Mapping Fault Distribution Using Lineation and Fault Fracture Density Methods in the Palu Basin and Surrounding Areas

M. R. Muin [a,1] , Livya. J. Pandesia [a,2*], Abdullah [a,3]

[a] Geophysical Engineering Study Program, Department of Physics, Faculty of Mathematics and Natural Sciences Tadulako University, Jl. Soekarna Hatta, Palu, 94118, Indonesia
[1] livyapandesi20@gmail.com
*corresponding author

ARTICLE INFO

Keywords
Fault Fracture Density
Fault
Lineation

ABSTRACT

Introduction: Research has been carried out with the title "Mapping Fault Distribution Using Lineation and Fault Fracture Density Methods in the Palu Valley and Surrounding Areas" with the aim of determining the direction of fault distribution and analyzing fault density based on lineation data. **Methods:** This research uses the lineation method with a total of 40 grids. Data processing uses Global Mapper 18, rockwork 17, PCI Geomatica 2014, and Arcgis 10.8 software. **Result and Discussion:** The results obtained show that the lineation data from the dominant rose diagram has a relatively east-west direction. Areas that have high fault density are in Lindu District, Palolo District, Nokilalaki District, Gumbasa District, Dolo District, Sigi Biromaru District, and Mantikulore District with fault density values of 5,945 - 18,950/km2. **Conclusion**: The direction of lineation obtained tectonically is influenced by the Palu-Koro fault which tends relatively north-south, the Graben Palolo A and Graben Palolo B faults which trend relatively southeast-northwest, and the Lore Lindu fault zone. Areas with high density are weak zones that are vulnerable to natural disasters and potential ground movements.

1. INTRODUCTION

The Palu Valley region is prone to earthquake disasters due to the Palu-Koro fault. This fault is an active fault that has a dominant horizontal motion. In the eastern part of Palu Valley, faults are generally found in the southwest-northeast direction and show horizontal or oblique movement. In addition, most of the faults show the direction of dextral displacement [1].

A fault is a fracture that is displaced. The displacement on a fault can occur along a straight line (translation) or rotate (rotation). The displacements can range from a few millimeters to hundreds of meters and can be a few decimeters to thousands in length.

meters. As a result of displacement, faults will change topographic development, control surface and subsurface water, damage rock stratigraphy, and so on. One of the methods that can be used to identify faults is the Fault Fracture Density (FFD) method, which is a geospatial analysis to determine the condition of the macrostructure in an area. Macrostructure can provide an assessment of the structure formed by faults and fractures [2]. In this analysis, the fractures identified are alignment patterns, either river alignment patterns or faults caused by fault activity [3].

The results of research using the FFD method show that areas with high density are influenced by the main structure in the area. The results obtained from previous research using the FFD method in the North Luwu Regency area with the results of the alignment direction obtained are in accordance with the direction of the main structure, namely the Kulewana fault segment which tends to be West-East with a fault density value of 3,225 - 4,754 km2 [4].

In this research, the lineation and Fault Fracture Density (FFD) methods are used to determine the fault distribution pattern and analyze the fault density based on 2 lineation data located in the Palu Valley and surrounding areas.

Sulawesi and its surrounding areas have geological structures, especially regional faults. These geological structures have been recognized and discussed by many authors. The main geological structures of Sulawesi include the Palu-Koro Fault, Walanae Fault, Matano Fault, Batui Fault, Poso Rise Fault, Balantak Fault, Gorontalo Fault, Sulawesi Sea Rise, and Bone Bay. The study area has a major geological structure, namely the Palu-Koro fault.

