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Identification of Natural Fractures Using Digital Outcrop Model (DOM) and Filedwork Data at Granitic Basement Rocks Muaro Silokek, West Sumatra

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Abstract— Digital Outcrop model (DOM) is a three-dimensional model produced through image/photo data processing, therefore, it tends to provide a precise picture of rock outcrops or geological features. The use of this method have been discussed in some studies, however, research on the analysis is yet to be statistically compared to direct measurement data in the field. This research was carried out on granitic basement rocks in the Indragiri River, Muaro Silokek, West Sumatra with an area of 510 m x 19 m. Data was obtained by comparing the fracture characteristics in DOM and five scanline-windows scan locations with dimensions of 500 cm x 200 cm. Based on the fracture orientation spread over the DOM, there are four domain segmentations with three main orientation directions namely NNW-SSE, NE-SW, and ENE-WSW which are part of the Takung Fault. The results showed that by statistically analyzing the scanline - windows scan data, the direction and dip of the shear fracture is relatively similar to the fracture analysis on the DOM, with a measurement difference of ± 8°.

Keywords— Digital Outcrop Model (DOM), Natural Fracture, Scanline-Windows Scan.

1. Introduction

Research had previously been conducted by Koesmawardani et al., [1] on the fracture characterization, kinematic analysis, and density of fractures using Digital Outcrop Model (DOM) in Muaro Silokek area. Sapiie et al., [2] and Toreno [3] characterized the fracture by comparing scanline - window scan with subsurface data in the Suban Field, South Sumatra. However, both methods have never been compared directly especially the use of DOM, which is basically a new method in mapping fractures using photogrammetric data.

This study therefore aims to discuss and compare the analysis of fracture characteristics in DOM and direct measurement data. The DOM data used were collected from 12th February to 5th March 2019 using the DJI Phantom 4 Pro drone consistently from 9:00 WIB till 12.00 WIB with gridding techniques acquisition. For field measurement data were directly used at five scanline - windows scan locations with retrieval parameters based on granitic diversity at the study site.

Muaro Silokek is one of the outcrop locations where the granitic basement fractured reservoir is found in Sumatra. The region has a geological history similar to the Suban Field, in South Sumatra [2]. These pre-Tertiary granitic outcrops, show variations in the distribution of natural fracture intensities that are directly affected by its position on the fault zone, mineral composition and texture of the granite rocks [1]. Granitic intrusion in the Ombilin Basin is part of the Lasi Batolite that breaks through other Pre-Tertiary rocks such as Kuantan, Silungkang, and Tuhur Formations [4]. According to Silitonga and Kastowo (1975) in Koning [5], granite rocks in the Muaro Silokek area are as old as 206 million years or of the Upper Triassic age.

These are part of the Mergui Micro Plate that lies parallel to the Permian-aged plutonic and volcanic mountains [6].

Situmorang et al., [7] also used a gravity data to analyze the geological structure of the Ombilin Basin, which is divided into a NW - SE oriented structure that is part of the Sumatra Fault System. In the north, the basin is bounded by the Sitangkai and Tigojangko faults, which extends to the southern part into the Takung and Silungkang faults. North-south oriented structures form faults associated with tensional phases during the initial stages of basin formation, and plays an important role in its evolution. In addition, the east-west oriented structure forms an antithetic left lateral fault with a dominant normal fault component as shown in Figure 1.

