Fracture analysis to delineate tectonic evolution: case study at Ciherang, Bogor-Sukabumi, West Java, Indonesia

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Abstract. Indonesia, especially Java island is strongly influenced by tectonic processes and volcanic processes. The phenomenon of fractures in volcanic areas provide a significant contribution to the process of calculating the potential of its groundwater resources. Ciherang area, West Java is located among two quaternary volcanoes, namely Mt. Salak and Mt. Pangrango, composed by volcanic deposits of both volcanoes, and also affected by Pelabuhanratu fault as regional fault. Fracture pattern on Mt. Salak and Mt. Pangrango not only influenced by volcanism only but also influenced by Pelabuhanratu fault with relatively older than the volcanic processes that occur in both the mountain. By using the method of automatic lineament extraction on ASTER GDEM raster image with the resolution of 30m × 30m per pixel, then obtained the lineament of the ridge and valley. Each group has its character itself with influence by volcanic processes, tectonic processes or both of volcanic and tectonic processes. Subwatershed created to divide fracture and to describe tectonic style involved in each subwatershed, due to subwatershed become important parameter to restrict population of lineament. Delineation of fracture pattern based on subwatershed have a difference style of direction for each subwatershed.

1. Introduction
The Indonesia Archipelago is a country which highly potential of natural resources. Many natural resources in Indonesia such as oil and gas, mineralization and groundwater. Potential of its natural resources appears because the area of Indonesia Archipelago is included in active tectonic and active volcanic area. Therefore, there are many active mountains and unstable lands found as a result of tectonism and volcanism. Volcanic area is an area containing a large groundwater resources. Volcanic areas are contained large groundwater resources. Groundwater is contained in the volcanic rocks that have a high permeability values. Volcanic rocks with many variation of deposit because difference of eruption mechanism, many of eruption period. All those processes induce more variation of volcanic deposit. Igneous rocks- lava, with highly hardness, pyroclastic rock with variation of component-breccia, and tuff. Fracture in volcanic area involved as secondary porosity. Nowadays, the fracture system become one of many parameters for calculating groundwater reserves in volcanic area [1]. Ciherang as a study area has been chosen as an area with tectonic and volcanic affected. Ciherang area is affected by...
Pelabuhanratu Regional Fault and also two active volcanoes Mt. Salak and Mt. Pangrango. Two different processes may develop two fracture patterns which each pattern will depend on their process. The fracture patterns become important to be discovered as detail to know clearly the fracture system that develops in study area. In generally, fracture pattern appear is different for each volcanic fracture patterns. There is different fracture pattern between fracture pattern in Mt. Salak and Mt. Pangrango (figure 1). Beside of two volcanic patterns, there is another fracture pattern which is Pelabuhanratu Fault as a tectonic product involved to this Ciherang area This regional fault has been formed relatively older then volcanic processes and still an active fault until present.

![Figure 1](image_url)

**Figure 1.** Location of Ciherang between Bogor - Sukabumi, West Java, Indonesia (shown in red point in map of Java Island).

2. **Regional Setting**

The oldest deposit in Ciherang area consist of pumice tuffaceous included in Old Volcanic Rock Unit. This unit spread out at eastern, northern, and southern part of study area. The Old Volcanic Rock Unit is composed of andesitic and basaltic lava that included as Mt. Pangrango volcanic deposit. The western part of study area composed with lava, tuffaceous breccia and lapilli tuff. The characterization of lava flow is andesitic basalt which included on Mt. Salak volcanic deposit. All deposits as included to quaternary Volcanic Rock Unit as shows in figure 2 [2].

Tectonic activity in Ciherang area has been started at early Tertiary, followed with Plio-Pleistocene tectonic activity which is reactivation of products of early tectonic period as a fault with direction of northeast-southwest and northwest-southeast. Fractures develop was formed become weak zone and as a media for late quaternary volcanic deposits appears in surface area. Geological setting of his area, generally consist of quaternary rock unit as a young volcanic deposit unit that consist of tuffaceous pumice, tuffaceous laharc breccia from Mt. Pangrango with thick deposit. Below of this unit, the old volcanic rock had been deposited which is consist of andesitic-balsaltic breccia, andesitic lava, tuff and agglomerate. Fine clastic sediment rock until coarse spreading out southwardly which had been folded and faulted [3].

Appearance of volcanic mountain in Java Island closely related with subduction activity between oceanic plate and continental plate of Java Island. Based on geophysics data, show that subduction zone at southern Java Island is a constantly zone, but the appearance of volcanic mountain on surface area appears desperately between the others. This phenomenon indicate that volcanic activity not appears to surface itself, but must be fracture as a media become a pathway to release magma to surface. Those Fracture are always become fault zone, such as in Sumatera Island, the position of its volcanic mountain is in volcanic arc that its appearance on surface is located in Sumatera Fault Zone. As a geological fact above, many active mountains found with paleogence until present volcanic age certainly must be related with fault zone [4].
3. Methodology
The indication of geological structure in field almost undefined clearly at volcanic deposits. It was due to weathering rock condition. A Fault can be form as a fault plane or single fracture, but also found as fault zone which is consist of more than one fault. The fault zone or shear zone have long and wide dimension. The variation of fault zone dimension from minor until hundreds of kilometers. Joint shown the deformation and also state as minor fault. Fault with extensional mechanism such as subsidence, landslide, called fissure is not in fault definition [5].

