 1. Sumatra region map. The black triangles are location of active volcanoes. The red lines is the Sumatran Great Fault and the black lines with triangles shows the Sumatra trench and Mentawai fault, respectively.

2. Geological Background
The extensive descriptions and interpretations by [8] were among the first to put Indonesia into the context of the new framework of global plate tectonics. The subduction zone southwest Sumatra is part of a long convergent belt that extends from the Himalayan front southward through Myanmar, continues south past Andaman and Nicobar Island and Sumatra, south of Java and the Sunda Islands and then wraps around the north (Figure 1 and Figure 2). This trench accommodates the northward motion of the Australian plate into Eurasia. Sumatra is situated on the Sunda continental margin and exposes granitic as old as 240 Ma. Predominantly, from northeast to southwest, the islands geologically characterized by oil-bearing sedimentary basin in the northeast, the
Barisan Mountains (Figure 1 and Figure 3), which include the volcanic arc and Sumatra Fault, running along the length of Island near southwest coast, the offshore forearc basins, the forearc high (islands of the Simeulue Enggano ridge), deep trench and the subducting oceanic plate. [8] suggests that Sumatra was rifted from northern edge of Australia (north of New Guinea) during the Triassic to early Jurassic (200 - 250 Ma). Sumatra would have been a stable continental margin from then until subduction began in the Cretaceous (possibly 100 Ma).

The 100-km-wide Barisan Mountain, the backbone of Sumatra (Figure 1), include pre-Tertiary rocks covered by Cenozoic volcanic rocks. The structural central graben led [9] to conclude it was a rift structure and that the Sumatra Fault was dip slip in nature. Subsequent work revealed it to be a transform (transcurrent) faulting structure [10], and modern GPS measurements reveal no extension across it [11]. At the latitude of Toba Caldera 2 N (Figure 1), the range broadens into what van Bemmelen called the Batak Tumor, a two-kilometer-high bump in the range that includes 500-m-deep Toba Lake, the surface of which is at 900 m above sea level.

The active volcanoes of Sumatra fall along the Barisan Mountain (Figure 1) and, like most arcs, are generally parallel to the subduction zone and above the 100 to 150 km depth contours of the subducted plate [12][13]. This pattern of subduction-related volcanism has persisted since at least Oligocene time [8]. The modern arc rocks are andesite, dacite, and rhyodacite to rhyolite, and their strontium ratios indicate variable amounts of crustal contribution. The volcanic arc continues to the north, forming the islands of Barren and Narcondam, both approximately 100 km east of Andaman Island. Even farther north, inactive volcanoes Myanmar may form part the same chain [14]. Thus volcanic rocks exposed a long history subduction as well the thorough southwestern margin of Sunda. Approximately 74,000 years ago, more than 2800 km$^3$ of dacite and rhyolite were ejected from the Toba caldera complex [15], a 100 by 30 km topographic depression in the arc. The Toba depression overlies two magma reservoirs in the shallow (< 10 km) crust, one of which appears to be at least 40 by 60 km across [16]. These reservoirs also fed caldera forming, ash-flow eruptions at 0.5 and 0.84 Ma. The eruption at 74 ka is thought by some to have produced a near extinction of the human population.

3. GNSS Data Collection and Processing
In this study, we used 15 Continuous GNSS installed by EOS Singapore (Figure 4). The GNSS observation for our analysis were obtained from 17 September 2009 to 15 October 2009. We adopted the step function to obtain the fitting time series. GAMIT/GLOBK ver10.4 were used to acquire the time series. The sampling rate of GNSS that has been used in this study 30 seconds. Data obtained from elevation cutoff lower than 15 were used.
to reduce the multipath effects and noise. Our 10 IGS fiducial stations on the International Terrestrial Reference Frame (ITRF 2005) were used to determine the positions of 15 GNSS local permanent stations.

Figure 4. The Sumatran GPS Array. Fifteen GNSS were adopted in this study.

4. Coseismic Displacement Field
The surface deformation field resulting from Mw 7.6 Padang Earthquake can be clearly observed in GNSS measurements (Table 1). The coseismic horizontal displacement field relative to earth center shows that the GNSS sites along Southern coast of Sumatran mainland experienced coseismic horizontal motion.