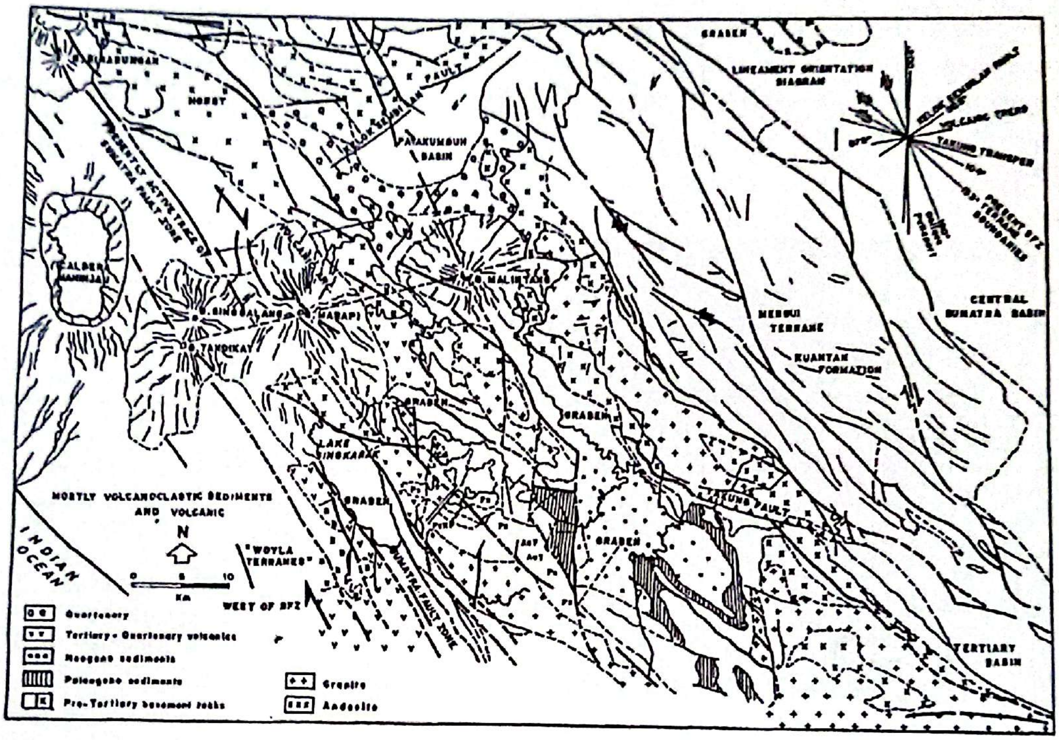

Figure 1. Regional structural framework of the Ombilin Basin [7]

2. Methodology

The research methodology carried out was on the fracture characteristics of DOM and scanline - windows scan data. The results of these analyzes are statistically compared from the measurement parameters of the strike and dip to determine the level of precision of the DOM data.

2.1. Digital Outcrop Modeling (DOM)

Digital outcrop modeling or photogrammetry in the field of geological science is carried out with specific objectives, such as special geological mapping [8], structural [9], and heterogeneity analysis of sedimentology [10]. In this study, photogrammetry was carried out using photo data also known as Structure from Motion (SfM) [11]. Drones were used to takes photos of each geographic reference point with consisting of a slice value of 50% to 75%. This is based on the purpose of digital outcrop modeling, outcrop geometry complexity, and outcrop dimensions.

A total of 392 photographs were used to model digital outcrops. The process of taking photos was divided into three sessions. The first was at close range to obtain a detailed description of the outcrop. Each photo acquired in this session has a slice value lower than 75% with a distance of 3 to 5 meters. The second session is the intermediate stage of shooting that aims to tie each photo obtained in the first session at a distance of 5 to10 meters with the value of slices between ranging from 50%. The last session is a long distance shooting that aims to form the outline geometry, with the picture shot from a height of 40 to 50 meters above the outcrop.

Furthermore, the photo data is processed to produce digital outcrop models using surface models developed by Madjid et al., [8] in Figure 2, by identifying and making key-points, clouds, and digital surface models. In the first stage, the key and tie-points are identified in two or more photos. In this research, 392 photo data were successfully tied to each other with a total connecting point of more than 455,000 points. Furthermore, the bonding point is processed to produce a cloud, with a higher density value than the tie-point and used to produce digital models. The DOM used in this study is the result of a point cloud of more than 29 million points.

