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# IDENTIFICATION OF FAULTS AND SLIP DIRECTIONS THROUGH A STUDY OF FOCAL MECHANISMS IN NORTH SUMATRA (2018-2024)

**Maysa Indah Ayu Lestari[1], Ratni Sirai[1], Lailatul Husna Lubis[1]**
[1]Department of Physics, Faculty of Science and Technology, Universitas Islam Negeri Sumatera Utara
*lailatulhusnalubis@uinsu.ac.id*

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## ABSTRACT

North Sumatra is located in the Ring of Fire zone, making it prone to earthquakes due to the convergence of the Indo-Australian and Eurasian plates, which form the 390 km long Sumatra Fault. This study aims to analyze the focal mechanism of earthquakes in North Sumatra during the period 2018-2024 using data from the Global Centroid Moment Tensor (GCMT). The analysis focuses on determining the type of earthquake mechanism, fault plane orientation, and slip direction and characteristics based on 21 earthquake events with magnitudes ranging from 4.8 to 5.4 Mw, analyzed using parameters such as location, time, depth, and nodal plane orientation. The results of the study indicate that earthquakes occurring in North Sumatra are dominated by strike-slip faults with horizontal movement. The orientation of the fault planes generally points northwest-southeast (NW-SE) and northeast-southwest (NE-SW), consistent with the characteristics of the Sumatra Fault and its segments, such as Renun, Toru, Barumun, and Angkola. Most of the earthquakes occurred at shallow to intermediate depths, posing a potential risk of damage in densely populated areas. These findings are expected to enhance regional geotectonic understanding and support earthquake disaster mitigation strategies in North Sumatra.

**Keywords**: Earthquake, Focal mechanism, Fault plane pattern, Strike-slip fault, North Sumatra

## INTRODUCTION

Earthquakes are natural phenomena that occur due to the sudden release of energy, causing vibrations on the earth's surface. In Indonesia, earthquakes are generally triggered by tectonic plate movements or ground shifts that travel through the earth's crust (Triton, 2009). In North Sumatra, earthquakes are triggered by sudden shifts in the earth's crust, which generate seismic waves that reach the surface. This process is closely related to the focal mechanism, which represents the orientation of the forces causing the earthquake and the pattern of movement of the fault plane (Putri et al., 2024)

North Sumatra is one of the provinces in Indonesia located in a tectonic zone due to the convergence of the Indo-Australian and Eurasian plates. The interaction between these two plates has formed a subduction zone off the west coast of Sumatra, stretching from Aceh to Lampung(Sieh & Natawidjaja, 2000)

The focus mechanism is the result of analyzing seismic waves recorded by seismographs during an earthquake. This analysis produces a three-dimensional representation in the form of a focal ball that describes the characteristics of the earthquake source(Pratama & Santosa, 2018). The focus mechanism can be

used to identify the existence and type of faults in an area and show the orientation of the fault plane and the direction of its movement based on a geographic coordinate system (Ekarsti at al., 2023)(Ekarsti et al., 2023). The focal sphere is a visual representation of the propagation of seismic waves originating from the earthquake's center. This illustration depicts how earthquake waves spread from their source until they reach the recording station (Wibowo & Nurhaci, 2017).

A fault is a boundary zone between two blocks of the Earth's crust that experience relative movement. This area is usually structurally weak and characterized by cracks or gaps. In general, faults are formed as a result of strong tectonics, causing rocks to crack or shift position suddenly (Pradana, 2021).

Slip direction is defined as a unit vector that lies in the fault plane and is parallel to the relative movement between rock blocks during an earthquake (Vavryčuk, 2014). In the focal mechanism, the slip direction is generally parallel to the shear traction on the fault plane based on the Wallace-Bott hypothesis (Chang, 2024). Slip direction data is used to determine the shear stress component on the fault plane, which is an important indicator in evaluating fault stability (Angelier, 2002).

GMT (Generic Mapping Tools) is software that provides around 80 commands for processing geographic and Cartesian data. GMT is capable of producing visualizations ranging from simple two-dimensional plots to three-dimensional displays with support for more than 30 types of map projections and transformations (Hudayat, 2021).

This study aims to create a focal mechanism in North Sumatra using GMT software and Visual Code programming.

## RESEARCH METHODS

### Research Tools

Data processing was performed using GMT, ArcGIS, and Visual Code software. Data obtained from GCMT was input into Visual Code.

