Analysis of Seismotektonic Patterns in Sumatra Region Based on the Focal Mechanism of Earthquake Period 1976-2016

F P Indah¹, S Syafriani²*, Z S Andiyansyah²

¹Physics Department, Faculty of Mathematics and Science, Universitas Negeri Padang, Indonesia
²Badan Meteorologi Klimatologi dan Geofisika, Pusat GempaBumi Regional VI Padang Panjang, Sumatera Barat, Indonesia

Fitripermataindah33@gmail.com

Abstract. Sumatra is in an active subduction zone between the indo-australian plate and the eurasian plate and is located at a fault along the sumatra fault so that sumatra is vulnerable to earthquakes. One of the ways to find out the cause of earthquake can be done by identifying the type of earthquake-causing faults based on earthquake of focal mechanism. The data used to identify the type of fault cause of earthquake is the earth tensor moment data which is sourced from global cmt period 1976-2016. The data used in this research using magnitude m ≥ 6 sr. This research uses gmt software (generic mapping tolls) to describe the form of fault. From the research result, it is found that the characteristics of fault field that formed in every region in sumatera island based on data processing and data of earthquake history of 1976-2016 period that the type of fault in sumatera fault is strike slip, fault type in mentawai fault is reverse fault (rising faults) and dip-slip, while the fault type in the subduction zone is dip-slip.

1. Introduction

Indonesia is at the center of the collision of large tectonic plates, the collision of the Indo-Australian tectonic plates in the south, the Eurasian Plate in the North and the Pacific Plate in the Northeast to the southwest [11]. The collision between the Eurasian Plate and the Indo-Australian Plate affects western Indonesia (off the coast of Sumatra, Java and Nusatenggara). In addition, the territory of Indonesia is also skipped magmatic arc.

The island of Sumatra is located in an active seismic subduction region as a result of its location which lies on the boundary of the plate between the Indo-Australian plate to the north that dips down the Eurasian plate. This situation also resulted in the island of Sumatra has many volcanoes and hills known as hill ranks. In addition, this situation also resulted in the island of Sumatra has a fault or fracture that stretches along the mainland of Sumatra from the bay semangko in Lampung to Banda Aceh in Aceh Province.

The movement of the Indo-Australian plate initially had a speed of 86 mm / year and then decreased drastically to 40 mm / year as a result of the collision process. This decrease continues to occur up to 30 mm / year at the beginning of a new tectonic configuration process. Furthermore, the rate of return has increased significantly up to 76 mm / year [6].
Based on the explanation of the above tectonic causes the formation of three earthquake-prone zones namely subduction zone, Mentawai fault, and Sumatera faults. The subduction zone is located in the northwestern part of Sumatra Island, the Mentawai fault is located around small islands in the northwestern part of Sumatra island (Sunda strait - Nias island), and the Sumatera fault lies on the mainland of the western island of Sumatra from Semangko Bay (Sunda Strait) to the northern part of the island of Sumatra (Aceh). Natawidjaja, (2007) says that the potential “megathrust” earthquakes of subduction zones vary along the path depending on the fault segmentation and the size of the locked zone, as well as the history of the earthquake recurrence. These three parameters determine where there is a large accumulation of strain energy (tectonics) that can produce large earthquakes later on. The great earthquake of Aceh-Andaman (2004, Mw 9.15) [14] and also the Nias-Simelue earthquake (2005, Mw 8.7) [3] were previously characterized by seismic zone gaps.

Next row of two large earthquakes in the northern part of this subduction megathrust zone of Sumatra, the next megathrust zone is the Mentawai fault [10]. The last major quake on this Mentawai was the year 1797 (Mw8.4) and 1833 (Mw 8.9) [8]. These two large earthquakes resulted in a large tsunami occurring on the coasts of western Sumatra and Bengkulu. Paleoseismic and paleogeodetic research using microatol coral method reveals the fact that there was a great earthquake in the 1300s and 1600s similar to that of 1833 [7]. This shows that Mentawai megathrust has an earthquake cycle of about 200 years [8].

On Sumatra land, the Sumatera fault extends along the Bukit Barisan Mountains, from Semangko Bay in the Sunda Strait to the northern part of Aceh [13]. Already about 20 major and devastating earthquakes have occurred along the Sumatra Fault in the last 100 years [9]. In other words, a major earthquake in Sumatera fault occurs on average in every five years. Thus, unlike in the Sumatera fault that has the potential to release a large earthquake with magnitude of > 8 but only about 2-3 times in the span of 100 years, the earthquake in Sumatra fault magnitude < 7.7 but often and the source closer to the population [10].

