IDENTIFICATION OF LOCAL ACTIVE FAULTS IN MAINLAND GORONTALO REGION BASED ON FOCAL MECHANISM ANALYSIS

Listya Dewi Rifai[1], Imanuela Indah Pertiwi[2]
[1]Gorontalo Geophysical Station - Meteorology, Climatology, and Geophysics Agency of Indonesia
[2]Kendari Geophysical Station - Meteorology, Climatology, and Geophysics Agency of Indonesia
e-mail : ishty.geoph43@gmail.com

Abstract. *One of the nations that experiences devastating earthquakes frequently is Indonesia. Local active faults on land are one of the causes of these earthquakes. New information on the purported presence of local active faults can be obtained from the quantity of small-magnitude earthquake occurrences. By analyzing the focal sphere mechanism, small-scale earthquake data are used to identify local active faults in the Gorontalo area. The minor magnitude earthquakes (M<5) that struck the Gorontalo region in February 2023 and were recorded eleven events at the BMKG- Gorontalo Geophysical Station that were used in this investigation. The resulting focus sphere diagram can be used to ascertain the faults or strike direction propensity. The focal mechanism of the earthquake in the Pohuwato region demonstrates the Oblique Thrust Fault's inclination toward a northeastern-southern strike orientation. The tendency of the strike orientation of the east-west-oriented Oblique Thrust Fault, which is the focal mechanism of the earthquake that happened in Buol, also demonstrates the same thing. According to the Gorontalo Fault diagram provided by the National Earthquake Study Center, the focal mechanism of the earthquake in Cluster A (earthquake numbers 1,6,9), the Gorontalo region, also demonstrates the strike direction of the Northwest-Southeast-oriented Oblique Thrust Fault. The earthquake occurrences in cluster B (Pohuwato area), earthquake numbers 2,3,8, and cluster C (Buol area), earthquake numbers 4, 5,7, raise the possibility of a new local active fault on the Gorontalo region's mainland. The Gorontalo region's suspicion of the existence of local active faults is strengthened by the monitoring of earthquake intensity based on occurrences that occurred between March 2023 and March 2024. Over the course of a year, there are nine to twenty-seven earthquakes with a magnitude of less than five (M<5). These seismic occurrences provide credence to the theory that Pohuwato and Buol, Gorontalo, have local active faults.*
Keywords: *Focal Mechanism; Gorontalo Mainland; Local Active Fault; Strike*

INTRODUCTION

One of the nations that experiences devastating earthquakes frequently is Indonesia. Local active faults on land are one of the causes of these earthquakes. BMKG's catalog of significant and destructive earthquakes records that Indonesia has experienced several powerful earthquakes with epicenters on land, such as the Jogjakarta earthquake in 2006 (M 5.9), the Palu earthquake in 2018 (M 7.4), the Majene earthquake in 2021 (M 6.2), and the Cianjur earthquake in 2022 (M 5.6). Due to the proximity of the epicenters of these devastating earthquakes to residential areas, they have drawn a lot of attention. Not only may a huge magnitude earthquake inflict damage to towns and fatalities, but local factors that might intensify the shaking from an earthquake can also have a big effect. The community must be aware of the likelihood of earthquakes occurring in their region in order to make preparations for probable future earthquakes.

Gorontalo is among the places where earthquakes frequently occur. The major plates of the world Eurasian, Pacific, and Australian Plates meet to produce the tectonic structure that has developed in the Gorontalo area. The Gorontalo area experiences regular earthquakes because of the movement activity of these plates. (Katili, 1974). On the Gorontalo region's mainland, the movement of the three plates also contributes to the formation of isolated active faults. The Gorontalo Fault is one of them; it runs from Lahengo Bay in the north to Gorontalo Bay in the south. There are subduction zones in the Maluku Sea Subduction Zone east of the Minahasa Peninsula and the Sulawesi Sea Subduction Zone north of Gorontalo. Both subduction zones overlap and descend towards Gorontalo. The Sulawesi continent is split into a number of minor plate blocks as a result of the interaction of the three plates, including the Makassar, Manado, East, and North Sula blocks (Rangin et al., 1990).