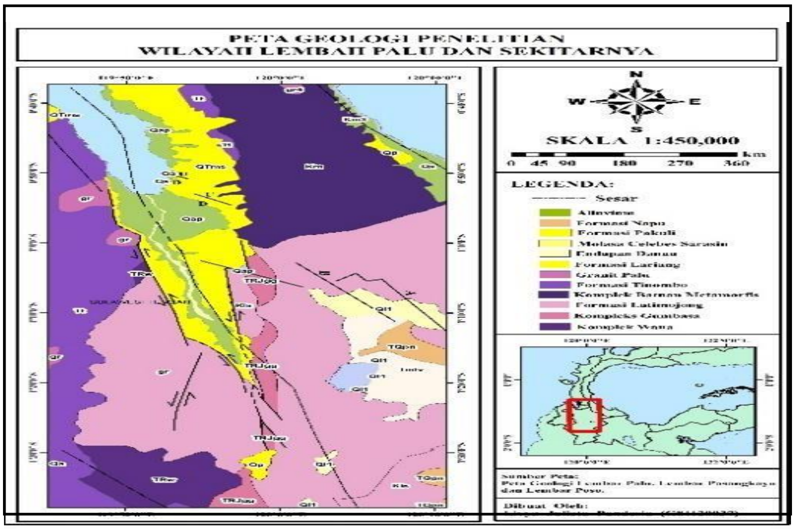

Fig 1. Geologic Map of the Research Site Palu Sheet, Pasangkayu Sheet and Poso Sheet

A fault according to [5] is a plane or fracture zone that appears to have undergone movement. Based on [6], a fault is a fracture in rock that has undergone a shift so that there is a displacement between the opposite parts, in a direction parallel to the opposite parts, in a direction parallel to the fault plane. The displacement occurs

There are three types of faults: horizontal, strike-slip, and dip faults. In addition to these three types of faults, there are also faults that are a combination of horizontal faults and up/down faults called oblique faults.

1. Strike-slip fault is a fault whose movement is parallel, the left block is relatively displaced in the opposite direction to the right block. Based on the direction of fault movement, horizontal faults can be divided into 2 types of faults, namely:
    a. Dextral horizontal faults are faults whose direction of movement is in the direction of clockwise rotation.
    b. Sinistral horizontal faults are faults where the direction of displacement is counterclockwise.
2. A reverse or thrust fault is a fault that occurs due to a compressive force in the vertical direction, causing the rock plane to move downward following the fault plane. This fault is divided into two: reverse fault (RF), if the dip angle is large enough or dip > 45°, and thrust fault (TF), if the dip angle is relatively small or dip < 45°.
3. Normal faults are faults that occur due to forces acting on the rock in a horizontal direction. A lineament is a linear feature that has a different direction and pattern to features in the surrounding area and can reflect subsurface features.

Straightness delineates ridges or boundaries of high and low areas, rivers, coastlines, and rock formation boundaries [7].

According to [8], in analyzing straightness the modular algorithm consists of extracting lineages from the image and converting these linear features into vector form by using 6 optional parameters (RADI, GTHR, LTHR, FTHR, ATHR, and DTHR).

1. RADI (Filter Radius) is the data range detection filter radius value of the pixels that will be subjected to the edge sharpening filter.
2. GTHR (Gradient Threshold) is the edge gradient threshold value. This parameter is to determine the minimum gradient level threshold for edge pixels.
3. LTHR (Length Threshold) is the value of the minimum length of pixels that are connected as a straightness vector. This parameter is used to determine the minimum length of the curve in pixels.
4. FTHR (Line Fitting Error Threshold) is an error tolerance threshold value. This parameter is used to determine the maximum error in pixels. A low FTHR value will depict a better fit but also shorter segments in the polyline.
5. ATHR (Angular Difference Threshold) is the maximum value of the angular difference between two vectors to be connected. This parameter is used to determine the maximum angle (in degrees) between polyline segments.

Tadulako Science and Technology Journal
Vol. 3, No. 2, 2023, pp. 1-8
e-ISSN 2776-4893

6. DTHR (Linking Distance Threshold) is the maximum length value between two vectors (in pixels) to be linked. This parameter is used to determine the minimum distance (in pixels) between the endpoints of two vectors to be linked [9].

