

Identifying Non-Volcanic Geothermal Potential in Amohola, Southeast Sulawesi Province, by Applying the Fault and Fracture Density (FFD) Method

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Indonesia has numerous volcanic areas that lead to a significant geothermal potential. The geothermal potential could be produced by volcanic and non-volcanic processes. To date, geothermal possibilities by volcanic process are the most commonly known and explored in several areas in Indonesia, whereas, geothermal potential by non-volcanic process is rarer. Therefore, Indonesia is likely has a promising non-volcanic geothermal also. Non-volcanic geothermal systems could be identified by using Fault and Fracture Density (FFD) method, lineaments analysis from SRTM and topography data, as well as using earlier research models by previous researchers. By using those methods, the existing of fractures and possibility level of area that being recharge and discharge zones for geothermal might be predicted. Thus, the result could be the next target of exploration. This paper describes the application of those methods for the Amohola region and surrounding areas in Southeast Sulawesi Province. In general, the study area has complex geological characteristics. Consequently, the methods could be applied to identifying the presence of non-volcanic geothermal system in this study area.

1. Introduction

Geologically, Sulawesi is situated at the intersection of three major plates, which are the Eurasia, Indo-Australian and Pacific. Consequently, these tectonic activities result in the formation of volcanoes in Sulawesi, and in particular, both volcanic and non-volcanic hosted geothermal areas.

Sulawesi is well-known for its complex tectonic setting resulting in faults and fractures (Sompotan, 2012), among other geologic feature, e.g., volcanoes. A discovery of geothermal manifestations in the Amohola region and surrounding areas [4] in a region with no volcanic activity has spurred consideration that a non-volcanic geothermal system may exist in this area. In geothermal systems, faults, fractures or contacts between intrusive and surrounding rocks may become conduits for thermal water [3].

The simple method to indicate highly fractured is Fault and Fracture Density (FFD) method. In addition, this method is possible to assess structure density areas that formed by interconnection of faults and fractures [3]. By applying this method to a non-volcanic geothermal system, the relationship between fractures and surface geothermal manifestations could be identified.

2. Geological Setting

The focus area of this study is the Amohola region and surrounding areas in Southeast Sulawesi Province with coordinates of 122°36'2.29" - 122°47'27.69" E and -4°16'22.98" - -4°16'22.98" S. Geologically,



the study area is comprised of the East Sulawesi Ophiolite Belt that contains an ophiolite complex and pelagic sediment on the east and southeast arms of Sulawesi. This belt consists of mafic and ultramafic rocks as well as pelagic and mélange sediments in several locations. Ultramafic rocks are dominant in the southeast arm and mafic rocks are dominant in northern Sulawesi, particularly along the north shore of Sulawesi Southeast arm [2].

The most important geologic structures for the occurrence of geothermal manifestation in the Amohola region are faults with patterns that strike NW-SE and NE-SW. The tectonic setting of the region generate normal faulting which locally may have increased permeability at the structural intersection of oblique and normal faults. Yushantarti and Rezky [4] reported that this increased rock permeability at the fault intersections creates a pathway for the upward movement of hydrothermal fluid from depth to the surface.

