Identification of Fault Structure in Lombok region, West Nusa Tenggara using Tomography Lombok Earthquake Data of July-August 2018

R Widyarta\textsuperscript{1}, S K Wijaya\textsuperscript{2,}, M S Rosid\textsuperscript{1,*}, and S Rohadi\textsuperscript{3}

\textsuperscript{1} Geophysics, Universitas Indonesia, Depok 16424 Indonesia.
\textsuperscript{2} Physics Department, Universitas Indonesia, Depok 16424 Indonesia.
\textsuperscript{3} Research and Development Center, Meteorological, Climatological, and Geophysical Agency (BMKG), Jl. Angkasa 1 No. 2, Kemayoran, Jakarta, Indonesia.

*Email: skwijaya@sci.ui.ac.id and syamsu.rosid@ui.ac.id

Abstract. Lombok and Nusa Tenggara are one of the regions in Indonesia that have quite complex tectonic arrangements. With this order, not infrequently in the region there are often natural disaster phenomena. One of the most striking things is the occurrence of a series of earthquakes of magnitude $M_w > 5.0$ that rocked the northern region of the Island of Lombok on 29 July 2018 ($M_w = 6.4$), 5 August 2018 ($M_w = 6.9$), 9 August 2018 ($M_w = 5.9$), 19 August 2018 ($M_w = 6.3$ and 6.9) and 25 August 2018 ($M_w = 5.5$). This study aims to identify the condition of tectonic structures under the surface of the earthquake occurring region using the tomography method. This method utilizes earthquake travel time data recorded at 15 BMKG seismic stations. The tomogram results show the contrast of anomalous values in the $V_p$ and $V_s$ models. The contrast of the anomalous is associated with the presence of fault structures that have an allowance angle of about $\pm 20-30^{\circ}$ and a thrust fault type, verified by focal mechanism ball data. This thrust fault is then indicated as the cause of the occurrence of earthquakes with magnitude $M_w > 5.0$, which shook the northern part of the island of Lombok in July-August 2018. According to the tomography result, the fault is located closer to the north side of Lombok Island than Flores Back arc Thrust.

1. Introduction

Lombok Island and the Islands of Nusa Tenggara are one of the archipelago regions in Indonesia that have a high degree of vulnerability to earthquakes. One source of earthquakes that has been clearly identified is the active subduction zone that plunges from the southern part of Indonesia [1]. This zone originates from collisions between the Indo-Australian plate (south) and Eurasia (north). Another cause of earthquakes is the presence of active faults below the surface of the earth. One of the earthquakes caused by the fault movement was the occurrence of a series of earthquakes with $M_w > 5$ in the Lombok region, West Nusa Tenggara which happened in the range of July - August 2018. The earthquake was quite horrendous, because it caused a lot of damage and claimed many lives. From the data of the National Disaster Management Agency (BNPB) there are about 555 people died and material losses worth for more than 5 trillion rupiahs.

Earthquakes in July-August 2018 are classified as unique because there are 6 earthquakes with $M_w > 5.0$ that occur in the adjacent period, namely on 29 July 2018 ($M_w = 6.4$), 5 August 2018 ($M_w = 6.9$), 9 August 2018 ($M_w = 5.9$), 19 August 2018 ($M_w = 6.3$ and 6.9) and 25 August 2018 ($M_w = 5.5$) [2]. To
find out more about the structure that caused the earthquake, the tomography method was applied. It is hoped that the study can provide further information about the tectonic structures that exist in the Lombok region, West Nusa Tenggara, especially for further application in terms of disaster mitigation.

2. Methodology

Seismic tomography is a method to reconstruct the structure of the earth's surface by using waveform data or travel time data from seismic waves. In tomography the time of propagation seismic waves are slowness integrals that are passed by a beam that connects the source and receiver. Thurber defines wave propagation \( T_{ij} \) from source \( i \) to receiver station \( j \) in form of [3]:

\[
T_{ij} = \int_{source}^{receiver} u ds
\]

where, \( ds \) is the length of the segment of the seismic wave that is passed and \( u \) is the slowness function which is a position function. This integration function depends on the location of the hypocenter as the source and the location of the station as a receiver as well as an unknown 3-dimensional velocity structure. The arrival time of a seismic wave in a receiver can be written with the equation:

\[
t_{ij} = \tau_i + T_{ij}
\]

where \( t_0 \) is the wave arrival time, \( \tau_i \) is the time of the earthquake event. The tomography equation is a non-linear equation so it is necessary to do an inversion process where the process of this method is carried out using a Simulps12 software [4]. The steps of this study is drew in workflow diagram in Figure 1.

![Workflow Diagram](image-url)
3. Results and Discussion
The tomography inversion process using Simulps12 resulting cross sections of velocity structures \( V_p, V_s \) and \( V_p/V_s \) both horizontally (Figure 2) and vertically (Figure 3). The process of interpretation, carried out by analyzing the height and value of perturbation \( V_p \) and \( V_s \) models which then made the model of \( V_p/V_s \) ratio. The process is carried out based on the review in a mathematical formula that is matched with the possibility of geology in the study area. Mathematically, the P and S wave equations can be expressed as:

\[
V_p = \sqrt{\frac{K + \frac{4}{3} \mu}{\rho}} \tag{3}
\]

\[
V_s = \frac{\mu}{\sqrt{\rho}} \tag{4}
\]

