Geological structures control on the streamflow orientation pattern in the Cijulang area and its surroundings, Garut, West Java, Indonesia

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Abstract. The Cijulang area is one of the deposits included in the high sulfidation epithermal deposits in Garut Regency, West Java Province. Ore mineralization in high sulfidation epithermal deposits is closely related to the geological structure. The existence of streamflows can be used as a fundamental basis for identifying geological structures. Geological structure identification is done by classifying the orientation angle interval class in stream segments. Each grid unit in the orientation angle interval class stream segment which has the same pattern is controlled by geological factors, including geological structures or the constituent rocks. By utilizing streamflow data, Digital Elevation Model (DEM), and secondary data (e.g., geological features such as structure geology and lithology from previous research data), geological structures can be identified. Faults that can be identified are the Cikahuripan fault, Citando fault, Cisuren fault, and Cibuni fault. These faults affect streamflow by 44.54% in the research area while lithology affects 35.12% of it. The influence of lithology will be greater in lower-order stream segments and the effect of faults will be greater in high order stream segments.

1. Introduction

The geological structure is one of the factors controlling geological processes that occur in an area. A geological structure can be seen from its distinctive morphological appearance, such as presence of fault scarps, the stream position with a certain streamflow pattern, and the continuity of slopes or ridges of morphology. Using remote sensing, geological structure can be observed through streamflow pattern and can facilitate the early stage of exploration. The relationship between geological structures and streamflow patterns can be studied quantitatively to identify the geological structure and determine geological structures effect on the streamflow pattern. In this study, each stream order orientation formed by perennial streams and intermittent streams in a watershed is measured, and its pattern is observed using Digital Elevation Model DEM. The geological structure can be identified from DEM by the appearance on the surface in the form of lineament created by fault scarps, stream deflections, or the shutter ridges. With the geological structure in the rock body, the stream flows easily in the said zone [1]. This is because the fault itself is a weak zone in the rock body. Lineament of morphology can also be controlled by lithology, where in this case, the lineament in the rocks is in the form of streamflow due to slope morphology of an area controlled by rock resistance [2]. Streams can flow in a valley but generally do not have a distinctive orientation and pattern. By comparing
some of these aspects, the presence of lineament can determine the control of the geological structure or lithological lineament of a stream segment.

Mineralization in high sulfidation epithermal deposits is controlled by geological structure closely related to lithology. As in the Cijulang Area, mineralization is controlled by lithology and geological structure [3]. In this Area, mineralization is developed in Tertiary (Neogene) sedimentary rocks and altered Quaternary volcanic rocks. The Cijulang Area is located in Talegong and Cidaun Districts, Garut and Cianjur Regencies, West Java Province (Figure 1), which has been explored by PT ANTAM since 1966 [4]. This study aims to identify the geological structure and examine the geological structure’s influence on the streamflow patterns developed in the research area. This research can support exploration data in the research area by utilizing the relationship analysis between geological structures and streamflow.

Figure 1. The research area located in Garut and Cianjur Regencies, West Java Province.

2. Regional Geology of The Research Area
Cijulang Area is included in the Southern Mountain Zone of West Java Pangalengan Plateau [5]. The Southern Mountains of West Java is part of the Java Geosyncline’s limb, uplifted and tilted towards the south. Pangalengan Plateau then undergoes normal faulting and fracturing towards the Bandung Zone. In this area, the morphology is characterized by strong relief hills with a trellis streamflow pattern. The slope at this location ranges from 15° to 40° and slopes towards the west. The morphology of Cijulang Area is controlled by lithology and geological structure. It can also be seen that there is stream alignment, fault scarps, and cliffs with waterfalls in several locations [5]. The research area constituent rocks are Tertiary sedimentary rocks and Quaternary volcanic rocks, namely andesite, tuff, dacite, polymict breccia, andesite breccia, and diorite (Figure 2) [6]. The geological map made by PT ANTAM to determine the prospect zone of Cijulang Area. Detailed geological mapping had been conducted only on the area around streamflow, mainly on perennial stream (Cikahuripan River) and intermittent stream around it, based on soil and rock sampling. These were intended to prospect the area at an early stage of exploration.