The horizontal coseismic displacement shows two groups of stations moving in opposite direction (Figure 5). The western coast of Sumatran mainland move towards the trench or move away from the epicenter to south to west direction. In the GNSS sites which located in Sumatran mainland move towards the epicenter. The highest displacement were produce by MSAI station with value approximately reach 40 mm. The coseismic vertical displacement (Figure 6) shows most of Padang event produced the subsidence. The highest vertical displacement located at NGNG with value approximately reached 13 mm.

5. Kinematic Source Model

5.1. Uniform-Slip Model
To determine the fault geometry for the 2009 Padang, Indonesia Mw 7.6 Earthquake, GNSS observations with uniform slip model on rectangular dislocation in an elastic half-space was employed [17]. The Okada model gives a compact analytical expression of the surface displacement, strains, and tilts due to inclined shear and tensile faults in a half-space for finite rectangular sources. We then inverted the GNSS observation data with a two-step approach consisting of non-linear inversion based on Markov Chain Monte Carlo to study the source geometry with uniform slip model [18][19][20].

| Site name | Longitude | Latitude | dE  | dN  | dU  | s dE  | s dN  | s dU  |
|-----------|-----------|----------|-----|-----|-----|------|------|------|
| ABGS      | 99.390    | 0.220    | 0.009 | -14.545 | -8.119 | 0.466 | 0.551 | 0.524 |
| BSAT      | 100.284   | -3.076   | -3.891 | 0.399 | -5.317 | 0.733 | 0.735 | 0.882 |
| BTHL      | 97.71     | 0.57     | 0.878 | -5.497 | -11.753 | 0.517 | 0.559 | 0.574 |
| JMBI      | 103.52    | -1.615   | -1.954 | 0.175 | -7.829 | 0.541 | 0.632 | 1.044 |
| KTET      | 99.840    | -2.362   | -5.227 | -7.997 | 0.460 | 0.666 | 0.755 | 0.699 |
| LAIS      | 102.033   | -3.529   | -2.863 | 0.449 | -6.774 | 0.571 | 0.660 | 10.012 |
| LNNG      | 101.156   | -2.285   | -22.511 | 0.770 | -6.495 | 0.366 | 0.483 | 0.503 |
| MSAI      | 99.089    | -1.326   | -45.351 | -34.853 | 0.594 | 0.622 | 0.668 | 0.987 |
NGNG  99.268  -1.799  -24.123  -29.559  0.956  0.383  0.497  1.069  
PKRT  99.542  -2.151  -3.383  -20.191  -3.085  0.653  0.708  10.068  
PPNJ  99.603  -1.994  -7.458  -22.845  0.142  0.528  0.583  0.715  
PSKI  100.353  -1.124  -4.315  0.637  0.555  0.546  0.663  0.636  
SLBU  100.009  -2.766  -0.433  0.474  -8.32  0.578  0.663  0.943  
TIKU  99.944  -0.399  0.578  0.802  -5.587  0.59375  0.690  0.883  
TLLU  99.134  -1.800  -20.761  -27.232  0.648  0.594  0.690  0.883  

**Figure 5.** Coseismic Horizontal Displacement. The circle on the blue arrows shows interval of confidence that this study used. The star denotes the epicenter of Padang Event and the beach ball shows the focal mechanism of Padang Event provided by USGS.

**Figure 6.** Coseismic Vertical Displacement. The grey lines near the blue arrows show interval of confidence that this study used.

We simplify the earth as a homogeneous elastic halfspace with material properties that are typical for undrained rocks (Poisson's ratio: \(\nu_u = 0.31\) [21]. Offset (or slip) across rectangular dislocations in the halfspace cause surface displacements that can be described analytically [22]. Using these relations we can write the observed surface displacement \(d\) as a function \(g\) of the fault model parameter \(m\) in Equation (1).

\[
d = G(m)s + e
\]  

Where \(d\) is the GNSS observation; the Greens function \(G(m)\) is related to the fault parameters (strike, dip, depth, location, length and width): \(s\) is the quantity of slip on the fault plane and \(e\) is the observation errors.

In the inversion process, we first derived the location and strikes of the modeled fault directly according to the aftershock distribution and focal mechanism solutions. The initial derived fault model consists one segment whose strikes range from 70 to 80, which are very close to those in [1]. According to the inversion calculations, it is found that the optimal strike reached 72.68°. The dip and top of depth for the fault segment have value amounts 54.19 and 46.72 km, respectively (see in Table 2).