The Fault Fracture Density (FFD) method is used to apply straightness pattern calculation to satellite images so that weak zones can be identified based on straightness density [9]. The result of the alignment is a rose diagram and the FFD parameter is the number of alignments per unit area. Each alignment is then converted into a grid and the number of alignments is calculated. then the value of the number of alignments will be combined with other grids using equation 1 [10].

$$L = \sum xi/\ N\ i{=}1 \text{ Km2} \qquad (1)$$

Equation (1) serves to define that the straightness density value is obtained from the total number of straightnesses in a unit area.

A rose diagram can describe the value of an earth's appearance consisting of vector parameters (direction and magnitude) in a certain angle and direction and the number of occurrences. DEM data that has been extracted into hillshade data with different azimuth angles will produce different alignment directions. Based on the rose diagram, it can be concluded that the alignment generated automatically with the LINE algorithm can only identify the dominant alignment directions [11].

2. RESEARCH METHODS N

The lineation method is a linear feature that has different directions and patterns that can reflect subsurface features. Lineations can depict ridges or boundaries of high and low areas, rivers, coastlines, and rock formation boundaries. *Fault Fracture Density (FFD) is* used to apply the calculation of alignment patterns on satellite images so that weak zones can be identified based on alignment density. The existence of fault structures and fractures that are formed indicates that these areas are weak (unstable) zones that can be an indication of potential landslides and ground movements.

The research location is in the Palu Valley Region. Astronomically, the research location is located at 00º 42' - 01º 28' LS and 119º 52' - 120º 7' East. The map of the research location of the Palu Valley region and its surroundings can be seen in Figure 2.

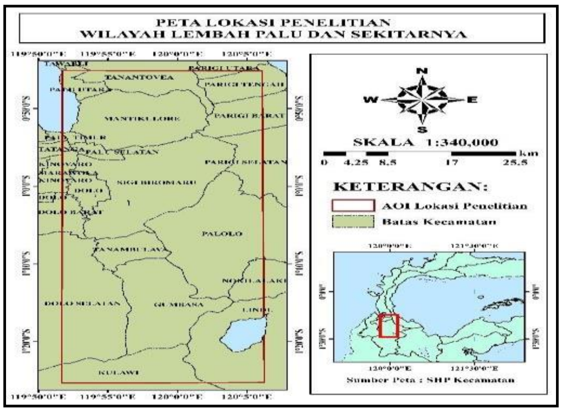

Fig. 2 Map of the Research Location of the Palu Valley and Surrounding Areas

3. RESULTS AND DISCUSSION

3.1 Fault Distribution Patterns in the Palu Basin and Surrounding Areas

Fault distribution patterns in the Palu Valley and Surrounding Areas using secondary data in the form of 30 M resolution SRTM *(Digital Elevation Model) (Shuttle Radar Topography Mission)* DEM data and primary data in the form of direct field measurements of *strike* and *dip. The* DEM was then analyzed and converted in the form of a *hill shade* based on the angle of illumination used. This process is carried out in *Global Mapper* software using *Slope Direction Shading* with each irradiation angle of 0°, 45°, 90° and 135° with an *altitude* of 45°.