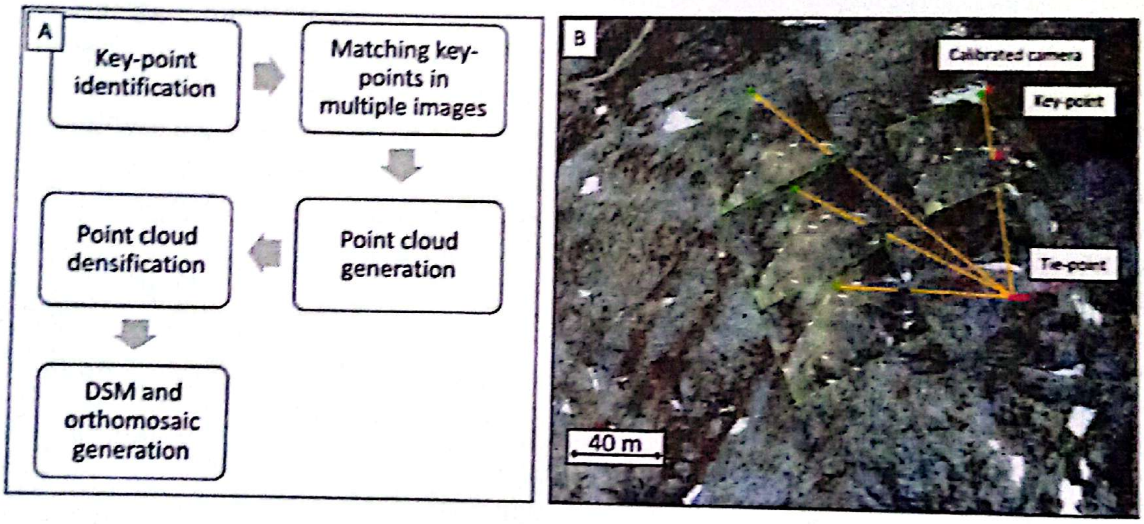

Figure 2. Stages of digital surface modeling (a) and illustration of key-point and tie-point definitions (b) [8]

2.2. Linear Scan Line and Windows scan

The scanline method includes measurements of coordinate, fracutre orientation, fracture aperture, fracture spacing and fracture length of granitic basement fractures as shown in Figure 3. The windows scan method includes measurements of fracutre orientation, fracutre aperture, fracutre length, cross cuting relationship [12], and lithological relationship with the natural fracture density of granitic basement. The equipment used in measuring the scanline method - windows scan are the Global Position System (GPS), geological hammer/compass, rope, measuring tape and calipers. However, in this study orientation measurements become the main focus compared with the DOM. Measurements were made at five scanline-windows scan locations on granitic rocks with a total 2,500 cm scanline and 500,000 cm^2 windows scan.

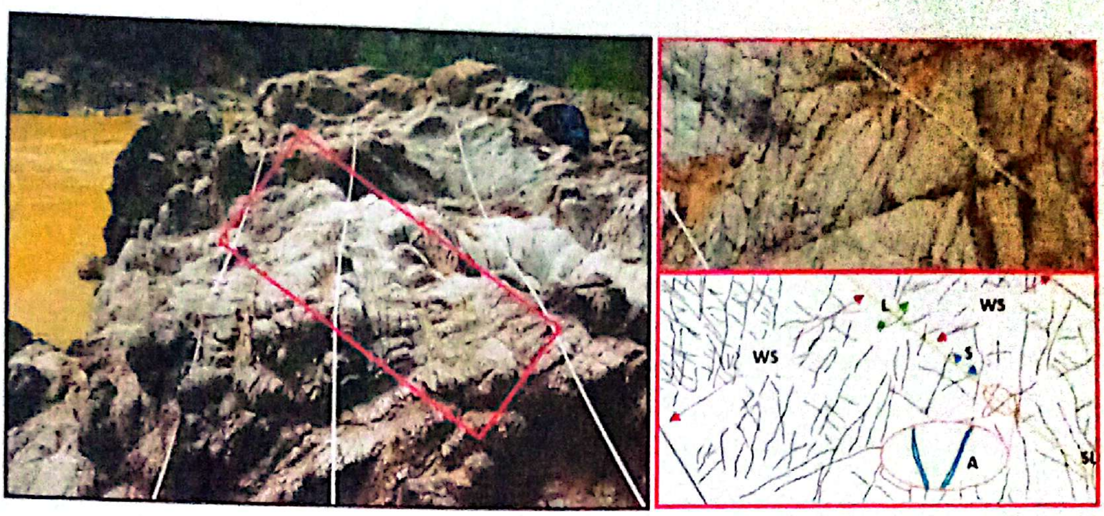

Figure 3. Retrieval of geological structure data using scanline (SL) and windows scan (WS) methods to determine the characteristics of fracture length (L), space (S), and aperture (A)

3. Results and Discussion

3.1. Fracture Orientation Characteristics of DOM Method

In the interpretation of DOM data structures, there were a total of 1,044 interpreted planar structures which representative of natural fractures as shown in Figure 7. According to the interpretation of the natural fractures, the relative direction of the natural fracture was divided into three as follows N 345° E / 75°, N 225° E / 72°, and N 85° E / 74°. The comparison of DOM data before (a) and after interpretation (b) are shown in Figure 4.