Geological structures that control mineralization are either strike-slip or oblique faults. The peak of structure formed in the research area was formed in Plio-Pleistocene. In this area, mineralization is generally found in tuff, andesite, and dacite, which are generally altered into silicification and advanced argillic alteration. Mineralization in high sulfidation epithermal deposits is generally initiated in the presence of geological structures and permeable rocks, including diatreme breccia pipes [7,8].
3. Methodology

Identification of geological structure control based on streamflow orientation can be made using a quantitative calculation. This method has previously been applied to the Loucka drainage basin, SE margin of the Bohemian Massif [9]. The degree of correspondence between the direction of drainage network segments and the orientation of geological structure was investigated by measuring the length of drainage segment oriented parallel with geological lineation. In this study, the drainage network map used has a scale of 1:25,000. Both perennial and intermittent streams were included. In the research area, streams are divided into segments based on their stream order (Figure 3). Strahler stream ordering method is used in this study. Strahler stream ordering is a method for assessing river size and complexity based on the number and hierarchical relationship of tributaries. The stream without any tributaries is considered a 1st order stream. When two of 1st order streams join, a 2nd order stream is formed. When two of 1st order streams join, a 2nd order stream is formed, and so on. The segment order divided into 4 orders, such as first order, second order, third order, and higher order. Higher order is referred to segment that has stream order higher than third order. The stream segment in the research area is processed by converting the streamflow into a straight line, and the angle of its orientation is measured clockwise from the 0° direction, which refers to the north. The measuring angles are divided into 12 classes of intervals, every 15° in an angle range of 0-180°. Interval classes with the same values are grouped into 1 area, where this area results from the conversion from the stream...
network to a grid size with a pixel size of 50×50 meters. Areas with the same class intervals are then compared with the DEM data resulting from the interpolation of elevation points, streams, and topographic lines. Areas with distinctive pattern in the DEM, such as fault scarps, stream deflections, and shutter ridges, are identified as geological structures. In contrast, those that do not have a distinctive or specific pattern will be grouped into lithological lineation. Each segment is then measured in length. The segment's position parallel to the geological structure or rock lineation is calculated for its length separately. This is done to determine the percentage of stream segment orientation affected by faults or rock lineation. Calculations are then made on each stream order, where the numbering uses ordering by Strahler.

Figure 3. The procedure for converting streamflow pattern, where all parts or segments are converted into straight lines. The orientation and length of each segment are then measured [9].

4. Results & Discussion
The streamflow in the Cijulang area has a trellis pattern (Figure 4a). It has streamflow with the stream direction of Northwest-Southeast with the direction of the tributaries the West-East and Northeast-Southwest directions. In the research area, the streams were converted to straight lines, and their orientations are then measured (Figure 4b). The stream is then divided into 46 segments. The stream's angular orientation is expressed in interval classes on a grid with a size of 50×50 meters. Grids with the same pattern and value will be grouped to identify geological structures in the research area. Based on this analysis, it is found that several stream segments formed lineament patterns, which are presumed to be the alignments of the geological structures because it has same interval class and distinctive pattern morphology in DEM.

The area that is presumed to be the geological structure's location in the DEM has a valley lineament with a distinctive pattern. Besides, there are also deep valleys in the constituent rocks. This structure was identified as a fault. The fault that can be identified is the Cikahuripan fault with the stream orientation of the Northwest-Southeast and is a dextral oblique fault. Then another identified fault in the research area is the Citando fault with a Southwest-Northeast orientation. This fault is a sinistral strike-slip fault with a reverse fault type. The other structures are dilatational faults, such as the Cibuni and Cisuren faults (Figure 5).
Figure 4. Streamflow in the Cijulang area, (a) the streamflow pattern of the stream in the form of trellis pattern, (b) the results of the stream conversion into straight lines and the stream order numbering.