This study collected data on earthquakes in North Sumatra from the Global Centoid Moment Tensor (GCMT) catalog. The observation period covered 2018 to 2024, with earthquake magnitudes ranging from 4.0 to 6.0 Mw.

A literature study was conducted first to determine the tectonic dynamics of North Sumatra and the focal mechanism and fault type. Next, a script was developed to display the focal ball distribution.

This research produced outputs in the form of beachballs and earthquake maps. These results can be used to identify the types of faults and the direction of earthquake slips in the North Sumatra region.

The following is a flowchart of the data processing process:

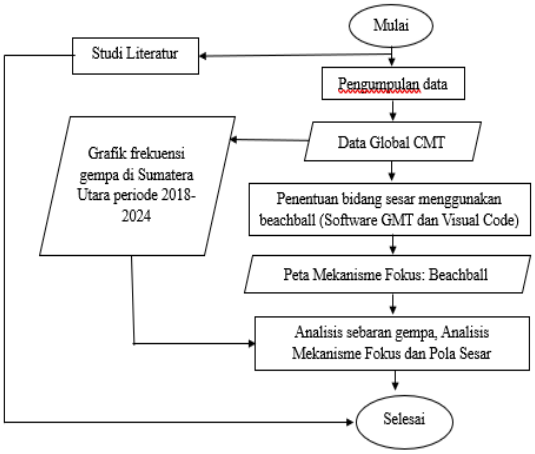


**Figure 1.** Research Flow Chart

## RESULTS AND DISCUSSION

The data obtained from GCMT can be classified based on the year of occurrence. The classification data is shown in Table 1. The earthquake magnitude ranges from 4.0 to 6.0 Mw with information including Origin Time, longitude, latitude, depth, and magnitude. Focal mechanism parameters such as strike, dip, and rake are also used.

Table 1. Earthquake Frequency Data for the Period 2018-2024

| No | Year | Number |
|---|---|---|
| 1 | 2018 | 2 |
| 2 | 2019 | 3 |
| 3 | 2020 | 2 |
| 4 | 2021 | 4 |
| 5 | 2022 | 6 |
| 6 | 2023 | 2 |
| 7 | 2024 | 2 |
| Number of earthquakes | | 21 |

Based on Table 4.1, the frequency of earthquakes in the study area shows significant annual variation. The highest seismic activity occurred in 2022, which was related to the Toru, Barumun, and Angkola segments (Jatnika at al., 2015).

**Results of the 2018 Focal Mechanism Ball**

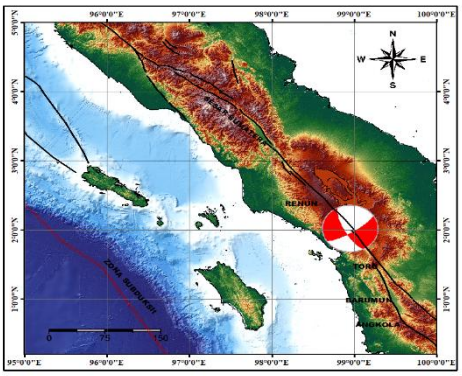


**Figure 2.** Focal Mechanism Ball February 24

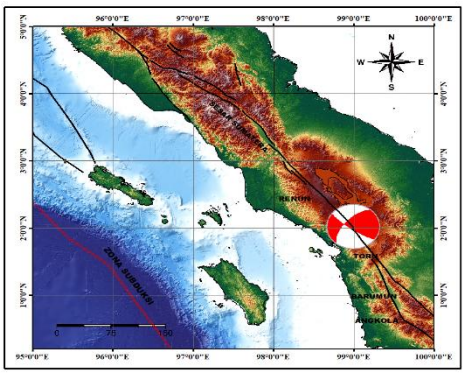


**Figure 3.** Focal Mechanism Ball March 13

Based on the focal mechanism in 2018, the fault pattern in this area is a strike slip fault. This pattern is the main source of earthquakes because the area is influenced by the activity of the Sumatra fault, namely the Renun and Toru faults. In this case, the slip direction moved horizontally to the right (dextral).

