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Analysis of Focal Mechanism Distribution in Northern Sulawesi

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Abstract. Sulawesi has been known to have the complex condition of the geology and tectonics. It is indicated by natural phenomena such as volcanoes and earthquakes in Sulawesi. This study aimed to determine the latest tectonic order in Sulawesi based on the distribution focal mechanism. The locations of the study were in the Sulawesi 2°22' N – 3°48' S and 119°22' – 124°22'. The earthquake data used were from BMKG since 2001 to 2015 with the criteria ≥ M4.5. The strike, dip, and rake data were through Global-CMT for the earthquake in Sulawesi at the same time. An AB cross-section lies along the neck of Sulawesi which has strike-slip fault type of focal mechanism with a shallow depth allegedly caused by Palu Koro Fault activity. CD longitudinal section elongated in the eastern arm of Sulawesi to the ocean, which is dominated by the strike-slip fault showing the activity of Batui Fault at the shallow depths. Matano Fault activity was observed in EF cross-section dominated by a strike-slip fault on the land and at sea by a normal fault. This activity was observed at the shallow depths which shows Matano Fault activity. GH cross section was an event with depth with various subtypes of reverse fault which is relatively uniform turning into an indication of the Sulawesi Sea subduction activity.

Keywords: Distribution, focal mechanism, northern, tectonic

1. Introduction

Sulawesi has been known to have the complex condition of the geology and tectonics. It is caused by main world plate & micro-continent movement around Sulawesi. It is indicated by natural phenomena such as volcanoes and faults in Sulawesi. Faults in Sulawesi such as Walanae Fault (South Sulawesi), Palu Koro Fault (Bone Gulf through Makassar Strait), Gorontalo Fault, Batui Fault (Central Sulawesi), Makassar Thrust (West Sulawesi), Matano Fault, Lawanopo Fault, and Kolaka Fault (Southeast Sulawesi) [1]. If Sulawesi is divided into two main regions, Northern and Southern Sulawesi, we saw more faults located in Northern Sulawesi. Earthquake information gives new perception about the tectonic process in Sulawesi. This perception can be used to explore the natural resource exploration, or for people in the earthquake hazard mitigation.

The research results reported that the hypocenter is on the fault zone or on the meeting area inter-plates. If this information is combined with focal mechanism data, it can visualize the tectonic pattern.

This study aimed to determine the latest tectonic order in Northern Sulawesi based on the focal mechanism distribution.

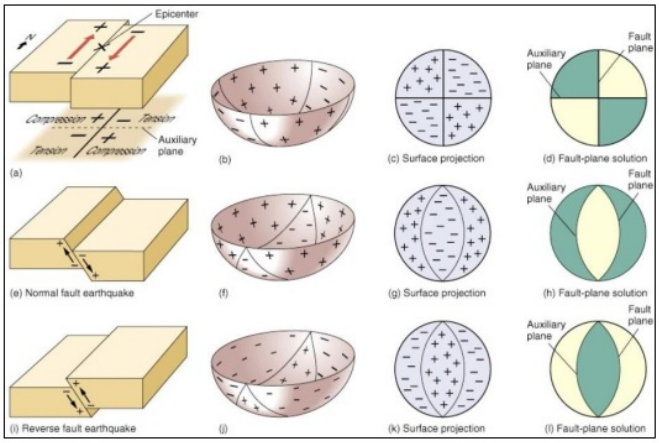

Figure 1. The relation between movement mechanism of faults and their focal mechanism [3].