The northern regions of North Sulawesi, Gorontalo, and Central Sulawesi are covered by the Sulawesi Sea trough subduction zone, which stretches along the North Arm of Sulawesi. To the west or north of Toli-

DOI : http://dx.doi.org/10.12962/j25023659.v10i3.2217

Artikel Masuk : 09-10-2024 Artikel Diulas : 31-10-2024 Artikel Diterima : 26-11-2024

Toli, prismatic accretion grows, while it becomes weaker to the east or along the shore of Amurang, Manode. This subduction zone is a part of the decaying subduction system, which is a very ancient subduction system. The Benioff Zone, which has a dip depth of 170-180 km and a slab angle of around 45°, and the trough that forms along the northern border of Sulawesi are both eastward-moving. The Sulawesi Sea often has earthquake occurrences with hypocenters smaller than 30 km, whereas the region south of Gorontalo frequently experiences medium-sized earthquakes between 40 and 150 km (Thenhaus et al., 1993), Milsom, 2001), Kertapati, 2006, and Hayes et al., 2018). The Sangihe and Halmahera arcs, which make up the Maluku Sea double subduction system, include the Maluku Sea subduction zone. The Moluccas Sea Microplate, which is nearly totally subducted and positioned between the Pacific, Philippine, and Eurasian plates has the most complicated geological structure in this collision zone. The Sangihe Arc has a normal fault mechanism that may produce earthquakes up to a maximum magnitude of 8.7 Mw. Its length is approximately 567 km, and its movement rate is 13 mm/year (National Earthquake Study Center Team, 2017). Small to medium sized earthquakes are frequently caused by the Sangihe arc's movement in the Siau Islands region and the Maluku Sea, Minahasa Peninsula, and Tomini Bay, which border Bolaang Mongondow's southern section and Bone Bolango's eastern portion. The Gorontalo area has substantial seismic activity due to the geological complexity around it. There may be more earthquake sources that originate within the plate (intraplate). The surrounding plate deforms as a result of the stress and strain mechanism in the flat joint area. Faults are the source of this earthquake. When two blocks move against one another, non-elastic deformation occurs, creating a fault plane (Fossen, 2010). Because of past deformation, Gorontalo has a lot of faults, but only active faults may produce earthquakes. If a fault exhibits movement during the previous 10.000 years, it is considered active (Keller and Pinter, 2002). Sulawesi and its environs are made up of many tectonic blocks that are connected by a complicated network of thrust, normal, and horizontal faults (Watkinson, 2011; Nugraha et al., 2022).

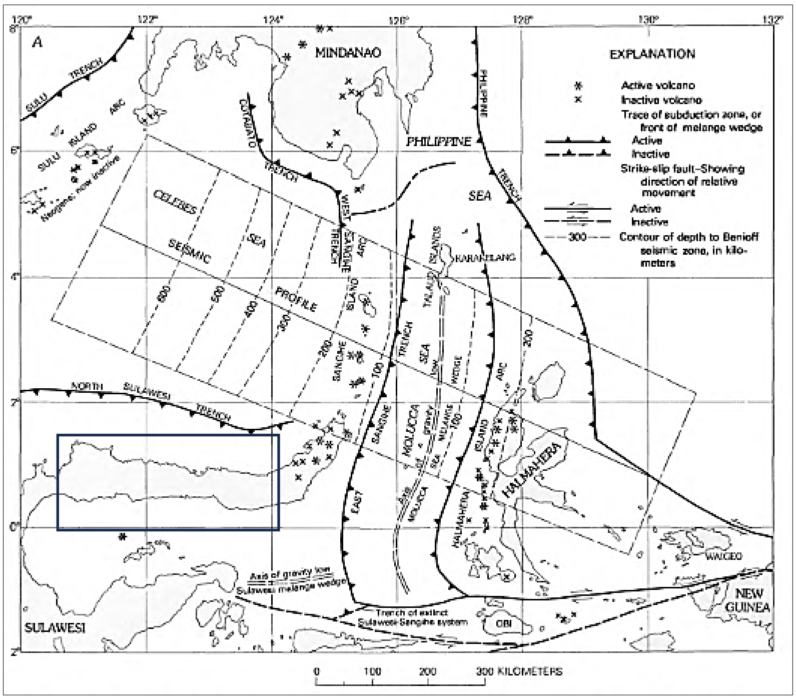


Figure 1. Tectonic Structure Around Gorontalo Region, Subduction Zone of The Southward-Dipping Sulawesi Sea Trough and Westward-Dipping Maluku Sea Trough (Hamilton, 1979).

The nearby Subduction Zone is not the only source of earthquakes in the Gorontalo area. There are also regular earthquakes on the Gorontalo region's mainland. Shear deformation between two rock planes, either vertical (normal fault and thrust fault), horizontal (transform fault), or a mix of both (oblique fault), is

DOI : http://dx.doi.org/10.12962/j25023659.v10i3.2217

Artikel Masuk : 09-10-2024 Artikel Diulas : 31-10-2024 Artikel Diterima : 26-11-2024

what drives tectonic earthquakes. Data on the polarity of the first motion of the earthquake P wave at the observing station are necessary to derive the focal mechanism model (Yang et al., 2021).