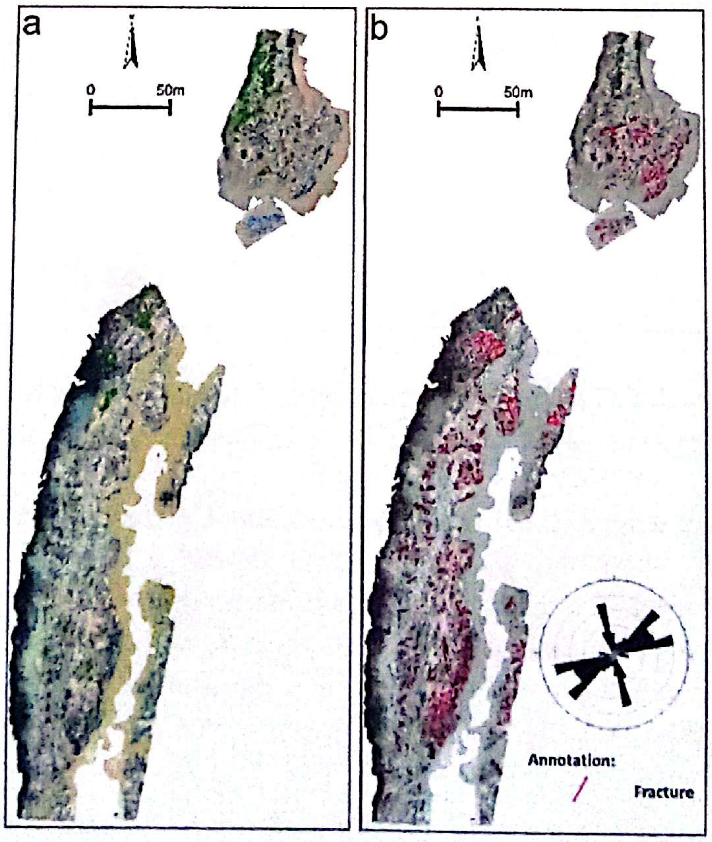

Figure 4. (A) Digital Outcrop Model (DOM) results before (B) and after interpretation

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Structural domain segmetation is divided to determine the distribution and pattern of natural fractures in the study area. Furthermore, the domain structure is divided into five segments based on the analysis of its fracture orientation. After the interpretation of the SL1 domain, a total of 168 fractures with NE-SW dominant orientation were obtained as shown in figure 5A. The analysis of SL2 domain after interpretation produced 182 natural fractures, with a dominant orientation based on the ENE - WSW as shown at rosenet diagram in Figure 5B. In addition, the SL3 domain produced with a total of 632 natural fractures after interpretation. Natural fractures in SL3 domain have a dominant orientation of NNW - SSE based on the rosenet diagram as shown in figure 5C. In the SL4 domain analysis after interpretation, produces with a total of 680 natural fractures with a NE-SW dominant fracture orientation based on the rosenet diagram as shown in Figure 5D. The last, SL5 domain analysis after interpretation produced 158 natural fractures with NE-SW dominant orientation based on the rosenet diagram as shown in Figure 5E.