Morphotectonic aspect like describe above can be analysis with remote sensing method and with Digital Elevation Model (DEM) image. This method can describe and visualize morphology at study area and the dominant of processes involved. The texture of DEM shows the tectonic that was developed, rock hardness, and other geological processes. Further, this method namely remote sensing. Structural analysis can be processed directly, which mean with detail observation at some outcrop or indirectly with analyzing of maps, satellite images, inter-correlation well profiles or seismic profiles based on concepts and theories. Several studies of morphotectonic are DEM enhancement with relief shading, lineament pattern, fracture domain density, and finally combining all parameters in overlaid map in thematic map with GIS technique.

Digital Elevation Model (DEM), in this case ASTER GDEM can be use and easy to get it. It is free to download. The resolution of ASTER GDEM is 30m x 30m and it is enough to use for fracture analysis with relief shading in volcanic area. Slope is incline plane with leveling from plain to steep. DEM must be convert to TIN raster in order to make a relief shading image, then slope can be...
calculated as an elevation point at each location [6]. Unit dimension of slope can be degree or percent. The slope aspect is slope orientation, measured clocked wise in degree 0-360° where 0° facing to north direction, 90° to east direction, 180° to south direction, and 270° to west direction. Hill-shading is the technique that used to show relief shading of rock, illuminated with hypothetic light. Illumination value for each raster cell determined by orientation of illumination based on slope direction and slope aspect [7].

Frequency and length of lineaments produced by DEM extraction depend on input of parameters value representing from LINE module in PCI Geomatica software [8]. The algorithm module extract lineaments from raster DEM and convert this lineament feature to vectors. Six parameters in LINE module are Filter Radius (RADI), Edge Gradient Threshold (GTHR), Curve Length Error Threshold (LTHR), Line Fitting Error Threshold (FTHR), Angular Difference Threshold (ATHR), and Linking Distance Threshold (DTHR) [9]. Recommended value to extract lineaments related to tectonism in study area and the optimal value for parameters in LINE module display in table 1.

| Threshold Parameter                  | Value |
|-------------------------------------|-------|
| RADI: Filter Radius                 | 5     |
| GTHR: Edge Gradient Threshold       | 75    |
| LTHR: Curve Length Error Threshold  | 2     |
| FTHR: Line Fitting Error Threshold  | 10    |
| ATHR: Angular Difference Threshold  | 20    |
| DTHR: Linking Distance Threshold    | 1     |

4. Result and Discussion
In DEM processing to determine of lineament pattern at study area need to expanded due to easier interpretation. Presenting of lineaments at topographical objects in DEM, it will be processed with hill-shade method as described section before [10]. First step is producing four relief shading images with each direction of illumination: 0°, 45°, 90°, 135°, 180° for positive image as a primary dataset. Second step is producing four relief shading images with each direction of illumination: 225°, 270°, 315° for negative image as a secondary dataset. Inclination of sun angel at 30° with contrast 0.20 to produce greater shade. Setting ambient light only for scale factor at shading in topographic program [11]. The edge enhancement is one of many methods for sharpening raster image which is detail geometric from an image can be modify or increase [12]. Lineament, drainage, and morphology feature particularly almost indicated by extreme difference of its value in radiometric respond. The edge enhancement is useful technique and efficient to increase those features. The edge enhancement should be applied to both relief shading dataset to improve frequency and contrast of both raster image [13]. Then, both dataset is already to extract lineament automatically by LINE module algorithm. Lineaments appears and convert to line vector and restricted by subwatershed shows in figure 3 and 4.

Spatial techniques used to delineate distribution of lineament pattern that has been produced by automatic extraction before. Subwatershed created to divide fracture and to describe tectonic style involved in each subwatershed, due to subwatershed become important parameter to restrict population of lineament. Delineation of fracture pattern based on subwatershed have a difference style of direction for each subwatershed. Distinction of style direction of each subwatershed has been plotted to Rose Diagram of lineament. Each direction of each subwatershed (SW) describe in table 2. (figure 5).
Figure 3. Positive relief shading dataset.

Figure 4. Negative relief shading dataset.

Figure 5. Style direction shown in rose diagram of each subwatershed to delineate tectonic style involved.
Table 2. Direction of each subwatershed to delineate tectonic or volcanic process in Ciherang area.

| Subwatershed | Description |
|--------------|-------------|
| SW-2, SW-8   | high various direction |
| SW-4, SW-7   | low various direction |
| SW-4, SW-5   | relative identical direction |
| SW-7         | unique direction, different from another SW |
| SW-2, SW-3   | Northeast direction 40° NE, equal to Pelabuhanratu fault (regional fault system) |
| SW-4, SW-5, SW-7, SW-8 | Many truncated lineament, affected by regional fault |

Subwatershed-2 dominated with northeast-southwest direction or relatively 40° NE, it may be predicted to have identical direction with regional fault system of Pelabuhanratu Fault direction with dextral strike slip fault mechanism. This regional fault gives an impact to subwatersheds near of Pelabuhanratu Fault Zone. Subwatershed 4, 5, 7, and 8 are subwatershed that highly affected by this fault. Other characterization of lineament in those subwatershed are truncated lineament that indicate as a fault zone also.

5. Conclusion

Subwatershed with northeast-southwest direction or relatively 40° NE, it may be predicted to have identical direction with regional fault system of Pelabuhanratu Fault direction with dextral strike slip fault mechanism. This regional fault gives an impact to subwatersheds near of Pelabuhanratu Fault Zone. Other characterization of lineament is truncated lineament that indicate as a fault zone also. Pelabuhanratu strikeslip fault will contribute a significant impact to groundwater flow system in study area. This regional fault become a bearing plane as a boundary of groundwater flow system between Mt. Salak and Mt. Pangrango. Moreover, this regional fault will provide many fractures near fault zone and generate anomalies in groundwater flow system.

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