New information on the existence of local active faults can be obtained from the quantity of earthquakes with minor magnitudes. The study of fault plane orientation characteristics, such as fault direction, fault inclination angle, and fault movement orientation on both sides, during an earthquake occurrence is known as focal mechanism. By analyzing the focal mechanism, small scale earthquake data are used to identify local active faults in the Gorontalo area.

METHODOLOGY

The minor magnitude earthquakes (M<5) that struck the Gorontalo region in February 2023 and were eleven events recorded at the BMKG- Gorontalo Geophysical Station are the seismic events that were used in this investigation. The borders of the research area are 120.50°E–124.00°E and 0.33°N–1.66°N. Earthquakes that occur on land at shallow depths are the earthquake event data used in the analysis procedure. Based on P and S wave signals captured in SeiscomP4, the seismogram data was selected with the least values of Ellipsoid Error less than 10 km, Azimuth Gap less than 180°, and RMS less than 2.0. The Ellipsoid error, Azimuth Gap, and RMS are the first three factors to consider when considering the feasibility of the analysis findings. Using the original, unfiltered seismogram data, the vertical component was used to execute the P-wave first-motion selection.

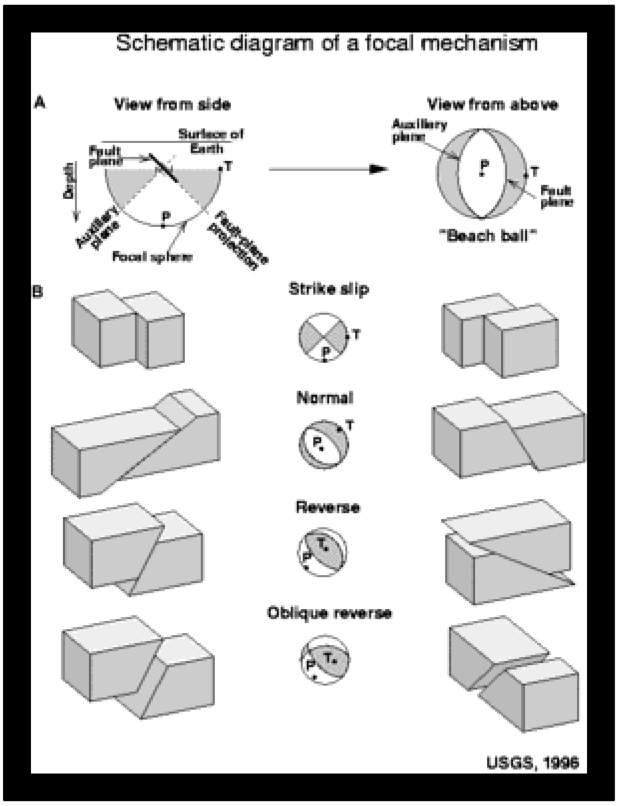


Figure 2. Examples of Earthquake Focal Mechanisms and Their Associated Fault Displacements. "P" and "T" Indicate The Pressure and Tension Axes, Respectively, Associated with The Fault Motion of Each Focal Mechanism (source: USGS, 1996)

The focal mechanism approach describes how the initial motion of the P wave from an earthquake (tectonic event) might lead a fault shape to be interpreted as a focal sphere. Focal mechanism information can reveal fault geometry and slide direction, claims Michael (1987). Seismologists have been using the idea of

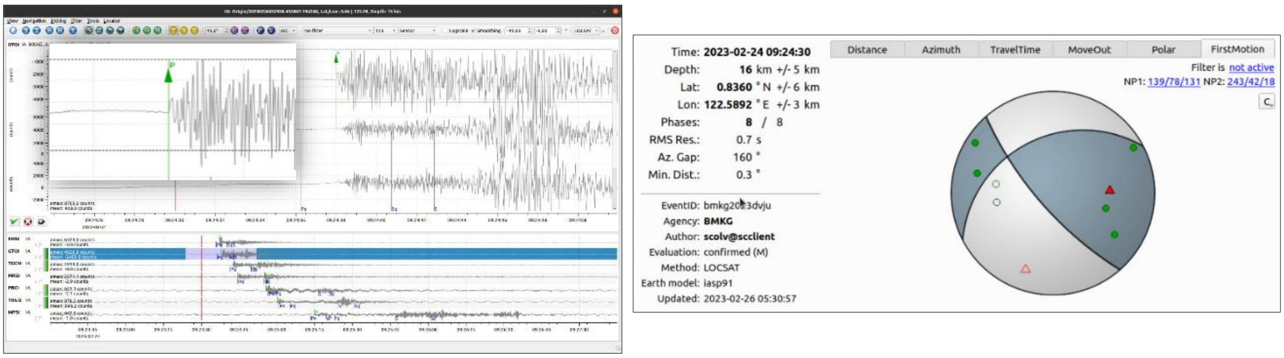
DOI : http://dx.doi.org/10.12962/j25023659.v10i3.2217
Artikel Masuk : 09-10-2024 Artikel Diulas : 31-10-2024 Artikel Diterima : 26-11-2024