**Results of the 2019 Focal Mechanism Ball**

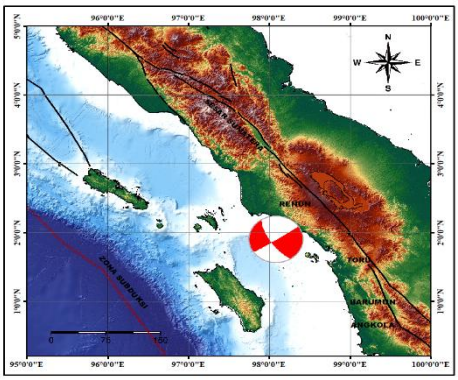


**Figure 4.** Focal Mechanism Ball January 14

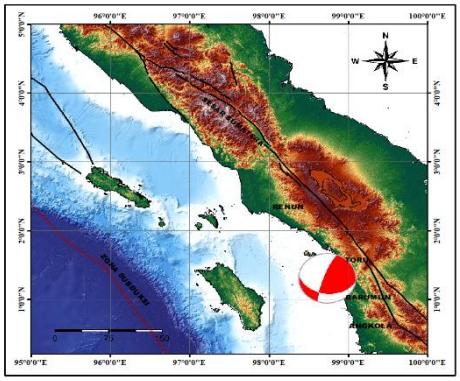


**Figure 5.** Focal Mechanism Ball March 11

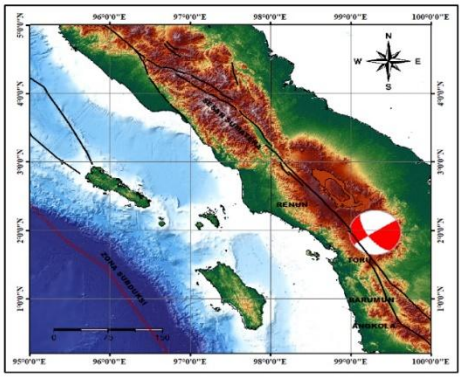


**Figure 6.** Focal Mechanism Ball December 1

Based on the focal mechanism sphere in 2019, there were two focal spheres that occurred off the southwest coast of North Sumatra. The earthquake in was a shallow to medium earthquake triggered by strike slip movement. The slip moved horizontally due to tectonic interaction between plates.

**Results of the 2020 Focal Mechanism Ball**

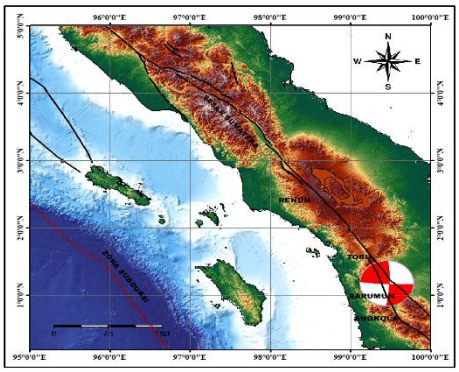


**Figure 7.** Focal Mechanism Ball April 30

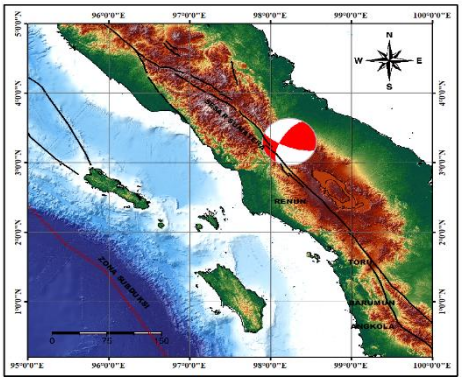


**Figure 8.** Focal Mechanism Ball December 3

Based on the focal mechanism solution in 2020, it shows a strike-slip fault pattern. The first earthquake was influenced by the Barumun and Toru segments, while the second earthquake was influenced by the Renun segment. Both had a horizontal slip direction due to the interaction between the Indo-Australian and Eurasian plates. These earthquakes were shallow to intermediate depth earthquakes outside the subduction zone.