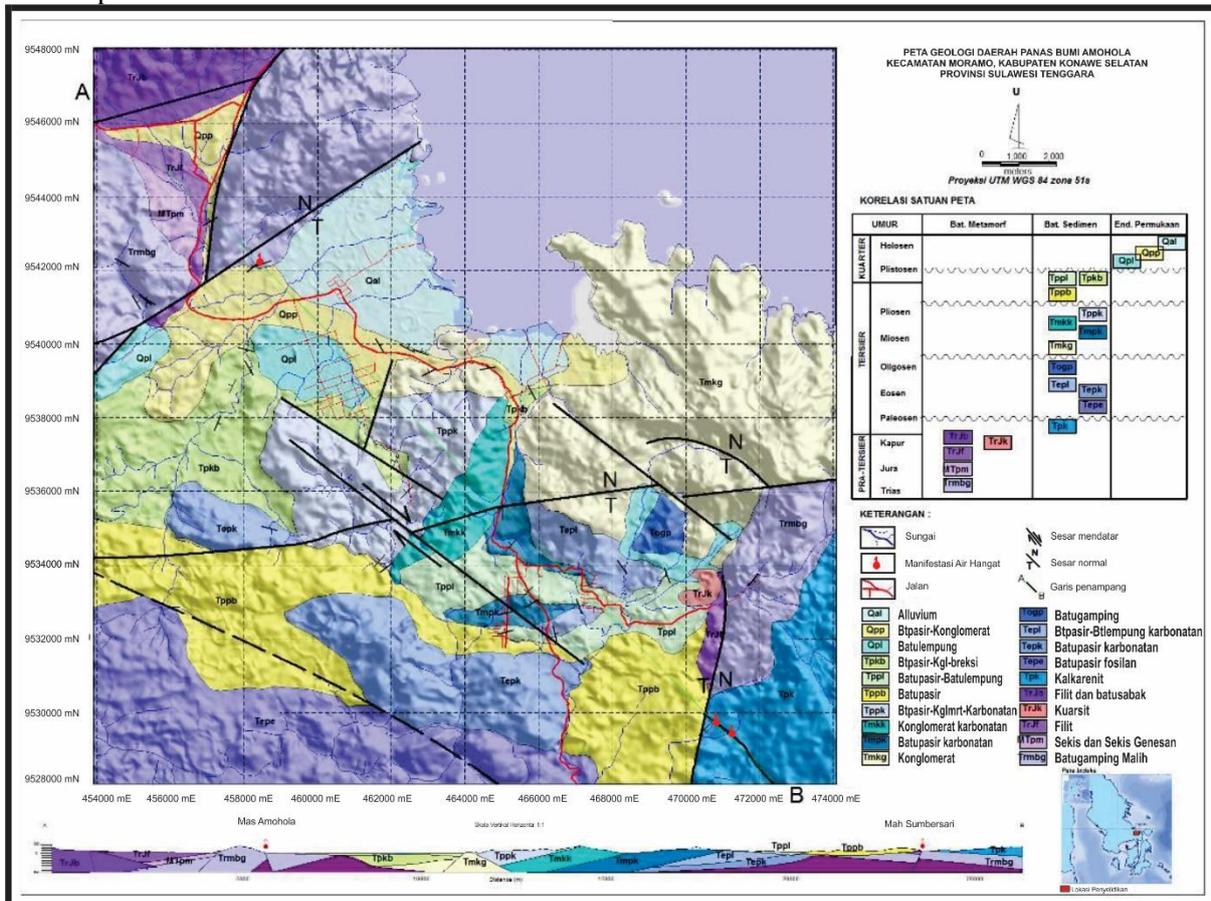


Figure 1. Geothermal Geological Map of Amohola Region [4]

3. Methodology

The FFD method has been applied in this study. Firstly, ASTERGDEM (Advanced Spaceborne Thermal Emission and Reflection Global Digital Elevation Map) image data was used for remote sensing image analysis. The data was processed by using GlobalMapper software to obtain lineament patterns.

Shading features from ASTERGDEM image are used in lineament analysis. Identification of lineaments is needed to support the analysis and estimation of the extent of lineaments at the macroscopic scale. Azimuth of lighting direction is divided into 4 quadrants, which are 0°, 90°, 180° and 270° with similar lighting elevation. The next step is making a grid for determining density and total lineament length data for each grid. Furthermore, exact value according to total lineament length is

added in each center of grid. Then the grid values are contoured. The contour map will now reflect fractures density. High density contours indicate high density fracturing and could be interpreted as correlating to high permeability.

In addition to the FFD analysis, another literature study of the geochemistry data was conducted to identify the type of thermal water present in study area.

4. Discussion

In this study, ridge and valley lineaments data are used as a primary dataset, while geological and geochemistry data based on Yushantarti and Rezky, [4] are used as secondary dataset.

The lineament data are processed into rose diagrams and the resulting lineaments direction for the ridges is relatively NNW – SSE and various directions (Nm– S, NW – SE and NE – SW) are indicated for the valleys (Fig. 2). Additionally, the lineament data is also used to create a FFD map (Fig. 2). There are nine different zones that reflecting high permeability value. In this study, 2 km/km² FFD contour is applied as a cut off value to define an anomalous area.