double coupling theory to identify the mechanism of an earthquake source since the early 1960s. According to the double coupling hypothesis, an earthquake source consists of two mutually perpendicular moments of force, or four forces operating in equal and opposing directions. A system of forces linked between dilatation and compression makes up the double-couple hypothesis. The pattern of seismic wave propagation in the ground governs the mechanism of an earthquake. The propagation medium's pattern, the condition of the earth's crust, and the distribution of forces and stresses all affect how this mechanism behaves. The fundamental presumptions used to view the Earth in order to explain seismic waves are that it is an entirely elastic medium made up of different layers, that each layer is an isotropic homogeneous medium, and that the discontinuity in specific gravity only occurs at the boundary between the Earth and air.

A focal sphere diagram, which is divided into four quadrants, is typically used to describe a type of focal mechanism, according to Hardebeck and Shearer (2002). Two of the quadrants represent the P wave's initial motion away from the source (dilation), and the other two represent the P wave's initial motion approaching the source point (compression). The seismic wave source mechanism that each sensor station's seismometer records determines the initial P-wave velocity. When establishing the form of an earthquake point's focal mechanism toward its station, the beginning motion of the P wave is crucial. Since the P wave is the clearest reading, the focal mechanism is then ascertained by observing the direction of the P wave's first movement.

The first P-wave polarity signal data from the recording sensor stations is used to detect the focal mechanism of an earthquake occurrence in the Gorontalo region. SeisComP4 software may be used to determine whether the polarity is positive (up), negative (down), or neither. An area under compression is indicated by rising polarity (pressure area). A diminishing polarity indicates dilatation (also known as an area of attraction) in the region. The amplitude of the wave decreases as one approaches the focal mechanism's quadrant line, making it more challenging to identify the P-wave's original polarity. All sensor stations that collected data were divided into four quadrants of the focused sphere, or the focal mechanism, once their polarity was established.

Sensor stations that identify earthquake signals with various beginning P-wave polarities make up the following SeisComP4 display. When the initial polarity is established, the focal mechanism's characteristics—which include the strike/slip/dip angle — are derived. These parameters describe the fault pattern that develops at the epicenter. The angle created by the fault's strike in the direction of the north is known as the strike. In the vertical plane, dip is the angle that the fault plane forms with the horizontal plane, measured perpendicular to the fault line. slide is the angle created by the fault line and the direction of slide.



(a) (b)

Figure 3. (A) The Analysis Process of Determining The Initial Polarity of The P Wave In Seiscomp4. (B) Solution Diagram of The Focal Mechanism; Gray Color is The Compression Zone and White Color is The Dilation Zone

The three-dimensional geometry of the acquired focus sphere is evaluated to determine the direction of P-wave migration. The focus sphere is divided into the top and lower regions for visual interpretation. A

DOI : http://dx.doi.org/10.12962/j25023659.v10i3.2217

Artikel Masuk : 09-10-2024 Artikel Diulas : 31-10-2024 Artikel Diterima : 26-11-2024

focus sphere diagram, which is a two-dimensional representation of the sphere, is produced when the lower half of the sphere is lit from below. The resulting focus sphere diagram can be used to ascertain the fault's or strike direction propensity. Monitoring of the severity of earthquake events in the research area is done based on earthquake occurrences from March 2023 to March 2024 in order to increase the suspicion that there are local active faults in the Gorontalo region.

RESULT AND DISCUSSION

The Gorontalo Fault is one of the region's active faults. The Gorontalo Fault, which links the Maluku Sea Subduction with the Sulawesi Subduction, is an active fault (Socquet et al., 2006; Molnar and Dayem, 2010; Katili, 1970). The Gorontalo Fault separates the North Sula Block from the Manado Block as a microtransform plate boundary. With a proper shear mechanism, the Gorontalo Fault has an accurate slip rate of up to 11 mm/year, according to GPS data and geodetic deformation models. The low frequency of earthquakes in the vicinity of the fault suggests that it is locked or dormant. Nonetheless, the Gorontalo Fault has been classified as an active fault based on surface morphometry study; nonetheless, activity is modest and minimal, and no notable seismic activity has been seen (Watkinson and Hall, 2017).

Seven devastating earthquakes were observed in the Gorontalo area between 1939 and 2017 (BMKG 2018). Mw 7.7 was the greatest recorded earthquake magnitude. The Sulawesi Sea is the epicenter of all devastating earthquakes, indicating subduction activity in the Sulawesi Sea Trough. There were fifteen notable earthquakes prior to 1939 (Wichmann, 1918). The parameters are not known for sure, though, because the catalog simply contains the event's time and date without any empirical geophysical evidence.