**Table 2.** The optimal fault geometry result from uniform slip model

| East Position (km) | North Position (km) | Strike (°) | Dip (°) | Depth (km) |
|-------------------|---------------------|------------|---------|------------|
| Upper bound       | 25                  | 20         | 80      | 60         | 50         |
| Lower bound       | -10                 | -20        | 70      | 50         | 30         |
| Optimal value     | -1.84               | -19.08     | 72.68   | 54.19      | 46.72      |

Because the distribution of aftershocks following the earthquake does not clearly delineate the fault geometry, we let the searching parameters for one million sampling looking the fit fault geometry with focal mechanism solution provided by Harvard CMT. The top depth of fault planes are set far away from to the surface due to the earthquake does not break the surface. Figure 7 shows the histogram of fault geometry after running one million samples.
The preferred model show the fault plane is associated with aftershock distribution (Figure 8). The preferred model shows that the location of the fault plane located above the slab that provided by [23]. The hypocenter of the earthquake located below the slab and most the aftershock distribution delineate above the slab that represent on the red colors of curvature.

**Figure 7.** Posterior probability distribution of seven parameters of fault geometry. The red lines represent the average, and the range between two stripes red lines is a 95% confidence interval.  

**Figure 8.** The 2-D projection of the fault plane. The fault plane shows in the blue line associate with aftershock distributions that denotes with red circles. The brown lines shows the slab.

5.2. Distributed-Slip Model  
In order to obtain a more realistic rupture model, a refinement has been made by inverting GNSS observations for the slip distribution on the fault plane. In the slip inversion for slip distribution, the geometry of the fault plane needs to be determined in advance [24][25][26]. For this purpose, we first fix the fault geometries (including strike, dip and location) to the preferred solutions determined from the uniform slip modelling, and further extend the length and the top and bottom of depth of each segments.

The fault model was discretized into 80 patches, each with a length of 6 km and width 8 km. Strike-slip and dip-slip components for each fault patch were solved in a least squares sense. Constraints of slip Laplacian smoothing across the fault patches were added to avoid unphysical oscillating slip distribution [27]. The smoothing factor was chosen by plotting the trade-off curve between RMS misfit and the solution of roughness (Figure 9), which can obtain a slip distribution model that has both lower misfit and roughness in general. In this study, we did not choose not in the cutoff point due to the result of smoothing parameters produce the underestimate result between observation and calculation. The smoothing parameters with 1.2 value is the preferred model in this study.

**Figure 9.** The trade-off curve between RMS misfit and roughness. The blue color dots denotes the smooth factor chosen for inversion.
The slip model indicates that length and width of the rupture plane fault plane are about 60 km and 70 km respectively, and the fault has an average strike of 72.68 and the average dip of 54.19. The slip is mainly range distributed in the range 40 - 75 km depth. The preferred fault geometry with one segments suggest that the strike for this event change significantly from central segment (Figure 12). The preferred slip distribution show the preferred slip distribution model exhibits one slip peaks with maximum slip reached 2500 mm at depth 66.0-72.8 km (Figure 10 and Figure 11) and resulting the geodetic moment $1.41 \times 10^{27}$ dyne-cm or equivalent with Mw 7.40.

Figure 12 concede the estimated fault slip model. It represents that this earthquakes is predominantly oblique thrust event with minor right lateral motion (in the upper part of fault). Main fault slip is located at the northeast of the hypocenter, which indicates that the fault rupture propagates from northeast to southwest direction. Figure 13 shows the coseismic fault has length 60 km. On the other hand, more than 95% of seismic moment is released in along-strike distance of 20 - 48 km from southwest to northeast of the fault. The fault slip has not propagates to the ground surface, and the estimated peak fault slip of approximately 3m locates at coast of Padang City near forearc basin. Significant slip is concentrated on bottom central part of the fault segment at depth 66 - 72 km (Figure 12) and an along-strike distance at 30 km.

Figure 10. Slip Distribution on the fault plane from distributed slip model in horizontal component. The blue arrow shows the best fitting result and the black arrow shows observation

Figure 11. Slip Distribution on the fault plane from distributed slip model in vertical component. The blue arrow shows the best fitting result and the black arrow shows observation

Figure 12. Slip Distribution of fault planes in map view. Color of patches on fault planes shows its slip value

Figure 13. Total slip distribution of optimized model. The black arrow shows the vector of coseismic slip. The bright color shows the value of the slip distribution along strike and along dip.
5.3. Checkerboard Test Model