Then the Equation 3 is substituted into Equation 4 to be

\[
V_p^2 = \frac{K}{\rho} + \frac{4}{3} V_s^2 \tag{5}
\]

where \( \rho \) is a density value, with \( K \) is a bulk modulus which has a value of \( \lambda \) as a component related to incompressibility (fluid ability holds pressure where water has a higher value of incompressibility than steam/gas). So, it can be said physically that the value \( V_p \) is related to fluids content in rocks. Whereas in \( V_s \), there is a rigidity component (\( \mu \)) which physically talks about the rock matrix contained. So, from the equation (5) an analysis of the possible types of geological structures that cover the study zone can be done.
In the horizontal tomography model, both at the depths of 0, 10, 20 and 30 km, the tomographic inversion results in the $V_p$ model showed a low perturbation anomaly in the Lombok Island region. The values of $V_s$ model are also showed there are contrast area low results (red in the South) and high value (blue in the North). According to Kusnandar, the presence of high-low contrast values can be indicated as the presence of fault zones [5]. Then the results of high $V_p/V_s$ ratio is obtained. It indicates that there is a considerable gap between the values of $V_p$ and $V_s$. In this case, if referring to the mathematical analysis in equation (5), it can be assumed that rocks in the Lombok region have a high level of incompressibility and a low level of rigidity (attachment between rock matrices), which means rocks in the zone are weak rocks.

Structure interpretation model is also made based on the $V_p$ and $V_s$ tomography modeling on the CC’ line (Figure 3a). There is low anomaly (in red color) in the region which is allegedly associated with the possibility of a weak zone. The zone could be the magma flow zone of Mt. Rinjani. The blue area on the other hand shows a high anomaly that looks contrasting to each other forms a zone that refers to the existence of fault-like zones. The fault zone is likely associated with the Flores back arc fault line which has a slope of up to ± 30° and the possibility of a new fault formed with similar allowance angles that are thought to be the cause of the Lombok earthquake that occurred in July - August 2018. This is confirmed by the results of the Widiyantoro et al. tomogram model [6] which shows the contrast which is thought to be a fault structure and the results of a study by Yadnya et al. [7] who had studied similar patterns in the Northern region of Bali.

From these indications, we tried to make a baseline (dashed black line) which is supposed to be a slope with a slope of approximately 20-30° in the anomalous contrast zone in the CC’ cross sectional model. As supporting data, then the fault line data was verified by Karima et al. [8] which examined the focus mechanism on the Lombok earthquake. The earthquake (yellow star) which occurred on August 19, 2018 ($M_w$ 6.9) happened not far from the CC’ line. The results of the plot indicate that the location of the hypocenter of the earthquake is right in the line of the fault. The results of the focal spherical mechanism also indicate that the earthquake originated from a thrust fault mechanism that has a dip value of 29° with a depth of 16.1 km below the surface.

Figure 2. Horizontal section of $V_p$, $V_s$ and $V_p/V_s$ tomographic inversion model at the depths of a) 0 and 10 km; b) 20 and 30 km.
Figure 3. a) An interpretation model based on the $V_p$ tomographic inversion model on the CC’ line is justified by the focus mechanism model of Karima et al. [8] b) The interpretation model made based on the results of $V_s$ tomographic inversion modeling on CC’ line.

The same results were also shown when the same hypocenters data in the CC’ cross section model are plotted (Figure 3b). Here the supporting data in the form of hypocenter distribution from Rosid et al. [9] are added. The result is the fault line that was drawn on the first model ($V_p$ tomogram model) in accordance with the hypocenter distribution which is seen to be in the area around the pull of the fault line. In addition to the faults indicated as the cause of the August 19, 2018 earthquake, the dashed red line is also tried to draw. The line thought to be related to the existence of Flores’s rear fault in the $V_s$ tomogram model of CC’ cross section. The drawing is also based on the distribution of hypocenter which forms a structural pattern near the location of the Flores reverse fault, where the results of the drawing form around an angle of approximately 30°. Refer to Daryono study [10], the Flores Fault is...
continued in the northern region of the Island of Bali. The predicted faults are appropriate because the faults in North Bali have fault angle allowances that vary from 20-35°. Figure 4 is a simple illustration that illustrates the results of the mechanism of the increase in the fault that allegedly caused the earthquake in the Lombok region.

![Illustration of the fault model for the Lombok 2018 earthquake](image)

**Figure 4.** Illustration of the fault model for the Lombok 2018 earthquake that is made based on the results of tomographic inversion modelling.

Based on the results of the tomography model above, the researcher draws conclusions, if the cause of several earthquakes with a $M_w > 5.0$ that occurs in the northern region of the Lombok Island, presumably due to the existence of fault which presence of compressive forces between the Indo - Australia plate in the South and the Eurasian plate in the North, giving rise to a force of stress which then slowly breaks and forms a fault zone with a faulty mechanism with an angle of approximately 20-30° which plunges southward to at a depth of more than 15 km.

4. Conclusion

The tomogram results show the contrast of low anomaly values and high in the $V_p$ and $V_s$ models which after being matched with focal spherical data, it is indicated if the anomalous contrast values are associated with the existence of a fault structure to the south around ± 20-30° and a type of upward fault. This upward fracture is then indicated as the cause of $M_w > 5.0$ magnitude earthquake that shook the North Island of Lombok in July-August 2018 (29 July 2018 ($M_w = 6.4$), 5 August 2018 ($M_w = 6.9$), 9 August 2018 ($M_w = 5.9$), August 19, 2018 ($M_w = 6.3$ and 6.9) and August 25, 2018 ($M_w = 5.5$).

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