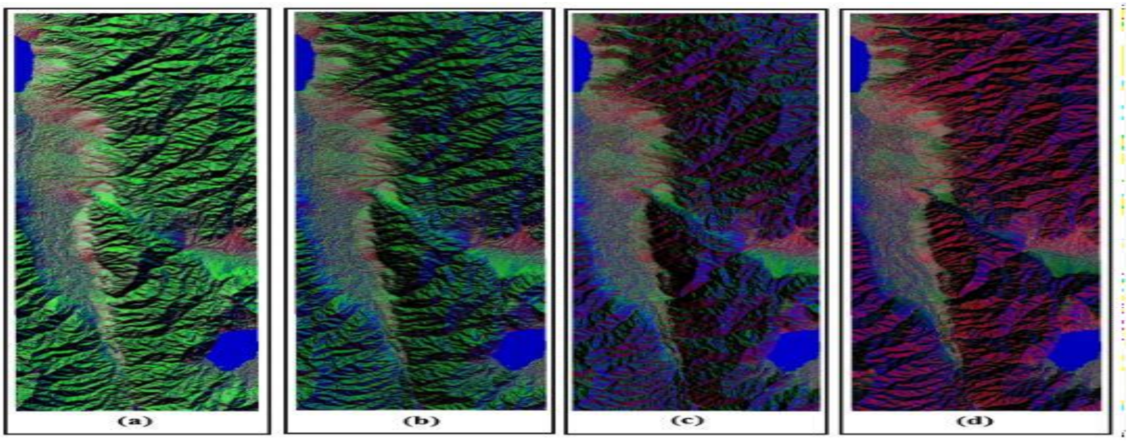

Fig 3: Relief of Palu Valley and surrounding areas based on *Slope Direction Shading* on *Global Mapper* with irradiation angles of (a). 0°, (b) 45°, (c) 90° and (d) 135°.

Next, we analyzed the straightness obtained from each irradiation angle using the LINE algorithm parameters in *PCI Geomatica* listed in Table 1.

Table 1. Parameter values of the LINE algorithm

Parameters	Nilai Parameter
RADI *(Filter Radius)*	5 (Pixel)
GTHR *(Gradient Threshold)*	70 (Pixel)
LTHR *(Length Threshold)*	5 (Pixel)
FTHR *(Line Fitting Error Threshold)*	3 (Pixel)
ATHR *(Angular Difference Threshold)*	30 (Pixel)
DTHR *(Linking Distance Threshold)*	10 (Pixel)

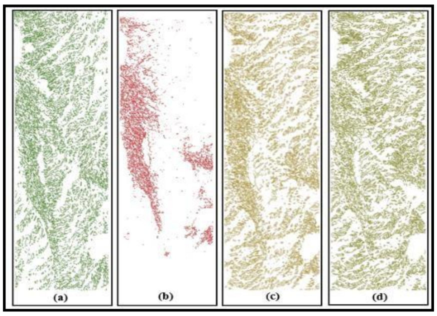

Fig. 3 Straightness pattern of each irradiation angle (a).0°, (b) 45°, (c) 90° and (d) 135°.

Tadulako Science and Technology Journal
Vol. 3, No. 2, 2023, pp. 1-8
e-ISSN 2776-4893

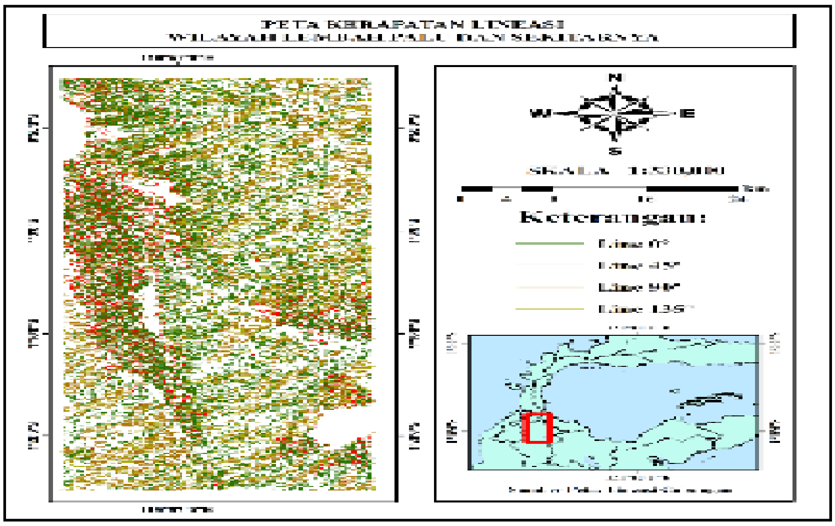

Fig. 4 Combined fault alignment pattern of each irradiation angle using LINE algorithm parameter values

The alignment direction obtained from *Arcgis software is* then plotted into *rockwork software* to obtain a *rose* diagram of each angle of illumination. The direction of the combined fault alignment pattern from each angle of illumination using the LINE algorithm parameters was found to be dominantly East-West and Southeast-Northwest. The dominant East-West direction is likely caused by the subduction activity that occurred after the expansion in the Makassar Strait *(post-spreading)* [12] and the thrust of the Pacific plate [13]. Meanwhile, the Southeast-Northwest direction is due to the thrust of the Indo-Australian plate from the South [13].