Data on shallow onshore earthquake sources in Gorontalo were chosen for this study, and 11 earthquakes with hypocenter depths ranging from 10 to 42 km in February 2023 were acquired. Although there were no notable earthquakes during this time, it is still possible to evaluate the first P-wave polarity signals from the events below. All quadrant directions of the focal mechanism, if the azimuth gap is modest, can be represented by the number of stations dispersed around the epicenter of the earthquake. The parameter data of each recorded earthquake occurrence is subjected to focal mechanism analysis. For two nodal planes, the values of the focal mechanism's striking, dip, and slip/rake parameters were obtained. Nodal planes 1 (NP1) and 2 (NP2), respectively, are made up of strike1, slip1, dip1, and strike2, slip2, and dip2. Table 1 displays the focal mechanism characteristics as well as the seismic event parameters.

Table 1. Lists The Focal Mechanism Parameters for Every Shallow Earthquake that Occurred on The Gorontalo Region's Mainland in February 2023 (source: Gorontalo Geophysical Station data catalog)

No	Date	Origin Time	Lat	Long	Depth	Mag	NP1			NP2		
							Strike1	Slip1	Dip1	Strike2	Slip2	Dip2
1	04-02-2023	03:08:01	0.6386	123.0667	10	2.6	106	65	48	321	115	48
2	06-02-2023	09:15:06	1.0535	121.9567	11	3.7	240	123	54	12	53	47
3	09-02-2023	03:43:37	0.9024	121.8470	32	2.7	310	47	81	210	167	44
4	09-02-2023	16:48:30	0.9629	121.0421	41	2.7	203	-132	14	66	-80	79
5	10-02-2023	06:34:51	0.8042	121.2027	38	3.2	75	68	9	277	94	81
6	11-02-2023	15:23:22	0.9624	122.6430	12	2.5	53	71	75	286	141	24
7	15-02-2023	08:07:41	0.7421	121.4367	12	3.2	279	35	72	177	158	57
8	17-02-2023	16:10:01	0.7377	121.6276	37	2.4	46	71	82	294	157	21
9	20-02-2023	13:38:41	0.9649	122.6407	24	2.7	55	-153	40	304	-53	73
10	23-02-2023	11:02:21	0.7886	122.0648	42	2.4	89	-91	61	271	-88	29
11	24-02-2023	09:24:30	0.8360	122.5892	16	2.7	139	131	78	243	18	42

The Gorontalo region's tectonic structure map is used to illustrate the parameter data from Table 1. Neighboring earthquake epicenters have a propensity toward the same strike direction, as seen by the focal

DOI : http://dx.doi.org/10.12962/j25023659.v10i3.2217

Artikel Masuk : 09-10-2024 Artikel Diulas : 31-10-2024 Artikel Diterima : 26-11-2024

mechanism map of land-based earthquake occurrences in the Gorontalo region. The fault's strike angle, or direction, is shown by the line joining the ends of the nodal arc in the focal mechanism. This angle is determined by working clockwise from the north. Three clusters are distinguished among earthquakes that share the same focal mechanism propensity and strike alignment.