The Sumatra fault consists of large segments. The fault segments are the Sundanese segment (6.75°S ~ 5.90°S), Semangko segment (5.90°S ~ 5.25°S), Kumering segment (5.35°S ~ 4.35°S), Manna segment (4.35°S ~ 3.85°S), Musi segment (3.65°S ~ 3.25°S), Ketaun segment (3.35°S ~ 2.75°S), Dikit segment (2.75°S ~ 2.30°S), Siulak segment (2.25°S ~ 1.70°S), Suliti segment (1.75°S ~ 1.00°S), Sumani segment (1.00°S ~ 0.50°S), Sianok segment (0.70°S ~ 0.10°N), Barumun segment (0.30°N ~ 1.20°N), Angkola segment (0.30°N ~ 1.80°N), Toru segment (1.20°N ~ 2.00°N), Renun segment (2.00°N ~ 3.55°N), Tripa segment (3.20°N ~ 4.40°N), Aceh segment (4.40°N ~ 5.40°N), Seulimeum segment (5.00°N ~ 5.90°N) [9]. The fault segments in Sumatera Island have made the tectonic structure of Sumatera Island to become active, so it is necessary to analyze the activity of fault section to know the type of faults in the area.

The activity of the earthquake fault field can be identified through the focal mechanism of the earthquake. Focal Mechanism Solutions (FMS) or focus mechanism is a fault analysis that is formed due to tectonic activity in a region based on the moment tensor value of the earthquake.

Moment tensor values used in analyzing focus mechanisms can be obtained from Global Centroid Moment Tensor (CMT). The value of tensor moment is then used as input or input on Generic Mapping Tools (GMT) software to get a beach ball which represents the movement of the fault field formed due to tectonic activity or earthquake in an area

2. Data and methods
The research data used is earthquake data sourced from Global CMT. The data used is the Global CMT in the Sumatra earthquake period 1976-2016. The study area is Sumatra with coordinates of 6°LU-11°LS and 95°BT-109°BT. Earthquake magnitude used in this research is M ≥ 5 with the depth of the earthquake 0-300 km.
Data processing technique using Focal Meananism to produce fault forms of earthquake in Sumatra. For the painting of earthquake focus mechanism can use GMT software. Fault type of earthquake can be analyzed based on earthquake focus mechanism generated. The focal mechanism will display the causative type of earthquake based on the parameters of the fault is strike, dip, and rake. Thus, from these parameters will be obtained type fault earthquake causes in earthquake-prone areas.

Aki and Richard (1980) [1] determine the type of fault based on strike, dip, and rake parameters as follows:

a) Strike slip fault, if $\delta = 90^\circ$ and $\lambda = 0^\circ$ (left shear) or $\lambda = 180^\circ$ (right shear).

b) Normal fault, if $\delta \neq 0^\circ$ and $\delta \neq 90^\circ$ and $-180^\circ \leq \lambda \leq 0^\circ$.

c) Thrust fault, if $\delta \neq 0^\circ$ and $\delta \neq 90^\circ$ and $0^\circ \leq \lambda \leq 180^\circ$.

Based on the above analysis can be identified fault type of earthquake based on the value of fault parameters.

3. Results And Discussion

3.1 Research Results

The data used in this study comes from the Global CMT in the form of data from the moment tensor earthquake value that occurred in the region of Sumatra period 1976-2016. Data derived from Global CMT is used to describe seismicity maps of earthquake distribution and focal mechanism to describe the type of fault cause of earthquake. The data format for seismicity map depiction consists of latitude, longitude, depth, and magnitude. Earthquakes with small magnitudes to large magnitudes often occur due to the tectonic order of the island of Sumatra. Figure 1 shows the seismicity map of earthquake distribution with magnitude $M < 5$ SR and $M \geq 5$ SR Period 1976-2016.

![Figure 1. Map of Seismicity of Sumatra Region Period 1976-2016](image)

Figure 1 shows the seismicity map of earthquake distribution period 1976-2016 with magnitude $M < 5$ SR and $M \geq 5$ SR. The focal mechanism depiction in each earthquake active zone can be seen in Figure 2.
Figures 2 represent the shape of an earthquake focal mechanism on the Mentawai fault and the Sumatra fault. Based on the data of moment tensor values obtained by the form of focal mechanism earthquake distribution based on earthquake data with magnitude ≥ 5 SR period 1976-2016 as shown in Figure 3. Figure 3 shows the shape of the earthquake focal mechanism in the subduction zone, the Mentawai fault, and the Sumatra fault. If we zoom the map of focal mechanism distribution of earthquake in West Sumatra Region in figure 3(b).

3.2 Discussion

In this study, data from Global CMT is processed using Generic Mapping Tools (GMT) software to obtain earthquake focal mechanism based on earthquake data of 1976-2016 period for three earthquake-causing zones in Sumatera region (subduction zone, Sumatera fault, and Mentawai fault).