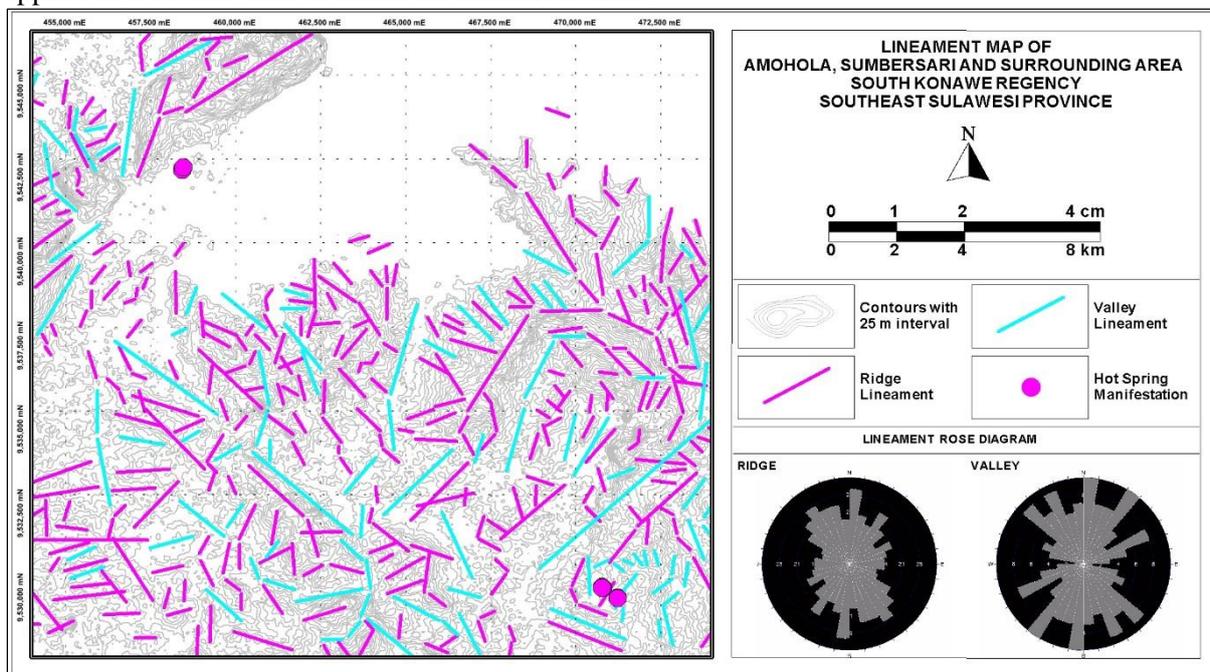


Figure 2. Lineament Map of Study Area

Of the total nine zones identified, four zones are located east of study area, two zones lie in the center and the rest occur to the NW and SW of the study area. By contrast, there is no zone at all in N and NE of the study area owing to those areas are a marine region, hence, lineament interpretation could not be done.

Based on topography, zone 1, 5, 6, 7 and 9 are situated on the slope areas, while zone 2, 4 and 8 are located on the hills as well as zone 3 occurs surrounding one hill (Fig. 3).

From the nine distinct zones (Fig. 3), only two are associated with warm or hot springs, which are in Amohola region (zone 1) and Summersari (zone 7). Those remaining seven zones not associated with warm or hot springs are dominated by graben blocks in a normal fault environment. Moreover, the control of erosion and rock weathering might have responsibility to this, in spite of excessively fractures existence in seven zones.

In addition, Amohola and Summersari geothermal manifestations emerge from permeable rocks. In particular, Amohola springs appear on altered limestone unit (Trmbg), whereas Summersari springs

come up on calcarenite unit (Tpk) (Fig. 1). It might be assumed that manifestation related to travertine associated with calcarenite unit.

4.1 Geothermal Possibility Area and Its Association with Geological Setting

Two zones that are interpreted as having possibility as a geothermal prospect area are associated with normal faults in the NW and SE portions of the study area.

Amohola springs are not located in one of the high permeability zones identified by the FFD method. However, these springs are situated on a normal fault zone with a NE – SW trend and its hanging wall facing SE. As a result, thermal manifestations could appear on the surface. As mentioned previously, Amohola springs issue through altered limestone [4]. The altered limestone was faulting as leaking normal fault that triggered the manifestation existence.

On the other hand, Summersari springs are exactly located in a FFD method designated high permeability zone (zone 7). This zone is also associated with a normal fault striking N – S and the hanging wall in W – NW slip. Based on fault movement, we refer that fault as an oblique fault. These springs appear on travertine. According to the discussion above, it could be concluded that Summersari springs emerge on the surface is caused by high fractures intensity and strengthened by its spring location that situated exactly on the fault zone.