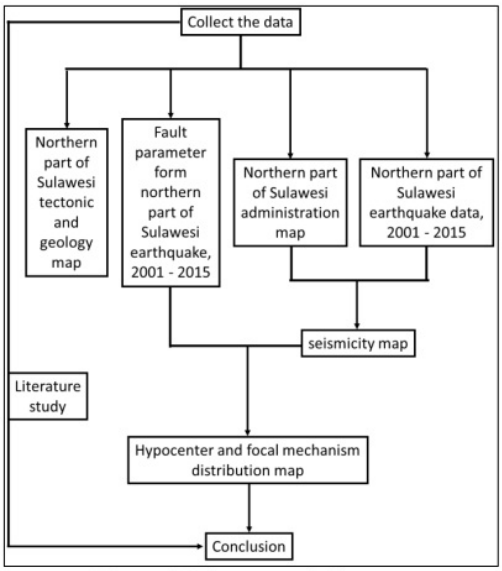

Figure 2. The research diagram

2. Experimental Methods

A focal mechanism solution is the result of waveforms generated by an earthquake and recorded by a number of seismographs. It usually takes at least 10 records to produce a reasonable focal mechanism diagram, and only the seismograph stations are well distributed geographically around the epicenter. The complete characterization of an earthquake focal mechanism provides essential information including the original time, epicenter location, focal depth, seismic moment (a direct measure of the energy radiated by an earthquake), and the magnitude and spatial orientation of the 9 components of the moment tensor. From the moment tensor, we could ultimately resolve the orientation and sense of the

fault slip [2]. Figure 1 provides the information about the relationship between the movement mechanism of faults and their focal mechanism.

The research location covered Northern Sulawesi with $2^0$22' N – $3^0$48' S and $119^0$22' E – $124^0$22' E. The earthquake data were from Geophysics, Climatology, Meteorology Agency of Indonesia (BMKG on Indonesian) along 2001 – 2015 with criteria ≥ M4.5. The focal mechanism data were from Global-CMT for the earthquake in same location and time. The research method is explained by the diagram in Figure 2.

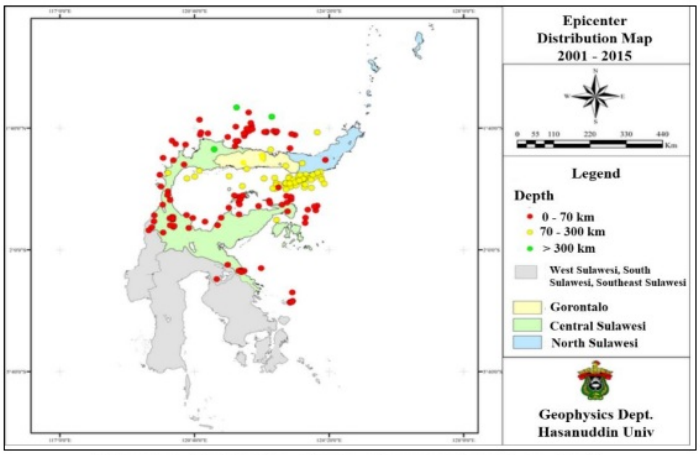

Figure 3. Epicenter distribution map based on depth

3. Results and Discussion

Figure 3 shows earthquake activity on the sea more than on the land. Besides, the shallow earthquake is more than others. The moderate earthquake occurred in southern Sulawesi North Arm (SNA), and the deep earthquake happened in northern SNA. The earthquake on the land is affected by the fault and the earthquake on the sea is influenced by subduction around SNA. This is caused by some structures such as Sulawesi Sea subduction and East Sangihe thrust in eastern and southern SNA [4]. The fault activity is shown from the shallow hypocenter, and the subduction activity is shown from the intermediate and deep hypocenter.

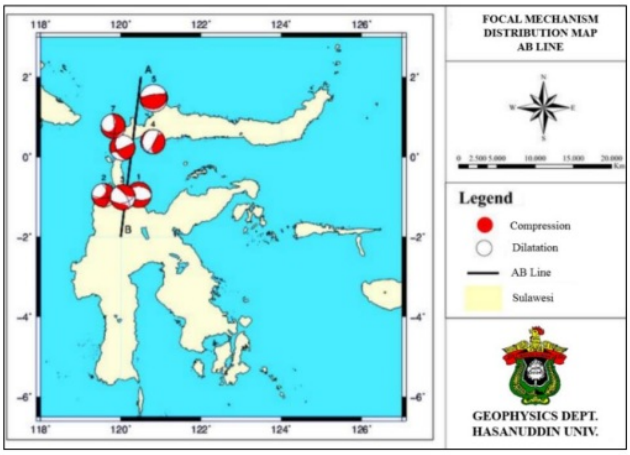

Figure 4. Focal mechanism distribution around AB line.