Based on Figure 1 it can be seen that earthquakes have occurred in Sumatra with magnitude <5 SR and magnitude ≥ 5 SR. This shows that the tectonic order of Sumatra is very active which is characterized by many earthquakes occurring in Sumatra. In Figure 1 it can be seen that the most
Prevalent earthquakes are shallow earthquakes with depths of 0-70 km distributed in subduction zones and Mentawai faults. While a small part of the earthquake in this period occurred at a depth of 71-300 km. Based on the depth and distribution of the earthquake it can be seen that the tectonic order of Sumatra is very active. The area of Sumatra in the marine region (Mentawai fault and subduction zone) is more active than inland Sumatra (fault / Sumatera faults).

An earthquake on Mentawai fault may also be caused by subduction activities where the Indo-Australian plate infiltrated under the Eurasian plate. In some earthquake events, the cause of earthquake in Mentawai fault is caused by subduction zone. One study that explains it is research on the Mentawai earthquake report on October 25, 2010 conducted by the Meteorology Climatology and Geophysics Agency, 2010 [2] which states that "Mentawai Earthquake on October 25, 2010, 7.2 magnitude, 3.61 LS - 99.93 BT, 78 km Southwest Pagai, Mentawai-western Sumatra meets the criteria as an earthquake that causes TSUNAMI (Magnitude ≥ 7.0 SR, position at sea, depth <33 km). This earthquake is a tectonic earthquake caused by the collision of the Indo-Australian Ocean plate to the Eurasian continental plate with a source mechanism of thrust fault." Therefore, it is necessary to identify the type of fault causing the earthquake.

In this study for the description of the type of fault causing earthquake using focal mechanism based on the data of moment tensor value. The result of the seismotectonic pattern formed in the form of a focal sphere used to display an earthquake focus mechanism that explains the fault parameters of the earthquake. Moment tensor can be used to measure the strength of the earthquake by using the seismic moment parameter \( M_0 \) shown in equation (14). Determination of the type of fault can be done through the analysis of fault parameters that cause earthquake strike (φ), dip (δ), and rake (λ). From the results of the analysis of fault parameters known fault type causes earthquake.

Figure 2 shows an analysis of the type of faults that cause the earthquake on April 01, 1998 with magnitude 6.9 SR based on strike (φ), dip (δ), and rake (λ) obtained from Global CMT. An earthquake on April 01, 1998 has a strike value of 320, dip = 21, and slip = 105 on the nodal 1 and strike = 124, dip = 69, and slip = 84 fields of nodal 2 obtained from Global CMT. After analysis based on strike parameter (φ), dip (δ), and rake (λ) it is known that the type of earthquake fault of April 01, 1998 is reverse fault where Aki and Richard, 1980 [1] stated that the reverse fault, if \( δ \neq 0^0 \) and \( δ \neq 90^0 \) and \( 0^0 \leq λ \leq 180^0 \). The seismic moment of earthquake on April 01, 1998 is 3.32 obtained using equation (14).

The depiction of the focal mechanism of the entire earthquake with the magnitude of M ≥ 5 SR in the period 1976-2016 is shown in Figure 4. Figure 4 shows the shape of the earthquake focal mechanism in the subduction zone, Mentawai fault, and Sumatra fault. The shape of the earth's focal mechanism has the same overall shape in each of the active zones.

The shape of focal mechanism in Sumatera fault based on the data of moment tensor earthquake of the period 1976-2016 shown in Figure 4 shows that the type of faults that cause earthquake in the fault of Sumatra is generally strike slip. This is in accordance with previous studies conducted by Sieh and Natawidjaja, (2000) [13] stating that "The Summit Fault is a stratified curvature strike slip consisting of 20 major segments along the backbone of Sumatra". The shape of this pattern is one of them caused by the influence of the geological condition of the island of Sumatra. The Indo-Australian Plate infiltrated in an oblique direction into the Eurasian plate. The oblique tilting caused the formation of SFZ is a dextral strike slip fault zone that extends from the northern tip to the southern tip of Sumatra Island.

The form of focal mechanism in Mentawai fault based on earthquake data of 1976-2016 period shown in Figure 4 is dominated by reverse fault. Mukti et al. (2012)[5] conducted a study of seismic cross section under the Mentawai Fault and stated that there are anticillin (rising rock structures) located on Mentawai fault. This is due to the encouragement of the Indo-Australian plate toward the Eurasian plate causing anticillin. The result of anticillin on Mentawai fault resulted in the formation of reverse fault pattern on Mentawai fault. In addition, in this study also obtained the form of strike
slip fault on Mentawai fault. Samuel and Harburry (1996) [12] say that for the Mentawai fault that extends to Nias island has a fault pattern of strike slip.

