Earthquake Generation Analysis Using the Focal Mechanism Method in the Flores Sea Region, East Nusa Tenggara

Afriansyah Afriansyah[1], Sandra Sandra[1], Wa Ode Awaliah[1], M. Rusydi H[1], Rustan Efendi[1], Mauludin Kurniawan[1]

[1]*Department of Geophysical Engineering, Tadulako University, in Palu, Central Sulawesi*
Corresponding Author E-mail: afriansyah.tnb@gmail.com

Abstract: East Nusa Tenggara is an area that has a fairly high seismicity level because it has 2 earthquake hazard zones. The first is the hazard from the subduction zone of the Eurasian Plate and the Indo-Australian Plate, the second is the hazard caused by the back arc thrust fault or also known as the Flores Thrust. This study aims to map the distribution of seismicity and the distribution of focal spheres to determine the characteristics of the fault. The method used is focal mechanism with earthquake data obtained from USGS and Global CMT fault parameters for the period 2017 - 2022. The results obtained show that the study area has an increasing level of seismicity from year to year. A total of 432 earthquakes were recorded, ranging from shallow to deep earthquakes during the last 6 years. In addition, the distribution of focal mechanisms spread across 38 points indicates that earthquake occurrences are dominated by strike-slip fault, although there are also those caused by reverse fault and normal faults. These faults are inseparable from the active geological structures in the Flores Sea region, namely the Kalatoa Fault, the Flores Thrust, and the Indo-Australian Plate subducting beneath the Australian Plate. This indicates that the study area has a very high level of earthquake vulnerability.

Keywords: Earthquake Flores Sea, Focal Mechanism, Indo-Australian Plate, Kalatoa Fault

1. Introduction

Indonesia is a country that is geologically located between 3 very active tectonic plates, namely the Pacific Plate, Eurasian Plate, and Indo-Australian Plate. The movement of the three plates forms a subduction line or subduction zone that is actively moving until now. In addition, the movement of the three plates is also the source of the formation of faults in Indonesia, both local faults and regional faults. The existence of subduction zones and faults can trigger tectonic earthquakes, one example is the seismic activity in the Flores Sea region, East Nusa Tenggara [1].

East Nusa Tenggara is included in the earthquake hazard area because it is bounded by two earthquake hazard zones: one from the southern hemisphere in the form of earthquakes caused by the subduction zone of the Eurasian Plate and the Indo-Australian Plate, and the other from the northern hemisphere in the of earthquakes caused by back arc thrust faults, also known as the Flores Thrust. The Flores Thrust often causes shallow earthquakes with depths of less than 70 km [2]. History records that 12 large and destructive earthquakes have occurred from 1962 - 2004 in this region [3]. Three of these earthquakes were followed by tsunamis, namely the 1977 earthquake with M8.3, the 1992 earthquake with M7.5 and the 1995 earthquake with M6.5 [4]. These earthquakes occur due to the consequences of subduction, namely back-arc thrusting with terrestrial faulting [5].

Based on the research on the December 14, 2021 earthquake conducted by Supendi et al. [6], the faults that cause earthquakes in the Flores Sea region are obtained. These faults are classified into 3 segments, namely the western segment, eastern segment and central segment. These three segments are associated with the back arc thrust in the southern part of the Flores Sea that causes many earthquakes in the region. Therefore, the author is interested in conducting further research to analyze the characteristics of earthquake generating faults in the Flores Sea region of East Nusa Tenggara using the focal mechanism method.

2. Method

The research location is in the East Nusa Tenggara Islands and Flores Sea, Indonesia with a geographical location at 119.5° - 123.5° East and 06° - 09° LS (Fig.1). This study uses earthquake catalog data from the USGS downloaded at the link (https://www.usgs.gov/) with the period 2017 - 2022 with M ≥ 4 which is used to create a seismic map at the research location. The catalog data obtained in the form of event time

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data, latitude, longitude, depth, magnitude. Furthermore, Focal Mechanism data in the form of fault parameter data, namely strike, dip, and rake along with latitude, longitude, depth, magnitude and time of occurrence were obtained from the Global CMT (Centroid Moment Tensor) downloaded at the link (https://www.globalcmt.org/) with M ≥ 5. In addition, supporting data such as Kalatoa fault data obtained from Supendi et al [6] as well as trench data and subduction slab models from USGS were also used. Data processing was carried out by making an earthquake vulnerability graph, making an earthquake seismicity map, cross sectioning the structure using the GMT 6 program from the earthquake distribution map that had been processed previously and making a map of the distribution of the earthquake focal mechanism.