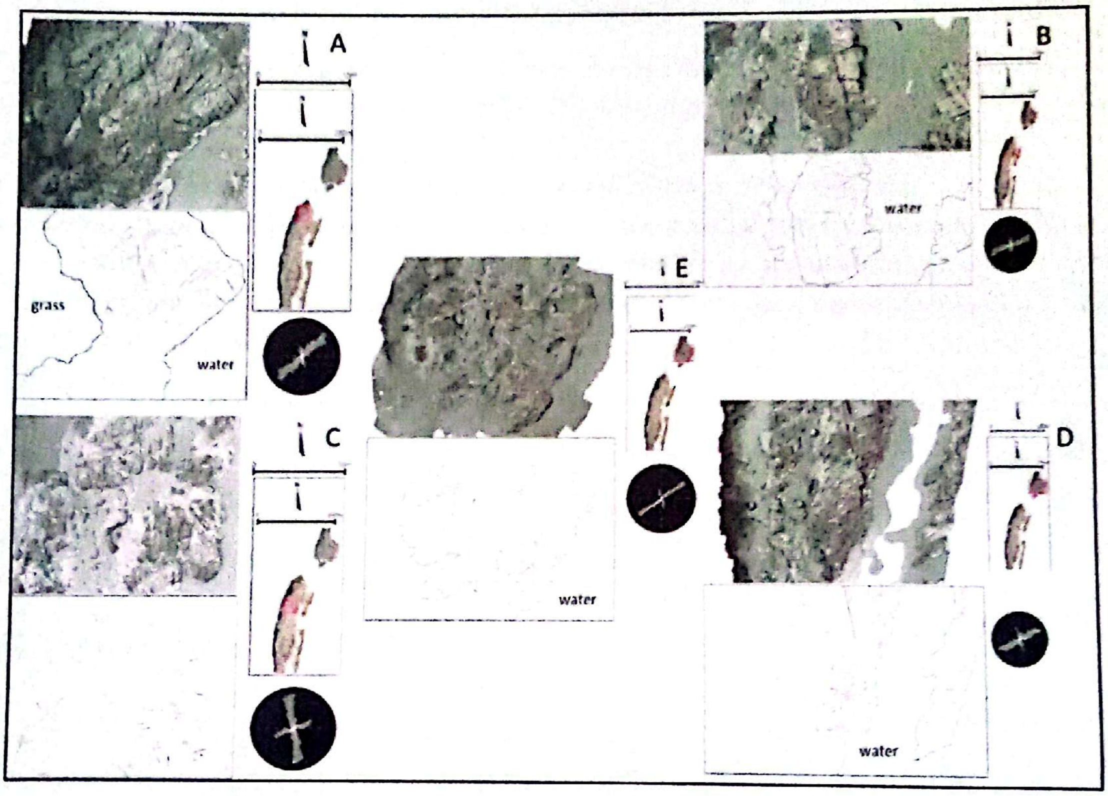

Figure 5. Division of domain structures based on DOM data, divided into (A) SL1, (B) SL2, (C) SL3, (D) SL4, and (E) SL5.

In all structural domains divided on the Digital Outcrop Model (DOM), three had different orientations as follows: north of NNW-SSE on SL3, NE-SW on SL1/SL5, and ENE-WSW on SL3/SL4. Based on the Riedel model, the NNW-SSE fracture orientation has a synthetic fault or R shears (green), while the NE-SW fracture orientation has an antithetic fault R' shears (red). Furthermore, the ENE-WSW fracture orientation is P' shears (yellow) which is a minor fault due to R 'shears as shown in Figure 6. The riedel shears pattern is very suitable with the orientation of the Takung Fault which close to the research location with NW-SE faults orientation.

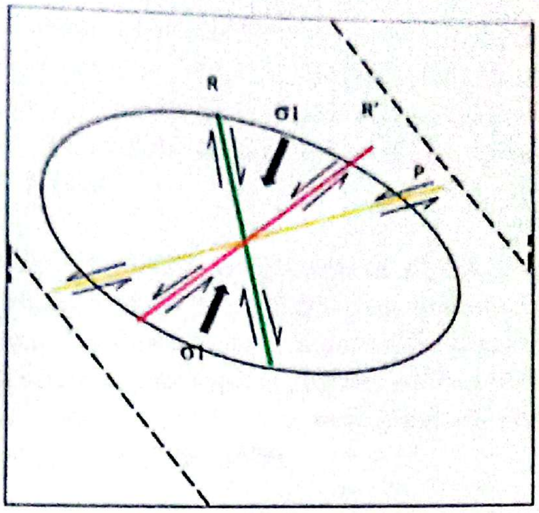

Figure 6: Riedel model in the study area is divided into three orientation segments as follows: NNW-SSE, NE-SW, and ENE-WSW

3.2. Fracture Orientation Characteristics with Scanline and Window Scan Methods

The data collected from the meso scale was carried out on the granitic rocks exposed in the Muaro Silokek area and used as confirmation from DOM data. Scanline - windows scan measurements were carried out at five locations representing different types of granitic at the study sites as follows: GT 1, GT 2, GT 3, GT 4, and GT 5 as shown in Figure 7.