**Results of the 2021 Focal Mechanism Ball**

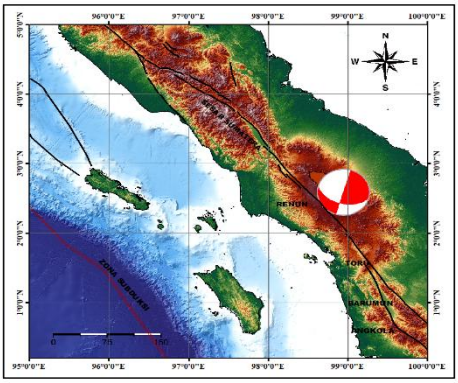


**Figure 9.** Focal Mechanism Ball March 27

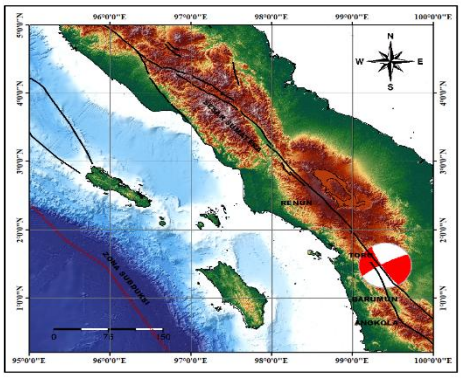


**Figure 10.** Focal Mechanism Ball August 11

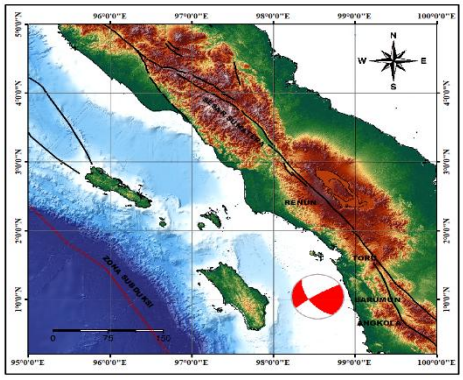


**Figure 11.** Focal Mechanism Ball November 3

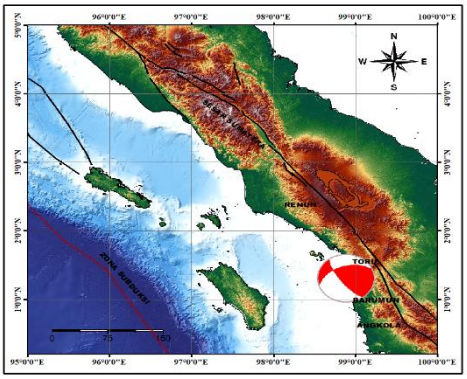


**Figure 12.** Focal Mechanism Ball November 12

Based on the focal mechanism sphere in 2021, all earthquakes that occurred showed strike slip faults at shallow to medium depths. The four earthquakes were triggered by the activity of the Sumatra fault, particularly the Toru and Barumun segments, with horizontal slip oriented along the nodal plane.