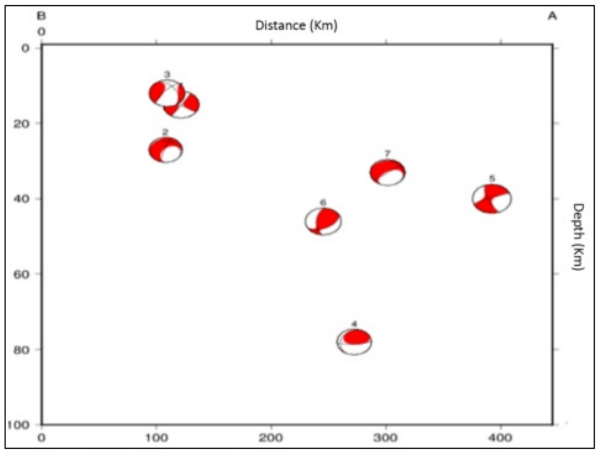

Figure 5. Focal mechanism cross-section around AB line.

Figure shows that many earthquakes occurred on northern Sulawesi. That is the indication for the complex tectonic pattern on northern Sulawesi. To find the depth effect of each earthquake in northern Sulawesi, the imaginary lines on several parts are drawn on the map to represent the earthquake in this area.

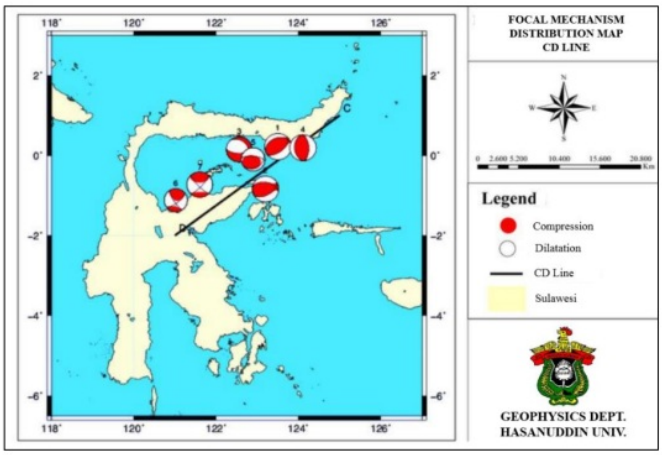

Figure 6. Focal mechanism distribution around CD line.

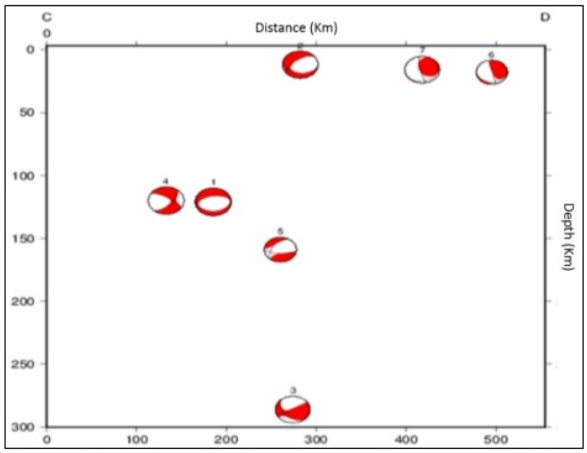

Figure 7. Focal mechanism cross-section around CD line.