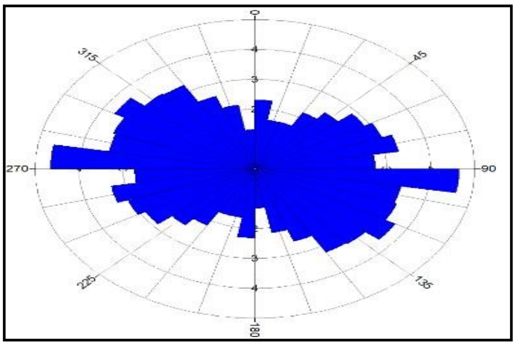

Fig 5. Combined rose diagram of each irradiation angle Based on the results of the *rose* diagram

Based on the results of the combined *rose* diagram, the dominant direction of each angle of illumination is East - West with a range of 90° - 270°. Based on the dominant direction of the fault alignment, the Palu Valley research area and its surroundings are tectonically influenced by the Palu-Koro fault which tends to be in the North-South direction, the Graben Palolo A, Graben Palolo B faults in the Southeast-Northwest direction and the Lore Lindu fault zone.

3.2 Fault Density in the Palu Basin and Surrounding Areas

Fault density was conducted to determine the tectonic conditions in the Palu Valley region. A high-density value indicates that the area has a high seismicity value. The fault density analysis was

Vol. 3, No. 2, 2023, pp. 1-8

conducted to determine the number of faults per unit area. The FFD method was used to obtain the alignment which is a reflection of the topographic features such as river alignment, valley alignment, fault structure, fracture structure, and rock contact.

The value of fault density in the Palu Valley and surrounding areas is analyzed based on the combined irradiation angle data. The parameter used in the calculation of fault density value is the number of alignments divided by the grid area.

The results of the *Fault Fracture Density* map of the study area are grouped into 3 density classes, namely low density (0-3492/km²) shown by dark green and light green colors. Medium density (5,945-8,843/km²) is shown in yellow. For high density (12,262 18,950/km²) shown in orange and red which can be seen in Figure 7.

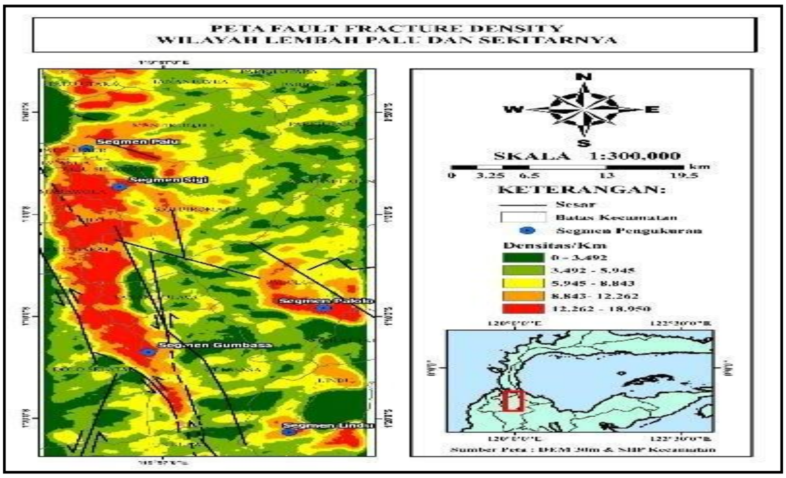

Fig 6. FFD Map of Palu Valley and Surrounding Areas

Areas that have high fault density values are around Palolo Subdistrict, Nokilalaki Subdistrict, Lindu Subdistrict, Dolo Subdistrict, Gumbasa Subdistrict, Sigi Biromaru Subdistrict, Mantikulore Subdistrict, which are shown in orange and red on the map. Areas that have a high fault density have fault reflections such as kinks, *fractures/joins*, hot springs and easily deformed rocks.