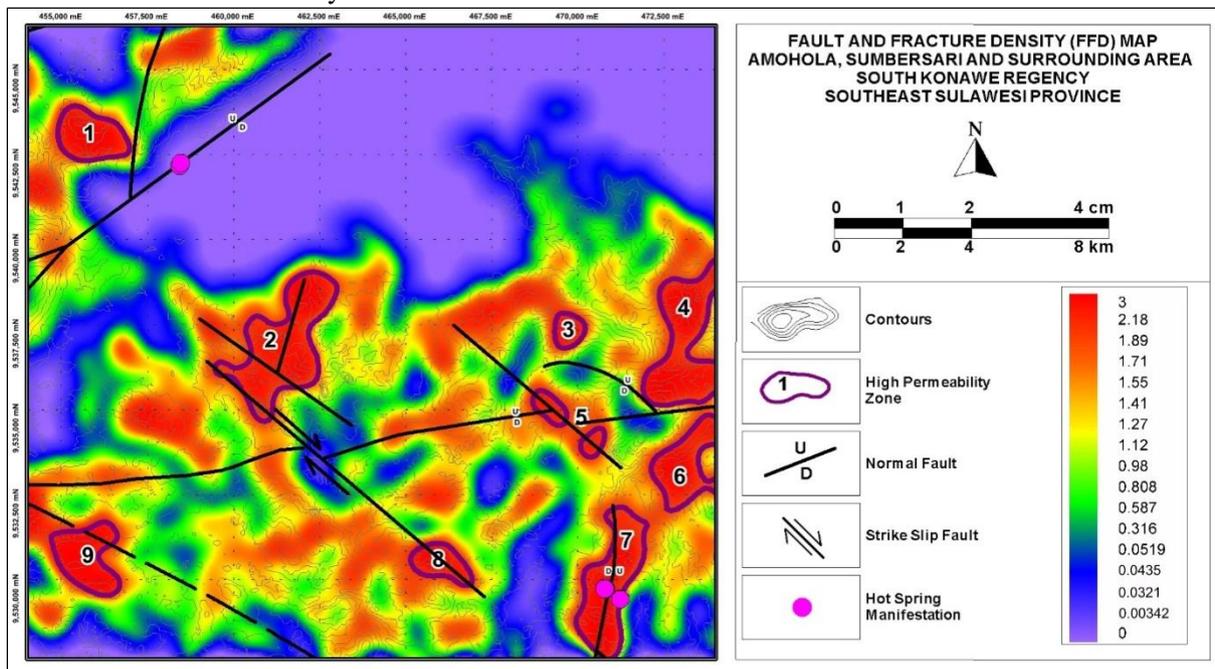


Figure 3. Fault and Fracture Density Map of Study Area

4.2 Geochemistry

Amohola springs consist of four separate springs, one that is hot and three that are warm [4]. The hot spring has pH 6.59 and 50°C water temperature at 26.8° C air temperature. In addition, the hot water in this spring is clear (colorless), odorless and tasteless.

In comparison, the warm springs have pH in the range of 6.35 – 6.62 with temperature ranging from 37.5°C to 46.3°C. Warm water in Amohola springs have various characteristics, such as color (white to colorless) and scent (sulfurous to odorless).

In terms of Summersari springs, there are five distinct manifestations that are categorized as warm springs with pH ranging from 6.65 to 6.94 and temperature from 33.3° C – 48.2° C. All springs in Summersari have similar properties which are clear (colorless), odorless and tasteless [4].

Warm water at Summersari springs is categorized as bicarbonate water. This type of chemical signature may indicate that the water has a surface water characteristic or may indicate mixing with surface water dominance. The presence of bicarbonate leads to an estimation that the springs are associated with the thermal water flow that contain gas, in particular CO₂ which condenses in a shallow aquifer.

According to the previous research [4], Amohola and Summersari springs are at different geothermal system. The geothermal system at Amohola springs is considered to be upflow or at the margins of an upflow. On the other hand, geothermal system at Summersari springs is interpreted as outflow.

5. Conclusion

Study area consists of nine high permeability zones based on the FFD method and seven of them have no associated warm or hot springs. It is postulated that the lack of a geothermal signature for the position of seven zones, which are located on normal fault graben (Fig. 1 cross-section). As such, these seven zones are thought to be far from a heat source.

The two remaining zones (Amohola and Summersari) have warm and hot springs associated with fractures. In comparison, these two hot springs have a different surface occurrence. At the Amohola springs, the warm or hot water appears to be correlated with a normal fault, whereas in the Summersari hot springs are associated with both a normal fault and a high permeability zone defined by the FFD method.

It could be assumed that both hot springs have a different genesis. This study results are strengthened by the the result of previous work [4] who report that geochemically, geothermal system between Amohola and Summersari is also different.

To obtain more convincing interpretation, a further study with another method such as drilling or geophysics survey is needed. From those methods, subsurface data in details could be procured for better analysis.

6. References

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