CD line (Figure 6 & 7) is along Sulawesi East Arm to Sulawesi North Arm like AB line that shows 2 focal mechanism clusters. Meanwhile, Matano Fault activity is shown in EF line (Figure 8 & 9). The earthquake on the land is dominated by the strike-slip fault, and the earthquake on the sea is mainly caused by the normal fault. This activity is shown on the shallow depth assigned by Matano Fault activity. Furthermore, Sulawesi Sea Subduction shows the earthquakes along the GH line (Figure 10 & 11). The earthquake with various depths until 600 km and reverse fault type indicates this structured activity.

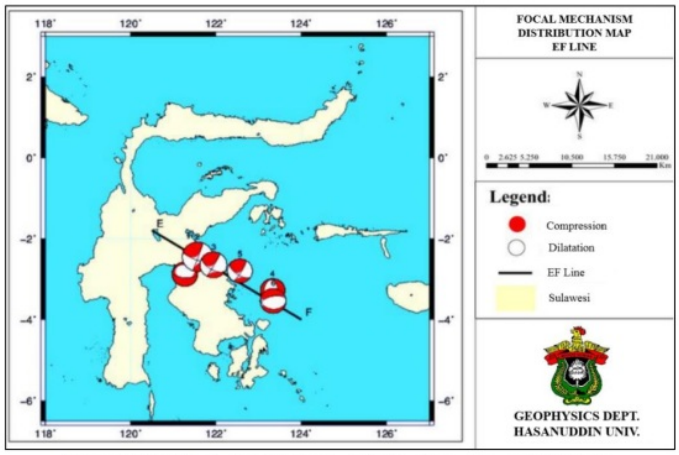

Figure 8. Focal mechanism distribution around EF line.

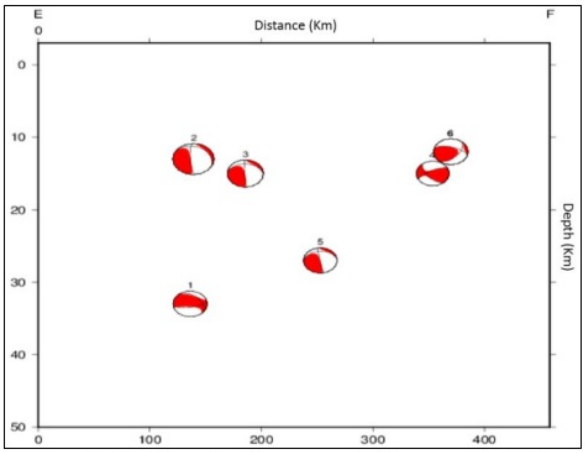

Figure 9. Focal mechanism cross-section around EF line.

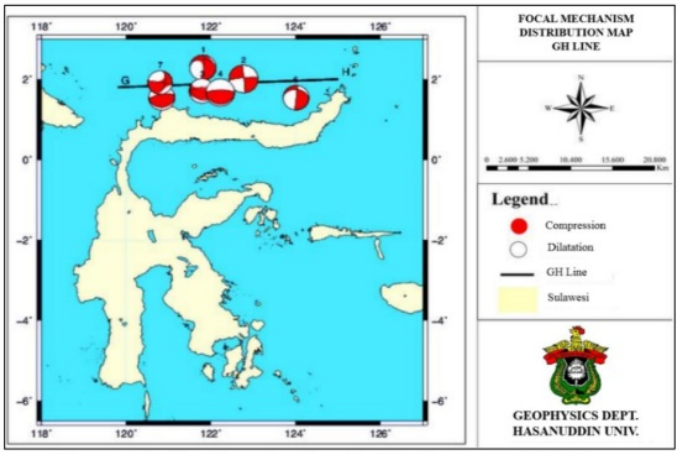

Figure 10. Focal mechanism distribution around GH line.