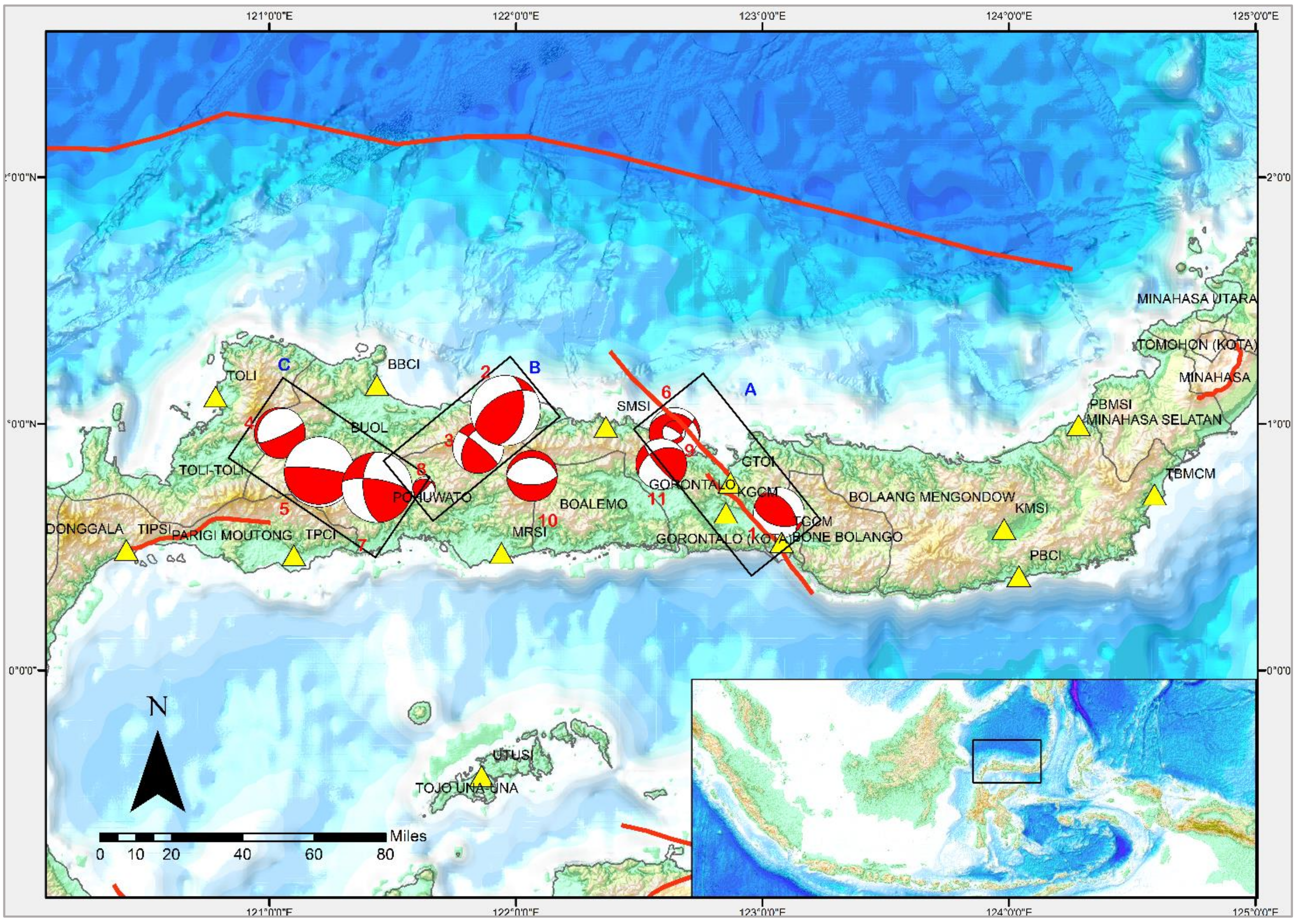


Figure 4. Focal Mechanism Map of Earthquake Events on Land in The Gorontalo Region During February 2023. Numbers in The Map Indicate The Number if Earthquake Events Based in Table 1. The Yellow Triangle Symbol is The Site of The Earthquake Recording Sensor, and The Red Line is Fault (Pusgen, 2017).

As can be seen in Figure 4, one of the nodal plane values of earthquakes numbers 1, 6, 9, and 11 (Table 1.1) has a striking angle that tends to be in the same direction, namely Northwest-Southeast. These earthquakes are scattered along the Gorontalo fault, and the fault model indicates that earthquake occurrences numbers 1, 6, and 9 have the same underlying mechanism — the Oblique Thrust Fault, which combines upthrust and horizontal shear. The eleventh earthquake incidence is not aligned with the previous distributions of earthquakes. By examining the fault mechanism and the direction of strike (direction of the fault plane), which tend to be the same, these three earthquakes demonstrate a strong indication that they originate from the same fault. Cluster A is the grouping of these earthquakes.

The striking angle in this set of earthquakes has the same orientation, namely Northeast-Southwest, and the same thing applies to one of the nodal plane values of earthquakes numbers 2, 3, and 8. The Gorontalo fault is the source of several nearby earthquakes, and the fault model depicts the same fault mechanism—oblique thrust. These earthquakes are categorized under cluster B in this analysis. Similarly, earthquakes numbers 4, 5 and 7 (cluster C). These earthquakes' nodal plane values have a striking angle that faces the same direction, which is east-west. The oblique thrust fault mechanism is shared by earthquakes that occur near each

DOI : http://dx.doi.org/10.12962/j25023659.v10i3.2217

Artikel Masuk : 09-10-2024 Artikel Diulas : 31-10-2024 Artikel Diterima : 26-11-2024

other in distance. There is conjecture that the earthquake was caused by a similar seismogenic fault based on the identification of the focal mechanism of earthquake events on land in the Gorontalo region, the distribution of aftershocks, the close spacing of the earthquake's epicenter, and the consistency of the geological structure (Li et al., 2022).

