Subduction modelling by Tomography inversion around Lombok

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Abstract. In July 2018, Lombok Island in Indonesia shaken by earthquake of Flores Fault. The earthquake is felt in surrounding Lombok like Bali. There are two major earthquake source in Lombok, they are Flores fault in the north, and subduction zone in the south. There are more than 300 fatalities of human, and more than 270,000 refugees. The government of Indonesia established that Lombok Earthquake was a national disaster. This research is aimed to describe how the subduction zone around Lombok both it come two major of earthquake source and to answer the rumor is the earthquake affect Rinjani vulcano in Lombok activity or not.

1. Introduction
In July, 29, 2018, Indonesia hitted by earthquake (6.4 SR), especially in Lombok, Nusa Tenggara Barat Province. There are several fore shocks that have quite high magnitude before the main shock and have range about 3 weeks. In August, 19, 2018, the main shock is occure with magnitude about 7.9 SR and it was surprised many agencies include the government of Indonesia which have authority to disaster. More than 3000 peoples in Lombok were affected and more than 7000 peoples were injured. Table 1 shows casualties of Lombok earthquake based on BNPB [1].

![Figure 1. Tectonic setting of Lombok](image-url)
Based on geology and tectonic setting of Lombok, there are two major earthquake source. They are Flores fault in northern of Lombok and Java subduction in the south. Flores fault was became the earthquake source of Lombok in 2018 as mentioned above. It is include to back arc zone of Java megathust and has length of 2000 km from east Java to north of Timor (Kulali et al, 2016 op cit [2]) as showed in Figure 1. The focal mechanism of the earthquake based on EMSC web site has orientation from east to west of the rupture and kinematics. The geology of Lombok is dominated by volcanic rocks like tuffs, lahar, lavas etc due to Rinjani volcano (Figure 2) [2].

| Table 1. Casualties of Lombok Earthquake in August, 15, 2018 [1] |
|---------------------------------------------------------------|
| **Location Parameter** | **East Lombok Regency** | **North Lombok Regency** | **West Lombok Regency** | **Central Lombok Regency** | **Mataram City** |
| **Affected Population** (exposed to earthquake intensity V-VIII MMI) | 1,192,110 | 218,553 | 685,161 | 939,409 | 477,476 |
| **Population Displaced (BNPB)** | 104,060 (8.73%) | 178,122 (81.5%) | 116,453 (17%) | Data collection in progress | 18,894 (3%) |
| Male (to be update) | 46,827 (48.3%) | 60,049 (50.3%) | 52,404 (50.3%) | 8,505 (41.6%) |
| Female (to be update) | 57,233 (51.7%) | 44,073 (47.7%) | 64,049 (49.7%) | 10,391 (58.4%) |
| **Families displaced** (estimated based on average family size in each city/regency of NTB, BPS) | 22,981 (avg family/ member: 3.41) | 38,106 (avg family/ member: 3.6) | 33,375 (avg family/ member: 3.56) | N/A | 5,018 (avg family/ member : 3.66) |
| **Fatalities** | 12 | 396 | 39 | 2 | 2 |
| **Serious Injuries** | 47 | 248 | 210 | 2 | 63 |
| **Light Injuries** | 95 | 392 | 189 | 18 | 89 |
| **Damaged Buildings** | | | | | |
| **Heavy Damage** | 2,938 | 12,546 | 11,925 | 9 | 110 |
| **Moderate Damage** | 0 | 0 | 0 | 722 | 250 |
| **Light Damage** | 2,853 | 5,328 | 11,701 | 4,036 | 619 |
| **Initial estimation of economic damage & lost (BNPB)** | IDR 417,3 billion/ USD 284,5 Trillion | IDR 2,7 trillion/ USD 184 million | IDR 1.5 trillion/ USD 102 million | IDR 174,4 billion/ USD 118,9 Billion/ USD 165 thousands | IDR 242,1 billion/ USD 165 thousands |
| **Severely damaged houses** | 4,772 | 14,841 | 12,193 | 9 | 110 |
| **Moderately damaged houses** | 0 | 1,841 | 547 | 722 | 25 |
| **Lightly damaged houses** | 10,912 | 8,307 | 12,806 | 4,036 | 619 |
2. **Methodology**

Tomography is one method from medical science that applied to geoscience to describe physical properties of Earth’s interior. It works like CT scan or MRI. In this research, the earth’s interior that used is seismic velocity, especially for P wave. Several step must allow to describe the subsurface, they are model parameterization, forward modelling (relocating hypocenter and calculate ray tracing travel time), inversion method and resolution and error analysis. Initial model of P wave is also needed to complete the process [3].