Figure 5. Geological structures in the Cijulang Area identified from the stream flow pattern.
In the research area, several segments are parallel to faults and lithological lineament (Figure 6). In which, 21 segment are considered to be affected by faults and 20 segment are considered to be affected by rock lineament. In contrast, the rest of the segment orientation is not parallel with faults or lithological lineation. The length of the segment parallel to the fault and rock lineation is then measured, and the percentage of segments affected by the presence of the fault or rock lineation is then calculated. The length of the segment parallel to the geological structure and rock lineation is calculated. The percentage calculation is carried out using the total length of the segment in each order. The results of the percentage effect of faults and rock lineation calculation are presented in Table 1.

![Figure 6. The position of the segments affected by faults and rock lineation.](image)

### Table 1. Percentage of the faults and rock lineation effect on streams in the Cijulang area.

| Segment          | Number of segment | Total length of the segment (km) | Length of segment parallel to the geological feature | Percentage of affected value |
|------------------|-------------------|----------------------------------|-----------------------------------------------------|------------------------------|
|                  |                   |                                  | Fault (km)                                      |                               |
|                  |                   |                                  | Rock lineation (km)                              | Fault (%)                     |
|                  |                   |                                  |                                                    | Rock lineation (%)            |
| 1st Order        | 27                | 22.396                           | 4.058                                           | 11.986                        |
|                  |                   |                                  |                                                  | 18.123                        |
| 2nd Order        | 12                | 9.350                            | 6.682                                           | 1.317                         |
|                  |                   |                                  |                                                  | 71.477                        |
| 3rd Order        | 1                 | 0.325                            | 0.325                                           | -                             |
| Higher Order     | 6                 | 5.805                            | 5.805                                           | -                             |
| Total Segment    | 46                | 37.876                           | 16.870                                          | 13.303                        |
|                  |                   |                                  |                                                  | 44.54                         |
|                  |                   |                                  |                                                    | 35.12                         |
Among the influence of the valley's existence on hills marked by lineation in rocks or geological structures in the form of faults, first order stream in the research area tends to be controlled by constituent rocks (53.52%) when compared to the effect of faults (18.12%) in the research area. This striking comparison can confirm the influence of the dominant constituent rocks in controlling the streamflow. These streamflows occupy small valleys on hills. Second order streams have several differences with first order streams. Second order streams are influenced by the structure with a percentage of 71.48% and are influenced by rocks with a percentage of 14.09%. In this order, streams are controlled by a combination of geological and lithological structures but are dominated by the influence of geological structures. Aside from that, the third order stream and higher orders generally have a position parallel to or coinciding with the faults that have been identified by previous researchers, and there are no segments that correlate singularly with rock lineation without the presence of faults. This is indicated by the presence of a regular stream pattern. In this case, the stream can indicate a geological structure in this research in the form of a fault. Major faults can be seen coinciding with or parallel to the streamflow by this method compared to minor faults.

The developments of morphology and streamflow patterns in the upstream (low order) area are closely related to morphology and lithology development in the research area. Meanwhile, streams that have reached a further order will be more influenced by geological structures. The older major structures generally have a major influence due to their increasingly complex developments. The higher the order of the streams, the higher the fault effects would be. Meanwhile, low order streams have less fault effect, more dominated by the constituent lithological conditions. This is also found in Macka's (2003) research, where faults predominantly affect streams in the high order. In general, the stream segment in the research area is also dominated by faults (44.54%), with an influence from the lithology of the research area's composition (35.12%). These structures will then become weak areas for the migration of hydrothermal fluids that form alteration and mineralization in the research area.

5. Conclusion
Geological structures in the form of faults identified in the Cijulang area are the Cikahuripan fault, the Citando fault, the Cisuren fault, and the Cibuni fault. The streams in the research area were affected by faults with a percentage of 44.54%. The higher the stream order, the higher the geological structure control in the stream's existence, and the lower order stream is influenced dominantly by lithology with a little influence of the geological structure.

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