To be able to assess the capability of surface data to resolve the spatial resolution of fault slip distribution, we generated synthetic dataset for the checkerboard-like slip distribution shown in Figure 14. The several patches has been made by divide 10 km to 8 km and with slip from 0 mm and 2000 mm. It is completely different than the inversion model resulting from distributed slip model. In this forward model, our purpose is to simulate or generate the synthetic dataset that we determine the slip on the fault as our first step. The outcome of forward model is the simulated of displacement. Afterwards, we adopted the simulated displacement and the fault geometry from forward model into the inversion to get the simulated slips. Later on, we just compared the checkerboard resulting from forward model to simulated slips. Figure 15 shows the result from inversion model. The result is really not good enough to explain the slip resolution distribution. Some part of fault patches shows reliable but it is not strong enough to represent the good spatial resolution in fault geometry and slip distribution on the fault plane. The smoothing parameter that have been chosen is the same as distribution slip model to endure dissimilarities outcome from both methods. However, in the depth around 40 - 50 km in the middle of fault geometry, it shows high resolution even tough in general the resolution of our model is very low. In this study area, we notice the spatial resolution is very low due to the dense of GNSS observation is not solid. However, we still could distributed slip model to analysis the tectonic meaning in the Sumatra.

Figure 14. Preset slip distributions of forward model. Black color denotes the slip while a white color denotes no slip

Figure 15. Slip Distribution of the inversion model. Grayscale of patches on the fault planes shows its slip values

6. Discussion

In this study, as we found that the location of Padang event in 99.867 E; 0.720 S which near the coast of Mainland Sumatra Padang. We divided the structure of Sumatra in the part of central Sumatra based on [28]. In the shallow part of the vp velocity model that they observed, it reveal regions of reduce vp velocities alternating with higher vp values at shallow depths (Figure 16). In the following, these regimes starting at the trench and moving towards the Mainland of Sumatra. The accretionary wedge comprises the frontal prism adjacent to deep-sea trench as well as the lower middle continental slope seaward of the forearc islands. The accretionary domain is characterized by moderate velocities of approximately 5 kms$^{-1}$ down to a depth down to a depth of approximately 15 km, increasing to 6 kms$^{-1}$ above the landward-dipping high velocity zone. Velocities in the upper 15 km increase underneath the Forearc Island with value around 6 kms$^{-1}$ which are also observed beneath the coast. In [28] images, region beneath the forearc island as a trench-parallel, elongated zone of increased velocity, sandwiched between the relatively lower velocities of the trenchward accretionary prism and the landward forearc basin the fast velocity anomalies below and between the island might be interpreted as occurrence of faster accreted Investigator Fracture Zone (IFZ) material beneath the Batu island. According to [29], the uppermost sedimentary section of the accretionary prism has low velocity and high porosity, suggesting these sediment remain uncompacted and unlithified for over 30 - 40 km landward off the trench. These low velocities are mainly associated with frontal thrust and bivergent folds.

Figure 17 shows the 3-D cross section of along trench-perpendicular. At depths around 20 - 30 km, there is highest Vp values occurred beneath Mentawai Island. It indicating of shallower location of the Moho under the Mentawai Island. The Vp values at depth 25 beneath forearc basin also higher and it may indicating the reduced thickness of the overriding crust. While the offshore forearc is made up of young sediments from the Eocene to Holocene [30], the mainland shows a 130 km wide belt of different rock units along the SFZ [28]. The Sumatran
Fault Zone is characterized by high seismicity rates because the stress and strain partitioning from the oblique subduction [31][32]. This belt mostly composed of Permian to Jurassic sedimentary rocks, Eocene volcanic rocks and Jurassic to Eocene intrusive units [33][34]. The low $\frac{v_p}{v_s}$ ratios shows in the region of Sumatran Fault Zone is about 1.65 at depth 0–20 km. However in the depth of above 30 km the velocity increase ($v_p$) up to 7.5 kms$^{-1}$. It indicates of continental Moho located apart from the good resolution and reached to larger than 30 km depths.