Model parameterization construct the research area to some grids or blocks with certain size (Figure 3). Ray tracing is an important way to do tomography. There are several methods can be used, they are straight forward, shooting and pseudo bending. The basic principal of ray tracing is Fermat, Hyugens and Snellius Equation (Figure 4). Ray tracing is calculated in each grid or block of model parameteres and arranged in one matrix called Kernell matrix. The next step is modelling earth’s interior by inverse the Kernell matrix and calculate the resolution to get a best model.

![Figure 3. Sketch of model parameterization [3]](image)

![Figure 2. Geologic Map of Lombok [2]](image)
Ray tracing calculate from hypocenter to the station by Equation (1):

\[ T = \int_{S}^{R} U \, ds \]  

(1)

Where \( T \) is travel time from source (S) to receiver (R), \( U \) is slowness and \( s \) is pathlengths. (Rawlinson).

To make it easier, it is important to give name in each grid or block, then the numbers of blocks will become amount of column in Kernel matrix, while amount of row is based on total events of earthquake. Inversion method is calculated by Equation (2):

\[ m = [G^T G]^{-1} G^T d \]  

(2)

where \( m \) is parameter models (slowness), \( G \) is Kernel matrix and \( d \) is data. Data \( d \) contain information about differences between calculated and observed travel time [5]. For the resolution test, hit count of ray trace in each block is choosen.

3. Result and discussion

Research area cover central and eastern of Bali and Lombok Island. From the latitude of 7.75°S and 11.48°S and longitude from 114.49°E to 117.84°E with earthquake data reach to 350 events, from various magnitude from 2 SR to more than 7 SR and the maximum depth is 340 km. The data used is downloaded from USGS web site catalogue with BMKG station for reference. Initial model of P velocity wave is take from AK135 Table.

The research area then divided into 5 slices to do tomography inversion like showed in Figure 6, it’s tomography seismic of P wave is given in Figure 7 and the resolution test in Figure 8.
Figure 6. Eight slices in research area

Figure 7. Subduction zone as the result of tomography seismic around Lombok Island. Red and blue color interpreted as low and high velocity zone. Furthermore, low velocity zone is associated with hot fluid or partial melting indication. The x axis (horizontal) is distance and y axis
(vertical) is depth in km. There are 10 axis in vertical axis, where axis 1 and 10 is associated with the depth of 340 km and 10 km.

**Figure 8.** Hit count of ray tracing (ray density) in each section.

Figure 7 show the subduction model around Lombok. From section A-A’ to E-E’ the subduction zone is more complicated. As the research of [6], tectonic in Bali (section A-A’) mostly affected by subduction zone in the south. It is showed by tomography in section A-A’ that low velocity zone dominant in the subduction zone in the south and not from Flores fault in the north. While in Nusa Tenggara Barat (section B-B’ to E-E’), the subduction is deeper than in Bali, and low velocity zone still dominant in the subduction zone in the south. Lombok island subsurface described by section B-B’ and C-C’ and Rinjani volcano is located in section (B-B’). Based on the section, partial metling of Rinjani volcano is affected by subduction zone in the south and not come from Flores fault. So, if there an earthquake in Lombok that come from Flores fault activity, it is low possible affect to Rinjani. Furthermore, in the eastern of Lombok, the subduction zone’s depth is deeper. It can be predicted that if there is earthquake come from subduction zone activity, the energy will become bigger than Lombok earthquake in 2018. There are also much low velocity zone too, but it is needed geological or geochemistry study to proof what kind of it, because there are no volcano around subduction zone in the south. Generally, Nusa Tenggara Barat area is more dangerous than Bali in the earthquake impedance. It also match with hazard map of Indonesia [7] that Nusta Tenggara Barat has bigger peak ground acceleration value than Bali.

The resolution model as showed in figure 8 show that generally, the subduction model is match with ray tracing distribution. Based on the theory, the area that have much amount of earthquake and through by ray tracing will be low velocity zone. Because of the earthquake and station distribution (there are 7 stations in the area), the contrast is not very good. But generally, in each section the ray density is reach to low velocity zone.
4. Conclusion
Based on the result of this research, it conclude that generally there are two earthquake souce around Lombok, they are subduction zone in the south and Flores fault in the north. Dominantly partial melting around resarch area coming from the subduction zone and not from Flores Fault, so it is low possibility that earthquake that coming from Flores Fault can affected Rinjani volcano activity in Lombok. Overall, Nusa Tenggara Barat Province, include Lombok is more vulnerability than Bali. It is shown from tomographic result that the subducion zone in Nusa Tenggara barat is deeper and more complicated than Bali. It is also supported by hazard map of Indonesia, that Nusa Tenggara Barat has bigger peak groud acceleration value than Bali.

5. References
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