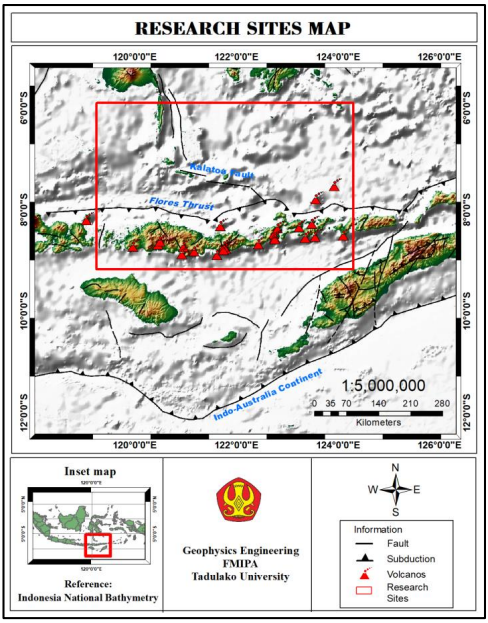

Fig.1. Map of the Research Site, located around the eastern Nusa Tenggara region and the Flores Sea

3. Result

3.1 Earthquake Frequency of Occurrence

The highest number of earthquake events occurred in 2022 with 129 earthquakes, while the lowest number occurred in 2018 with 46 events (Figure 2a). Based on the data, earthquake occurrences tend to increase, although there is a slight decrease in 2018 and 2020. This shows that there is an active structure in the Flores Sea region. Then the earthquake that occurred 432 times in the last 6 years shows that this region has a high level of seismicity. Of course this is inseparable from the tectonic setting of Nusa Tenggara which is located on the Sunda - Banda Arc transition at the intersection of the eastern boundary of the Australian Plate subduction margin and the western part of the collision zone between the Australian Plate and the Banda Arc [7].