The Pohuwato area in cluster B and the Buol area in cluster C are suspected of having a new local active fault based on the focal mechanism results. The frequency of earthquake occurrences in the area of the two clusters is being monitored after February 2023, from March 2023 to March 2024, which lends credence to this assumption.

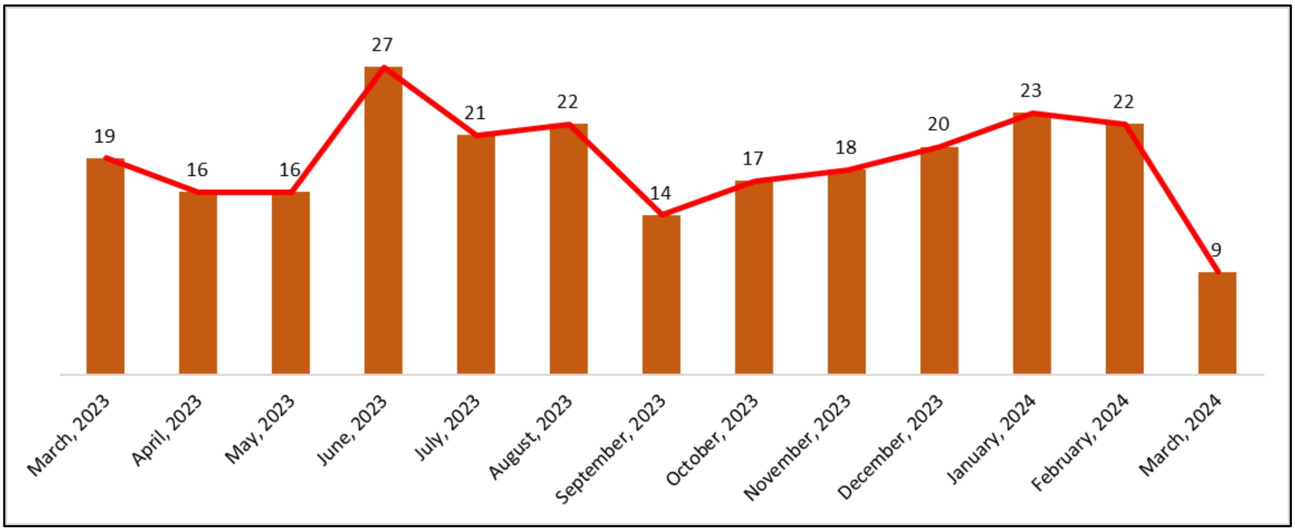


Figure 5. From March 2023 to March 2024, a Graph Showing The Frequency of Land-Based Earthquake Occurrences in The Pohuwato and Buol Areas (data source: Geophysical Station earthquake data catalog).

A graph showing the frequency of land earthquakes in regions suspected of having local active faults is shown in Figure 5. Seven earthquakes were reported in the Pohuwato and Buol regions in February 2023. Following February 2023, that is, from March 2023 to March 2024, there were a lot of earthquakes in both regions with magnitudes less than 5 ($M<5$). It is estimated that there are between nine and twenty-seven earthquake incidents every year. These seismic occurrences provide credence to the theory that Pohuwato and Buol, Gorontalo, have local active faults.

CONCLUSION AND SUGGESTIONS

The earthquake occurrences in cluster B (Pohuwato area) and cluster C (Buol area) raise the possibility of a new local active fault on the Gorontalo region's mainland. The focal mechanism of the Pohuwato earthquake demonstrates the Oblique Thrust Fault's inclination toward a northeastern-southern strike orientation. The focal mechanism of the earthquake that struck Buol likewise demonstrates this trend, with the Oblique Thrust Fault's strike orientation leaning east-west. According to the Gorontalo Fault, which has been mapped by the National Earthquake Study Center, the focal mechanism of the earthquake in Cluster A, the Gorontalo area, also demonstrates the strike orientation of the Oblique Thrust Fault in the Northwest-Southeast direction.

In order to increase the accuracy of focal mechanism parameters, more seismometers in Gorontalo and the adjacent areas are required to record micro-earthquake signals. Further investigation is required for mitigation reasons that may be applied in the design and redesign of public buildings in relation to the placement of fault connections, computation of fault length, and estimation of maximum magnitude for each fault.

DOI : http://dx.doi.org/10.12962/j25023659.v10i3.2217

Artikel Masuk : 09-10-2024 Artikel Diulas : 31-10-2024 Artikel Diterima : 26-11-2024

REFERENCES

Fossen H. (2010), “Structural Geology”, Ed ke-1st Volume ke-112. Cambridge: Cambridge University Press.

Hamilton W. (1979), “Tectonics of the Indonesian Region”, Volume ke-1078. Denver.

Hardebeck, J. L. and P. M. Shearer. (2002), :A new method for determining first-motion focal mechanisms”, *Bull. Seism. Soc*. Am., 92, 2264-2276.

