Characterization of Lombok Earthquakes on July-August 2018 using Focal Mechanism Analysis

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Abstract. Focal mechanism study was carried out on 5 major earthquakes that occurred in Lombok on July-August 2018. The KIWI program was applied here to compare the parameters of the 5 earthquake sources. The principle of the KIWI program is inversion of wave components at various stations to obtain the moment tensor. Green’s Function is also implemented to create synthetic waves representing the observation waves. Source parameters are taken from the synthetic waves from the five recorded events, and it was found that the 5 earthquakes on July 29th, 2018, August 5th, 2018, August 9th, 2018, and two earthquakes on August 19th, 2018 have strike values varying between 61°-74°, dip values between 18°-36°, and rake values between 75°-93°. These five earthquakes have similar source parameters, and have focal balls which state that the type of fault in these earthquakes are thrust faults. The similar source parameters, close range of time of occurrence, and hypocenter distances indicate that the earthquake events were most likely caused by the same fault.

1. Introduction
On Sunday, July 29th, 2018, at 05.47 WIB, Lombok experienced an earthquake with a magnitude of Mw 6.5 at a depth of 13 km. Exactly one week later, on Sunday, August 5th, 2018, the island was again rocked by an earthquake with a magnitude of Mw 6.9 at a depth of 15 km. Then, on August 9, 2018, Lombok was again struck by an earthquake by the magnitude of Mw 5.9. Exactly 10 days later, on August 19, 2018, two large earthquakes rocked Lombok with magnitudes of Mw 6.3 at 11.10 WIB and Mw 6.9 at 22.56 WIB [1]. These earthquakes have a close distance between the sources, and according to a study about earthquakes in Aceh, there is a possibility that close-distanced earthquakes are caused by the same fault [2].

Further analysis is needed to determine whether these earthquakes are generated from the same source. Focal mechanism analysis may be able to describe the source mechanism for the fault planes geometrically and mathematically when the earthquakes occurred [3]. The purpose of this study is to characterize those earthquakes as well as the fault planes that cause the earthquakes. Focal mechanism is used to evaluate an earthquake data to obtain the orientation of the fault movement that causes the earthquake. The analysis includes the determination of fault parameters, that are strike, dip, and slip angles [1]. Then, these parameters are compared to each other to find out whether the earthquakes have similar source mechanism characteristics.
2. Methodology
In order to analyze the focal mechanism of this earthquake sequence, the earthquake waveform data taken from BMKG catalog (webdc) is converted and the earthquake wave components, that show wave displacement in 3 directions, namely the Vertical (Z) direction, North-South direction (N), and East-West direction (E) are rotated into component of Vertical (Z), Radial, and Tangential directions. The reason why these components are rotated is because the N and E direction very rarely corresponds to the polarization of the S wave in the horizontal direction (SH) and in the vertical direction (SV) [4]. Band-pass frequency filters are then applied to eliminate the attenuation effect on high frequency waves. Aside of putting on filters, waves from seismographs are selected to eliminate stations or components that fail to record properly due to tool malfunctions when the earthquake occurs. The wave inversion process is then performed to obtain the focal beachballs and fault parameters for the Lombok Earthquake 2018. The parameters are then analyzed to see the similarity. The inversion was also carried out to differentiate compression and dilation quadrants by calculating synthetic waves for two possible solutions and cross-linking between synthetic waves and observation waves and applying the smallest misfit [5]. In addition, the distribution of aftershock from Lombok Earthquake 2018 sequence was also mapped to see the trends showing that could possibly indicate the presence of the faults.

3. Results and Discussion
The results obtained from processing the earthquake waveforms are in the form of source parameter values of faults, namely strike, dip, rake, and focal beachballs for each earthquake. There are two strikes, dips, and rakes values for each event, where both values represent 1 fault plane and 1 auxiliary plane. These two planes are perpendicular to each other.

The source parameters resulted from the Lombok Earthquake 2018 are shown in Table 1 as follows:

| Date and Magnitude | Strike  | Dip  | Rake  |
|--------------------|---------|------|-------|
| 29/07/18 (Mw = 6.5) | 64°  | 61°  | 75°  |
| 5/8/2018 (Mw = 6.9) | 260° | 28°  | 96°  |
| 9/8/2018 (Mw = 5.9) | 61°  | 62°  | 93°  |
| 19/8/18 #1 (Mw = 6.3) | 238° | 62°  | 88°  |
| 19/8/18 #2 (Mw = 6.9) | 62°  | 36°  | 81°  |

The comparison of these parameters showed relatively similar values. To strengthen the analysis, the focal beachballs of the five strong earthquakes are also compared to see the similarities. The comparison is shown in Figure 1.

![Focal beachball solutions of Lombok Earthquake 2018](image)

Figure 1. Focal beachball solutions of Lombok Earthquake 2018 on (a) July 29th 2018, (b) August 5th 2018, (c) August 9th 2018, and (d & e) August 19th 2018.
As shown in Figure 1, the 5 focal beachball solutions obtained from the Lombok Earthquake 2018 have a similar shape. These five beachballs indicate that the earthquakes occur due to the upward fault movement, widely known as thrust fault. Focal beachballs illustrate the direction of force, where the white part shows the maximum pressure zone and the red zone shows the minimum pressure zone [6]. The plotted beachballs for this earthquake sequence shows that the maximum force direction compresses the fault relatively from the North and the South, so that the fracture issues a minimum pressure to the top as shown in Figure 2.

Figure 2. Beachball distributions of Lombok Earthquake 2018 and the relative direction of forces acting on the earthquake sources.

Figure 3 shows the distribution of earthquake epicenters in Lombok between July-September 2018 with magnitude above Mw 3.5.
Figure 3. Epicenter distribution of Lombok Earthquake 2018 aftershocks on July-September 2018 (Mw ≥ 3.5)

The epicenter distribution shown in Figure 3 tends to form a line in East-West orientation. This line shows a trend that could be interpreted as a fault, but it is difficult to determine whether this fault is the back-arc Flores Thrust or a local fault based on the available data. For this reason, a validation using secondary data in the form of tomographic study is necessary. The result of tomography study from Widyarta et al. [7] is shown in Figure 4.
Figure 4. Tomography and hypocenter distribution of Lombok Earthquake 2018 on July-September 2018 [7].

From the tomography and hypocenter distribution shown in Figure 4, it can be seen that the hypocenter trend of aftershock distribution is not exactly in Flores Thrust, but is closer to the north coast of Lombok Island. Based on that data analysis, it can be said that this earthquake sequence was not caused by the activity of Flores Thrust, but rather by another local fault.

4. Conclusion
From this study, it can be concluded that the focal spherical patterns of the five Lombok Earthquake 2018 are able to characterize the faults. The earthquakes are caused by upward fault movements with similar focal spheres, similar parameter values, as well as the time of occurrence and adjacent distances. Therefore, the earthquake sequence is most likely caused by the same fault system. The sequence was most likely to be caused by the activity of a local fault along the north coast of Lombok Island, rather than the Flores Thrust.

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