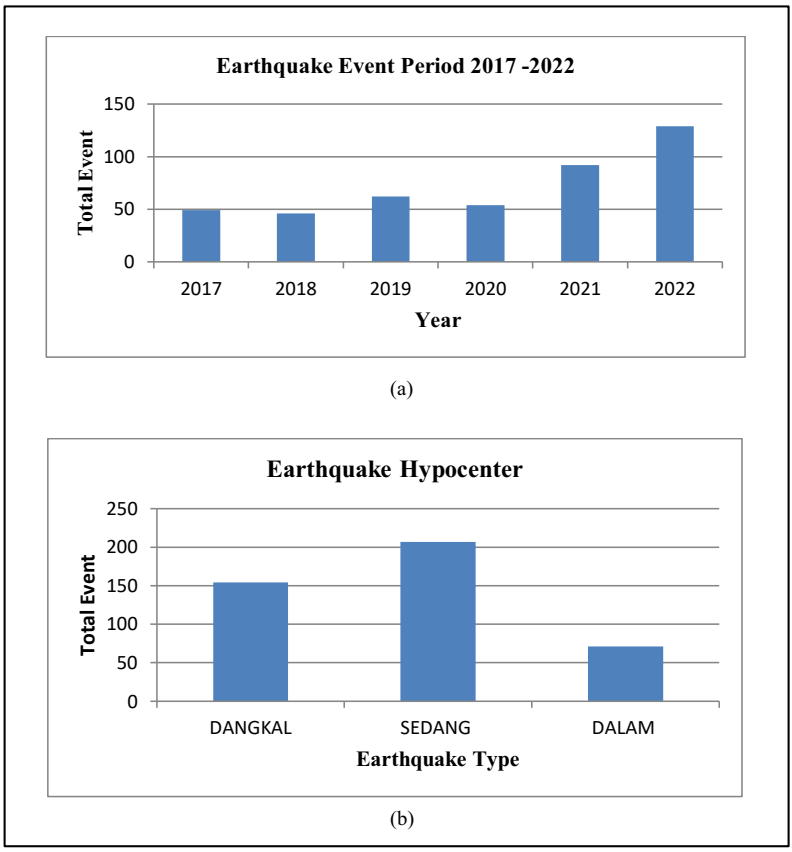

Fig.2 (a) Graph of Earthquake Occurrence
(b) Earthquake Types by Depth

The type of earthquake in the Flores Sea region of East Nusa Tenggara based on hypocenter depth (Figure 2b) is dominated by moderate earthquakes (70-300 km) with a total of 207 events. Shallow earthquakes (0-70 km) numbered 154 events and deep earthquakes (300-700 km) numbered 71 events. The large number of moderate earthquakes in this region is caused by the subduction of the lithosphere that subducts to the north at a depth of 200 km under the island of East Nusa Tenggara as a result of the convergent movement of the Indo-Australian Plate [7].

3.2 Distribution and Cross-Section of Earthquakes

In the earthquake distribution data in the Flores Sea region, cross-sections were conducted by considering the structure in the research area, namely by making a cross-section line perpendicularly cutting the existing structure in the Flores Sea region and its surroundings. The cross-section of the earthquake hypocenter is carried out as many as 3 tracks, namely the A - A', B - B', and C - C' tracks (Figure 3).

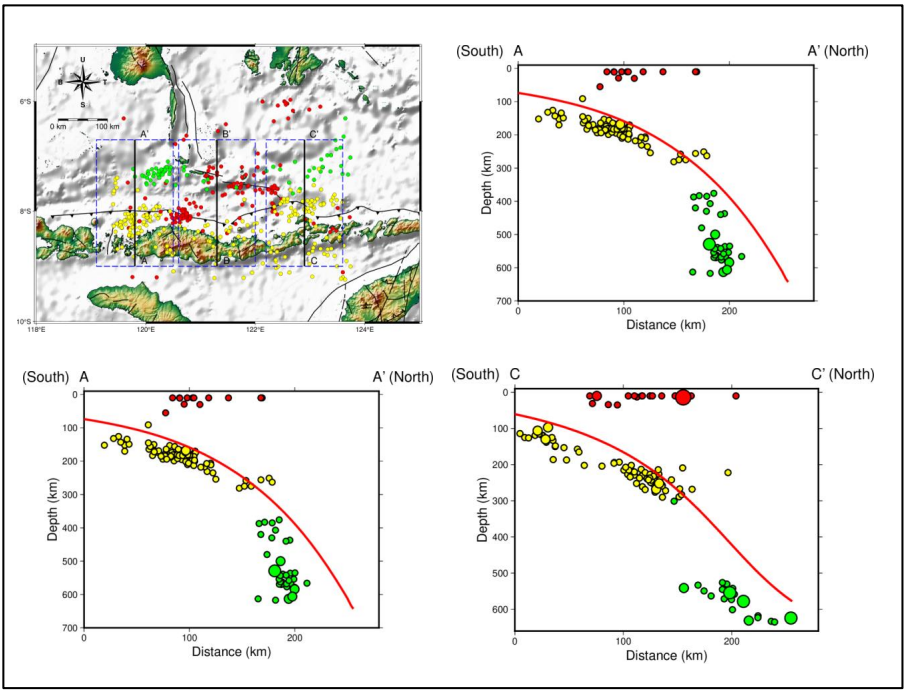

Fig.3. Earthquake Cross-Section of the three cross sections A-A', B-B' and C-C'

Cross-section profiles A - A', B - B', and C - C' are dominated by moderate earthquakes (yellow color) with depths ranging from 70 - 300 km. When viewed from the distribution of deep and moderate earthquake hypocenters (yellow and green colors), the shape of the subduction or subduction zone in the Flores Sea that causes many earthquakes is clearly visible. The earthquake hypocenter shows that the further north the earthquake hypocenter is, the deeper it is. The zone is thought to be associated with the subduction of the Indo-Australian Plate as seen in the slab model. Furthermore, the shallow earthquake (red color) shows that the earthquake accumulates in the area with an average depth of 10 km, which is the activity of the eastern segment of the Kalatoa Fault located in the northern part of the Flores Thrust and is also thought to be the result of the activity of the eastern Flores Thrust. [5]