**Results of the 2022 Focal Mechanism Ball**

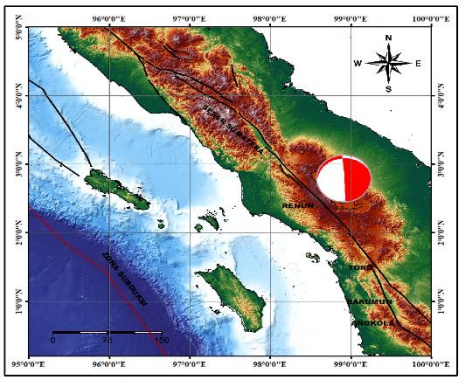

**Figure 13.** Focal Mechanism Ball March 5

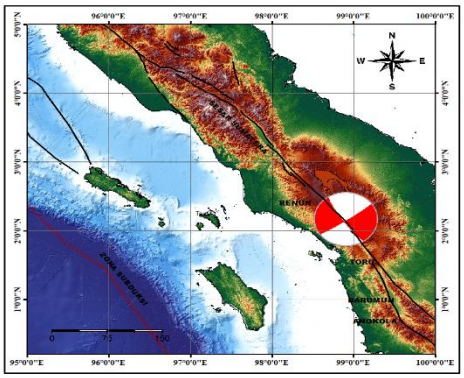

**Figure 14.** Focal Mechanism Ball September 30

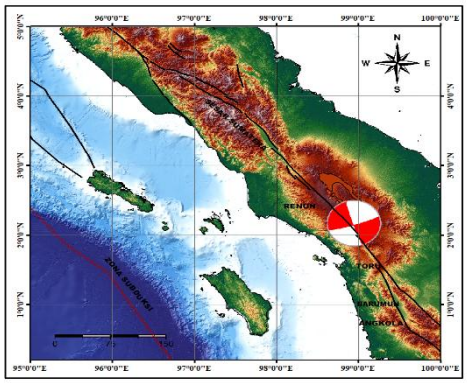

**Figure 15.** Focal Mechanism Ball September 30

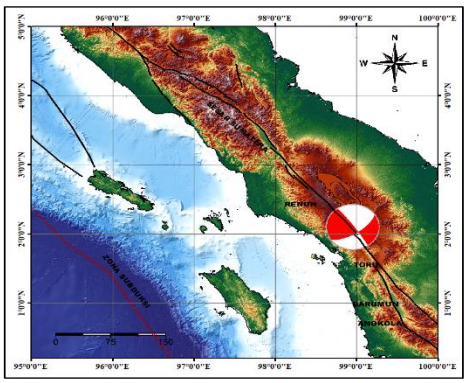

**Figure 16.** Focal Mechanism Ball September 30

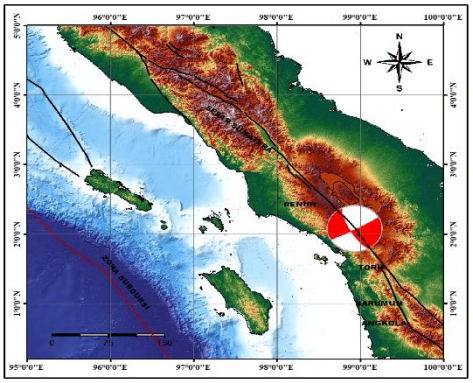

**Figure 17.** Focal Mechanism Ball October 6

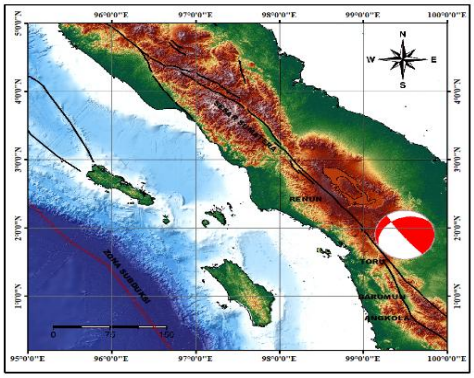

**Figure 18.** Focal Mechanism Ball October 30

Based on the focal mechanism sphere in 2022, it shows variations in the focal mechanism that reflect the complexity of local tectonics. The earthquake that occurred on March 5, 2022, was a normal fault earthquake caused by extension forces in the Sumatra back arc. Several earthquakes that occurred on September 30, 2022, and October 6, 2022, were dominated by strike-slip faults associated with active segments of the Sumatra Fault, such as Toru and Barumun. Meanwhile, the earthquake that occurred on October 30, 2022, showed a thrust fault mechanism associated with plate subduction processes in the subduction zone and the influence of the Sumatra fault structure.

**Results of the 2023 Focal Mechanism Ball**

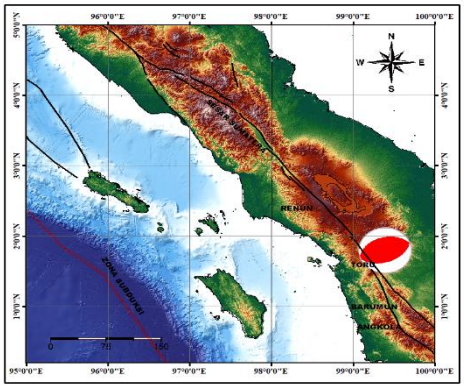


**Figure 19.** Focal Mechanism Ball June 2

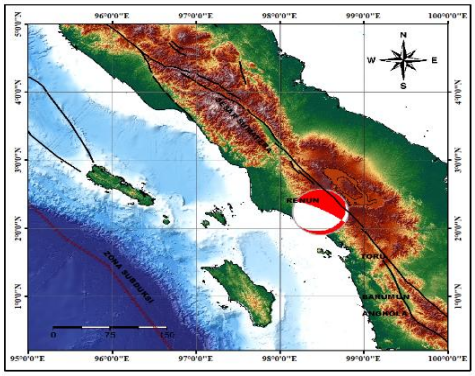


**Figure 20.** Focal Mechanism Ball June 26

Based on the focal mechanism sphere in 2023, there were two thrust faults with indications of vertical thrust due to convergent pressure from the subduction of the Indo-Australian and Eurasian plates, as well as the influence of active structures in the Sumatra fault zone.