Figure 16. 2-D tomographic velocity models for $V_p$ (a) and $\frac{v_p}{v_s}$ (b) models (profile direction is trench perpendicular). Regions with good resolution are encircled with red lines. Circles indicate hypocenters and grid nodes are shown with crosses. Stations are indicate hypocenters and grid nodes are shown with crosses. Stations are indicated with triangles. The dashed line in panel (a) indicates the $v_p$ 7.8 kms$^{-1}$ contour line and is used as a proxy for moho [28]

Figure 17. Cross section along trench-perpendicular trending profiles through the 3-D $V_p$ model. White circles indicate events within 10 km of the profile and stations closer than 25 km to the profile are shown by white triangles, the remaining ones by black triangles, the remaining ones by black triangles. The 46 OBS station of the 2-week deployment are shown with smaller triangles. Red lines encircle regions of good resolution defined by cut-off spread value of 1.5. Green line in panel (c) indicates the plate interface as defined by the global SLAB1.0 model [23]. The 7.8 km$^{-1}$ $v_p$ contour line is indicated by a black line [28]
The 2-D of optimized distributed slip model. The circle with the blue fill represent the aftershock of Padang Event. The line with color represent the fault plane of Padang event. The black line shows the maximum curvature that represent as a slab model.

The plate interface based on the seismicity (the white circle colors), it may located at approximately 25 below the forearc islands (Figure 16 and Figure 17). This discovered, is a little deeper than below the Pagai Island at 3 S, where it was found at 20 km depth [5]. The seismicity in Figure 16 and Figure 17 produce some seismicity transition from aseismic to seismic behavior in the downdip direction with a depth variations. The curvature of the subducting plate is approximately 25 within the depth range between 40 and 80 km. It is based on seismicity Sumatra. The most apparent that we could detect is the change of \( v_p \) from inclination subducting to the deeper depth. Based on this explanation which is \( v_p \) velocities beneath the magmatic arc, which spatially correspond to the Sumatra Fault Zone, are around 5 kms\(^{-1}\) at 10 km depth and the \( v_p=v_s \) ratio reached the lowest point, indicating the presence of felsic lithologies kind of continental crust.

The highest values are discover in west of forearc basin and close to the Mentawai Fault with value up to 1.85. However it hard to recognize large scale of the change of mantle wedge due to excess of liquids from hydrated Investigator Fracture Zone because serpentinized material is characterized by clearly elevated \( v_p=v_s \) and reduced \( v_p \) values [35].

The position and strike of the inferred fault plane suggest that the 2009 Padang Earthquake occurred near the Mentawai segment, which according to velocity model it might be the deeper part of accretionary wedge in between with continental Moho. Figure 18 reveal that comparison of the inferred fault geometry with the aftershock distribution following the 2009 Padang earthquake. Aftershocks mainly occurred within or near area that has a large coseismic slip on the inferred fault geometry.

If we assumed the structure Sumatra is a backstop model purposed by [36], because the inferred distributed slip model exhibit the high dip angle which is approximately 52.19, we thus purposed the 2009 Padang earthquake is a lateral ramp between two major thrust structures. Padang earthquake has a similar case like 2010 Jiashian earthquake that purposed by [37]. This kind of situation have a high potential for producing the large earthquake.

7. Conclusions
The 2009 Padang Earthquake reveal from focal mechanism solutions was a right lateral oblique thrust event. Step function in the time series has been applied to make a better result of coseismic displacement. Based on the time series displacement, the western part of Sumatra shows significant displacement. The movement of displacement in the western part of Sumatra is towards the trench. In the eastern part of Sumatra Island which is mainland Sumatra, the movement of displacement is moving towards the epicenter of Padang Earthquake. The largest displacement was take place in MSAI station with value approximately 40 mm in horizontal components.
For vertical components, most of GNSS sites shows subsidence. The highest value for vertical components was occurred in NGNG station on Siberut Island with value approximately reached 13 mm.

The uniform slip model of the Padang Event reveal that the preferred strike, dip, and depth shows 72.68°, 52.19° and 46.72 km, respectively. In this uniform model a selected relocation aftershock distribution is necessary to put the constraint in the model. The inferred distributed slip model shows that the highest peak of slip reached 3 m within depth 66.0 km - 72.8 km. The geodetic moment from the inferred model shows 1.41 1027 dyne-cm or equal to Mw 7.40.

Our inferred model suggests that the fault plane of Padang earthquake may located upper part of the interface not within the slab. It may be located in deeper part of accretionary wedge in Sumatra in between with continental Moho. According to velocity model, the depth of our inferred model may in the fluid saturated sediments which new part of former accretionary prism and also localized serpentinization. Assuming the backstop model from [36], We purposed Padang earthquake is lateral ramp due its strike perpendicular to the trench. However, the availability of high resolution data is necessary needed to understand the structure of Sumatra and also the tectonic implication in Sumatra. The dense of GNSS network also can be used to obtain the better outcome of distributed slip model and also the checkboard test. In addition, this invention such lateral ramp play an important role in seismic hazard in this region.

8. References
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