The focal mechanism of the subduction zone based on earthquake data of the period 1976-2016 is a dip-slip consisting of normal fault and reverse fault. Madrinovella et al. (2011) [4] states that geologically, the pattern of the fault plane formed in the subduction zone is due to the subduction of the Ocean. The Indo-Australian Plate moves north-northeast and pushes the Eurasian plate at a rate of 5 cm per year. Madrinovella et al (2011) [4] also mentioned that "the convergent boundaries on two rigid plates between the Eurasian plate and the Indo-Australian plate led to a dip-slip fault pattern occurring in the subduction zone of Sumatra."

4. Conclusions

Based on the research results obtained conclusion as follows:

1. Sumatran tectonic order is very active which is characterized by the frequent earthquake that is earthquake with magnitude <5 SR and earthquake with magnitude ≥ 5 SR in period 1976-2016.
2. Seismotectonic patterns formed on each region of Sumatra Island based on the data processing and earthquake history data from 1976-2016 is the type of fault in the fault of Sumatra is strike slip, the type of fault on the Mentawai fault is reverse fault and strike slip, and the type of fault in the subduction zone is dip-slip.
3. Characteristics of the fault area formed in each region on the island of Sumatra one of the earthquake on April 1st, 1998 has strike value = 320, dip = 21, and slip = 105 on nodal 1 and strike = 124, dip = 69, and slip = 84 on nodal 2 obtained from Global CMT has a fault type reverse fault.

Acknowledgments

This research is part of a research grant of the Superior Research Scheme of Higher Education Fiscal Year 2017 with a research team headed by Syafriani, Ph. D based on the Letter of Assignment of Research No. 1649 / UN35.2 / PG / 2017 dated May 31, 2017. The authors also thank to the Meteorology Climatology and Geophysics Agency (BMKG) Geophysics Station of Klas I Padang Panjang and Global CMT for the data used in this study. Additionally thanks to GMT Software for maps or pictures.

References

[1] Aki, K. and P. G. Richard. 1980. Quantitative Seismology and Method. San Fransisco: W. H. Freeman And Company.
[2] BMKG, 2010. Mentawai Earthquake Report, October 25, 2010. Jakarta.
[3] Briggs, R., dkk. 2006. Deformation and slip along the Sunda megathrust in the Great 2005 Nias-Simeulue earthquake.: Science, v. 311, p. 1897-1901. Earthquake Event in 2013. Journal of Science and Arts POMITS Vol. 3, No. 1, (2014) 2337-3520.
[4] Madrinovella, I., Widiyantoro, S., Irwan, M., 2011. Relocation of Padang Earthquake Hyposenter 30 September 2009 Using Double Difference Method. JTM Vol.XVIII No. 1.
[5] Mukti, M. M., et al. 2012. Structural evolution of backthrusting in the Mentawai Fault Zone, offshore Sumatran forearc. Geochem. Geophys. Geosyst., 13, Q12006.
[6] Natawidjaja, D.H. 1994. Quantitative Geological Assessments of Liwa Earthquake 1994. Proceeding of Annual Convention of Indonesian Association of Geophysicists (HAGI) 1994.
[7] Natawidjaja, D.H. 2003. Neotectonics of the Sumatran fault and paleogeodesy of the Sumatran subduction zone. Ph.D thesis, California Institute of Technology (Caltech).
[8] Natawidjaja, D.H., et al. 2006. Source Parameters of the Great Sumatran Megathrust Earthquakes of 1797 and 1833 Inferred from Coral Microatolls. J. Geophys. Res., v. 111.
[9] Natawidjaja, D. H., and W. Triyoso. 2007. The Sumatran Fault Zone: from Source to Hazard, 1 (No. 1),2147.
[10] Natawidjaja, D. H., et al. 2007. Interseismic Deformation Above the Sunda Megathrust
Recorded in Coral Microatolls of the Mentawai Islands, West Sumatra. *J. Geophys. Res.*

[11] Plummer, C et al. 2003. *Physical Geology.* New York: McGraw Hill Companies.

[12] Samuel, M. A. and Harbury, N. A., 1996. *The Mentawai Fault Zone and Deformation of the Sumatran Forearc in the Nias Area.* Geological Society, London, Special Publications. v.106, p337-351.

[13] Sieh, K., and Natawidjaja, D.H., 2000. Neotectonics of the Sumatra fault, Indonesia. *Journal of Geophysical Research, 105, B12,* pp. 28, 295-28,326.

[14] Subarya, C., et al. 2006. Plate-boundary deformation associated with the great Sumatra-Andaman earthquake: *Nature,* v. 440, p. 46-51