Hayes GP, Moore GL, Portner DE, Hearne M, Flamme H, Furtney M, Smoczyk GM. (2018), “Slab2, a comprehensive subduction zone geometry model”, *Science*. 362(6410):58–61.doi:10.1126/science.aat4723.

Katili JA. (1970), “Large transcurrent faults in Southeast Asia with special reference to Indonesia”, *Geologische Rundschau*. 59(2):581–600.doi:10.1007/BF01823809.

Katili JA. (1975), “Volcanism And Plate Tectonics In The Indonesian Island Arcs”, *Revue m??dicale de la Suisse romande*. 26:408–410.doi:https://doi.org/10.1016/0040-1951(78)90166-X.

Keller EA, Pinter N. (2002), “Active Tectonics”, 2nd Edition. New Jersey: Prentice Hall.

Kertapati EK. (2006), “Aktivitas Gempabumi Di Indonesia”, Bandung: Pusat Survey Geologi.

Li, G., Wang, A., & Gao, Y. (2022). “Source rupture characteristics of the September 5, 2022 Luding M 6.8 earthquake at the Xianshuihe fault zone in southwest China”, *Earthquake Research Advances*, 100201. https://doi.org/10.1016/j.eqrea.2022.100201.

Michael AJ. (1987), “Use of focal mechanisms to determine stress: a control study”, *J Geophys* Res 92:357. https://doi.org/10.1029/JB092iB01p00357.

Milsom J. (2001), “Subduction in eastern Indonesia: How many slabs?”, *Tectonophysics*. 338(2):167–178.doi:10.1016/S0040-1951(01)00137-8.

Molnar P, Dayem KE. (2010), “Major intracontinental strike-slip faults and contrasts in lithospheric strength”, *Geosphere. 6*(4):444–467.doi:10.1130/GES00519.1.

Nugraha, A. M. S., Hall, R., & BouDagher-Fadel, M. (2022), “The Celebes Molasse: A revised Neogene stratigraphy for Sulawesi, Indonesia”, *Journal of Asian Earth Sciences*, *228*, 105140. https://doi.org/10.1016/j.jseaes.2022.105140

Rangin C, Jolivet L, Pubellier M. (1990), “A simple model for the tectonic evolution of Southeast Asia and Indonesia region for the past 43 m.y”, *Bulletin de la Societe Geologique de France.* VI(6):889–905.doi:10.2113/gssgfbull.vi.6.889.

Socquet A, Simons W, Vigny C, McCaffrey R, Subarya C, Sarsito D, Ambrosius B, Spakman W. (2006), “Microblock rotations and fault coupling in SE Asia triple junction (Sulawesi, Indonesia) from GPS and earthquake slip vector data”, *Journal of Geophysical Research: Solid Earth. 111*(8).doi:10.1029/2005JB003963.

Thenhaus PC, Hanson SL, Effendi I, Kertapati EK, Algermissen ST. (1993), “Pilot Studies of Seismic Hazard and Risk in North Sulawesi Province, Indonesia”, *Earthquake Spectra. 9*(1):97–120.

Tim Pusat Studi Gempa Nasional. (2017), “Peta Sumber dan Bahaya Gempa Indonesia Tahun 2017”, Jakarta: Kementrian Pekerjaan Umum dan Perumahan Rakyat.

Tim Pusat Gempabumi dan Tsunami. (2024), “Katalog Gempabumi Signifikan & Merusak Tahun 1821 – 2023”, Jakarta: Kedeputian Bidang Geofisika BMKG.

United States Geological Survey (USGS). (1996), “Earthquake Focal Mechanisms – Life’s a Beach(ball)”.

Watkinson, I. M. (2011), “Ductile flow in the metamorphic rocks of central Sulawesi”, *Geological Society, London, Special Publications*, *355*(1), 157–176.

Watkinson IM, Hall R. (2017), “Fault systems of the eastern Indonesian triple junction: Evaluation of Quaternary activity and implications for seismic hazards”, *Geological Society Special Publication. 441*(1):71–120.doi:10.1144/SP441.8

Wichmann, A. (1918), “The Earthquakes of the Indian Archipelago until the year 1857”.

Yang, Y., Wang, S., & Su, R. (2021), “Focal mechanism and seismogenic structure of the Shiqu MS4.4 earthquake”, *Earthquake Research Advances*, *1*(4), 100065. https://doi.org/10.1016/j.eqrea.2021.100065

DOI : http://dx.doi.org/10.12962/j25023659.v10i3.2217

Artikel Masuk : 09-10-2024 Artikel Diulas : 31-10-2024 Artikel Diterima : 26-11-2024