3.3 Distribution of Earthquake Focal Mechanism

Figure 4 shows that there are 11 focal spheres that reflect the fault characteristics of the four regions described. The four regions are dominated by earthquakes caused by strike-slip faults. These earthquakes include 11 events caused by reverse faults, 9 events caused by normal faults and 18 events caused by strike-slip faults. 11 faults were mapped using the focal mechanism with 4 reverse faults, 3 normal faults and 4 strike-slip faults in the study area. The analysis obtained from the earthquake that occurred in the Flores region was influenced by the strike-slip fault pattern.

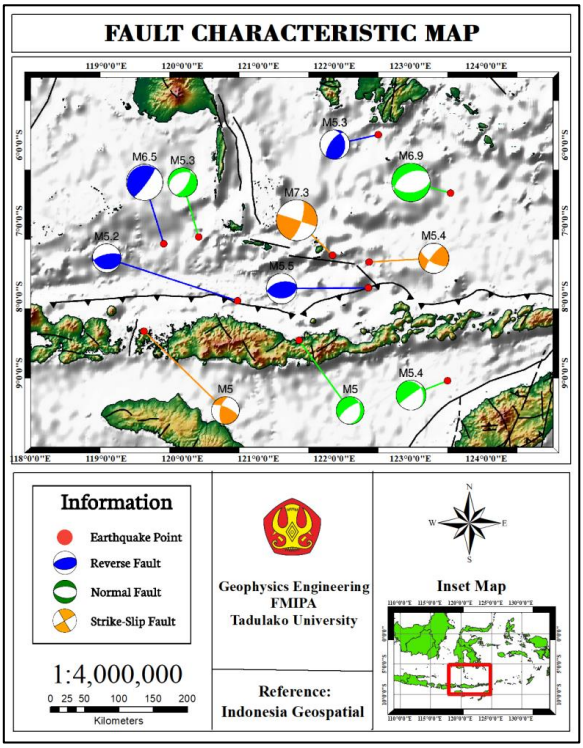

Fig.4. Map of Flores Sea Earthquake Characteristics, scattered types of strike-slip faults, reverse faults and normal faults

According to Supendi et al. (2022) [6], the strike-slip fault pattern in the Flores Sea is a sinistral fault. This can be seen from the shape of the focal sphere that is influential in the research area which causes many earthquakes in the sea area. The horizontal strike-slip fault that causes this earthquake is also called the Kalatoa Fault because it crosses Kalatoa Island in the middle of the Flores Sea. This fault has 3 segments that run from east to west with the length of each segment being 100 km, 50 km and 40 km. This causes many earthquakes caused by the strke-slip fault along the Flores Sea.

The map of focal mechanism distribution also contains several reverse faults and normal faults. One of the earthquake hazard zones according to Rysnawati et al. (2017) [2], is the back arc thrust rising fault or also called the Flores Thrust. This structure is the main cause of many earthquakes by rising faults. Meanwhile, the normal faults that occur in the study area are caused by the subduction of the Indo-Australian Plate that subducts to the north under the Eurasian Plate, which causes many intermediate and deep earthquakes on the island and in the Flores Sea. In addition, the complex tectonic setting of the Nusa Tenggara islands formed by volcanic arcs and is the Sunda - Banda transition zone is the cause of many earthquakes that occur in this region [8].

4 Conclusion

The types of faults based on the analysis of earthquake focal mechanisms in the Flores Sea region of East Nusa Tenggara for the period 2017-2022 with magnitude ≥ 5 are strike slip fault, reverse fault and normal fault. A total of 38 earthquakes are distributed along the East Nusa Tenggara region, which are dominated by strike-slip faults as many as 18 earthquakes, 11 by reverse faults and 9 by normal faults. The main cause of earthquakes in the Flores region of East Nusa Tenggara is caused by active structures, namely the Kalatoa Fault

which is a horizontal fault, the Flores Thrust (back arc thrust) or reverse fault and the Indo-Australian Plate Subduction as a descending structure which causes intermediate and deep earthquakes in the Flores Sea region.

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