**G. Results of the 2024 Focal Mechanism Ball**

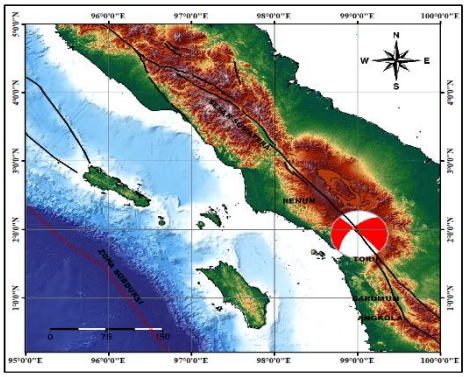


**Figure 21.** Focal Mechanism Ball September 14

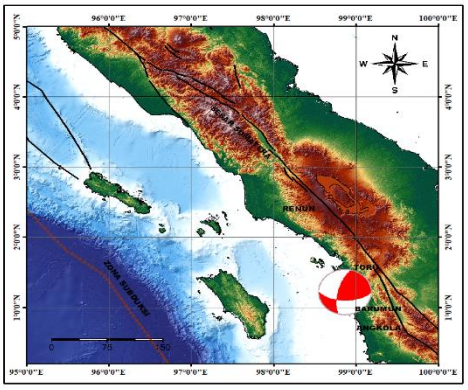


**Figure 22.** Focal Mechanism Ball October 1

Based on the focal mechanism solution obtained in 2024, both earthquakes were strike-slip faults with horizontal slip movement, activating active segments of the Sumatra fault such as Toru and Barumun.

**Discussion**

Analysis of the focal mechanism shows that the study area is dominated by strike slip faults with 17 occurrences, while thrust faults were recorded in 3 occurrences, and normal faults in 1 occurrence. This study indicates that strike slip faults are the dominant mechanism in North Sumatra.

In general, the characteristics of earthquakes occurring in North Sumatra indicate that tectonic activity is dominated by strike-slip fault mechanisms with dextral movement oriented NW-SE or NE-SW (Ekarsti et al., 2023). This phenomenon is influenced by the Sumatra Fault system as the main regional structure. The regional tectonic pattern is formed due to the oblique convergence between the Indo-Australian and Eurasian plates (Prayogo et al., 2025)

Throughout 2021, all earthquakes in North Sumatra were shallow to medium depth. This pattern is related to the activity of the Sumatra fault, which reinforces the consistency of horizontal slip movement parallel to the main system (Marliyani, 2017).

Earthquake data from 2022 shows variations in focal mechanisms that reflect the complexity of local tectonics in North Sumatra. The earthquake that occurred on March 5, 2022 was a normal fault earthquake associated with extensional processes in the back-arc zone.

Meanwhile, the earthquakes that occurred in late September-October were dominated by strike-slip faults in the Toru and Barumun segments. One thrust fault earthquake was interpreted as activity in the subduction zone (Natawidjaja, 2018).

In 2023, two thrust faults dominated, reflecting an increase in the vertical component due to plate convergence. while 2024 again showed the dominance of strike slip faults in the Toru and Barumun segments, which showed movement consistent with the horizontal movement of the Sumatra Fault (Sieh & Natawidjaja, 2000).

The focal mechanism of earthquakes during the 2018-2024 period shows consistency with the Sumatra Fault segmentation model, which has been considered stable based on seismicity studies on the Toru, Angkola, and Barumun segments (Aritonang at al., 2021). This pattern is reinforced by focal mechanism data indicating the dominance of right-lateral strike-slip faults on the Renun segment, consistent with the regional tectonic framework (Natawidjaja, 2018).

The tectonic system in North Sumatra involves dynamic interactions between several segments of the Sumatra Fault and the surrounding active subduction zones (Bock, 2003). This research is consistent with the concept of oblique convergence, which triggers the formation of horizontal faults in response to the rotation of microblocks in North Sumatra (Mccaffrey, 2009).

## CONCLUSIONS AND SUGGESTIONS

This study successfully examined the types of faults in North Sumatra through a focal mechanism using GMT. With this method, GMT is capable of producing visualizations ranging from simple two-dimensional plots to three-dimensional displays, with support for more than 30 types of map projections and transformations.

Based on an analysis of the focal mechanisms of earthquakes in North Sumatra during the 2018-2024 period using GCMT data, there were 21 events with magnitudes of 4.8-5.4 Mw, dominated by strike-slip fault mechanisms. The fault plane pattern is generally oriented in line with the location of active segments of the Sumatra fault, such as Toru, Barumun, Renun, and Angkola, reflecting the dominant horizontal tectonic forces in this region. The slip direction indicates horizontal movement, both dextral (right-lateral) and sinistral (left-lateral), with sufficient energy to trigger crustal deformation at shallow to intermediate depths.

For future research, other methods such as GPS analysis should be incorporated, and the data should be adjusted to local geological conditions so that the results obtained are more accurate and relevant.

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