The four imaginary lines (AB, CD, EF, & GH) show focal mechanism distribution pattern on Northern Sulawesi. AB line lies on Palu – Koro Fault track on the southern cluster. It can be said that Palu – Koro Fault is the strike-slip fault. This result is different from [1, 5] in the other research. Previous work [1] reported that Palu – Koro Fault is a normal fault. The explanation provided by [5] using deformation analysis said that Palu – Koro Fault acts a transtensional deformation, normal faulting with a left lateral strike-slip component. CD line is located on Sulawesi East Arm. The western cluster is dominated by strike-slip fault indicating Batui Fault activity on the shallow depth. This is different from [1] who said Batui Fault is a reverse fault. Batui Fault, as known as Batui Thrust, separates the ophiolites from sedimentary formation [6] on this location. As thrust, the mechanism is a reverse fault, but the result shows the strike-slip. It may be affected by the activity of strike-slip Balantak Fault [7] located near Batui Fault. The eastern cluster lies on the sea with the profound depth, signed by the reverse fault and a normal fault earthquake. This indicates Moluccas Sea Double Subduction. Molucca Sea Double Subduction is generally a reverse fault and has a standard fault mechanism under 200 km.

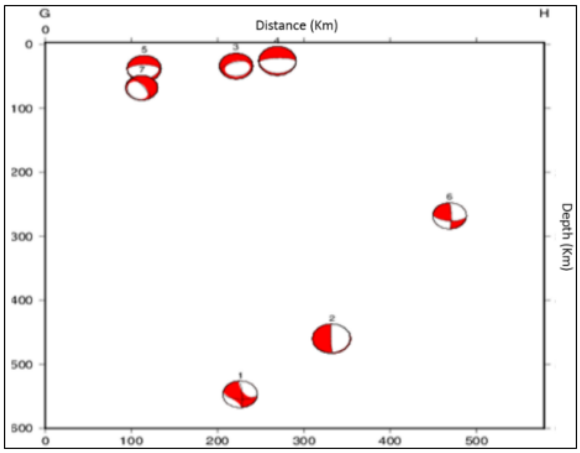

Figure 11. Focal mechanism cross-section around GH line.

EF line shows the activity of Matano Fault. Based on the focal mechanism distribution, that mechanism is a strike-slip fault. Matano Fault is a strike-slip fault with ESE – WNW orientation which cuts Southeast Sulawesi through Matano Lake. This fault is marked by a broad valley in the northern part of Southeast Sulawesi that disrupts local drainage pattern. Matano Fault is connected to Palu-Koro Fault on the western part and Sorong Fault on the eastern part [8]. Sulawesi Sea Subduction activity is shown in GH line. As known as North Sulawesi Subduction, this structure has a reverse fault on the shallow depth and strike-slip on deeper depth. This result agrees with [9] that earthquake focal mechanism on 0 – 200 km is a reverse fault and on 200 – 450 km is a strike-slip fault. The subduction has resulted in magmatism activities and a volcano that produces plutonic rocks and the volcano widespread in Sulawesi North Arm [10].

4. Conclusion

Some active structures in Sulawesi are shown by focal mechanism distribution. The strike-slip Palu-Koro Fault is shown on the shallow depth. Batui Fault is generally a strike-slip fault, with the segmentation of sea affected by Moluccas Sea Double Subduction activity and signed by a reverse fault type. Matano Fault is shown on the shallow depth with a strike-slip fault type. Sulawesi Sea Subduction activity is shown until 600 km depth dominated by the reverse fault type. This research needs to be developed in the future. Hypocenter determination becomes a vital thing for further interpretation. This result is expected to be a base in arranging the earthquake hazard mitigation.

Acknowledgments

We gratefully acknowledge BMKG and Global-CMT for their data used in this research. This research can be more informative if is completed by the other data, like geology, tectonics, geodesy, etc. We thank Geophysics Dept., Faculty of Mathematics and Natural Sciences Hasanuddin University (UNHAS) for supporting this research.

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