4. CONCLUSIONS

Based on the results of the research that has been conducted, it can be concluded that the results of the lineation data obtained the dominant direction of each angle of illumination is East - West with a range of 90° - 270°, while in the field measurements, the dominant direction of the fault obtained is Southeast - Northwest with a range of 135° - 315°. Based on the dominant direction of the lineation data and field measurement data, tectonically the Palu Valley area and its surroundings are influenced by the Palu-Koro fault which tends to be in the North-South direction, the Graben Palolo A and Graben Palolo B faults which are in the Southeast-Northwest direction and the Lore Lindu fault zone. The results of fault density in

Palu Valley and surrounding areas are grouped into 3 density classes, namely low density (0 - 3,492/km2) shown by dark green and light green colors. Medium density (5,945 - 8,843/km2) is shown in yellow. High density (12,262 - 18,950/km2) is shown in orange and red. Areas with high fault density values are located around the Palolo sub-district, Nokilalaki sub-district, and Nokilalaki sub-district.

References

[1] Sarp, G. (2005). *Lineament Analysis From Satellite Images, North-Westof Ankara* (Master's thesis, Middle East Technical University).

[2] Sudrajat, A. (1981). *Geological investigation of Palu Valley*, Central Sulawesi, using remote sensing techniques. Dissertation ITB

[3] Chemong, C. A., & Chenrai, P. (2013). Fracture density analysis in the sai yok fault, western Thailand, and its implications for hydrological exploration. Research *Journal of Applied Sciences*, 125-130.

[4] Hung, L. Q., Batelaan, O., & De Smedt, F. (2005) *Lineament extraction and analysis, comparison of LANDSAT ETM and ASTER imagery*. Case Study: Suomuoi tropical karst catchment, Vietnam. In Remote sensing for environmental monitoring, GIS applications. and geology V. *SPIE*. 5983:182-193

[5] Nugroho, U.C. and Susanto. (2015). Automatic *Lineament Extraction* Using SRTM DEM Data Case Study: Bangka Island. Proceedings of XX Annual Scientific Meeting

[6] Asikin, Sukendar, 1979, *Basics of Structural Geology*. Department of Geological Engineering: Institute of Technology.

[7] Billings, M.P., (1959). Structural Geology, New Jersey, Prentice Hall, Inc, Englewood Cliffs.

[8] Ragan, Donal M., (1973). *Structural Geology*: An Introduction to Geometrical Techniques, Second Edition, John Wiley and Sons, New York.

[9] Suryantini and Wibowo. H., (2010). Application of Fault and Fracture Density (FFD) Method for Geothermal Exploration in Non-Volcanic Geothermal System; a Case Study in Sulawesi-Indonesia Proceedings of World Geothermal Congress. Bali

[10] Hobbs, B.E., W.D. Means, and P.E. Williams (1976). *An Outline of Structural Geology*. John Wiley & Sons, New York, 571.

[11] Nasruddin, M.N. (2023). Analysis of Peak Ground Acceleration (PGA) and Fault Density on Ground Movement in North Luwu District, South Sulawesi. *Thesis*. Faculty of Mathematics and Natural Sciences, Tadulako University, Palu.

[12] Thannoun, R. G. (2013) Automatic extraction and geospatial analysis of lineaments and their tectonic significance in some areas of Northern Iraq using remote sensing techniques and GIS. International Journal Of Enhanced Research In Science Technology & Engineering Bulletin. Vol 2, no 2, pp 1-11.

[13] Baeda, Yasir. A., 2011, Seismic and Tsunami Hazard Potential in Sulawesi Island, Indonesia. *Journal of International Development and Cooperation*, Vol. 17, No.1, pp. 17-30.