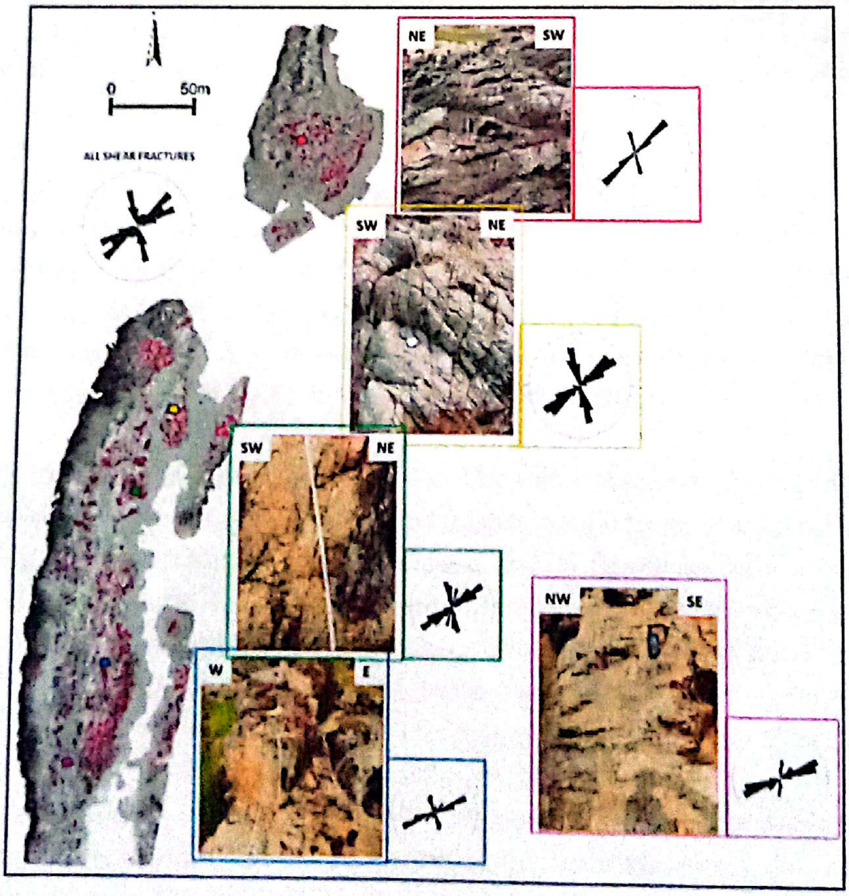

Figure 7. Locations for measuring the scanline - windows scan method on GL1 (red), GL2 (yellow), GL 3 (green), GL4 (blue), and GL5 (purple) with dominant orientation NNW-SSE, NE-SW, and ENE-WSW

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From the measurement data carried out at five scanline - windows scan locations on granitic rocks, a total of 1219 fractures consisting of 960 shears and 259 joints were obtained. The shear fracture orientation at five scanline - windows scan locations is generally divided into three main directions namely N 352° E / 75°, N 222° E / 78°, and N 252° E / 74°. Meanwhile, the orientation of joint has a general direction of N 207° E / 82°, N 337° E / 85 °, and N 278° E / 81°.

The GT 1 scanline is located north of the DOM, and consists of granitic rocks with weathered conditions in black, as well as minerals dominated by k-feldspar, plagioclase, and quartz, with a visible size of 0.8 cm. The granitic rock has a dominant k-feldspar mineral followed by plagioclase and quartz. The observed scanline length is 500 cm with a window scan width of 200 cm. At the GT 3 scanline location, a total of 240 fractures consisting of 213 shear fractures and 27 joints, were obtained. Shear fracture orientation is paired and dominated by NNW - SSE and NE - SW directions.

The GT 2 scanline is located in the southwest of GT 1. The rocks obtained are granitic with fresh white conditions, consisting of minerals dominated by quartz, plagioclase and k-feldspar, with sizes of 0.3 cm. The granitic rock has a characteristic quartz mineral that is quite dominant followed by the mineral k-feldspar and plagioclase. The observed scanline has a length of 500 cm with a window scan width of 200 cm. At the location of the GT 2 scanline, there are a total of 409 fractures with 335 shear fractures and 74 joints was obtained. The shears fractures are paired and dominated by NNW - SSE and NE - SW directions.

The GT 3 scanline is located south of GT 2, on granitic rocks and reddish-brown in color. It consists of minerals dominated by plagioclase, k-feldspar, and quartz with a visible size of 0.5 cm. The granitic rock consists of plagioclase which is quite dominant followed by k-feldspar and quartz minerals. The scanline length observed was 500 cm with a windowscan width of 200 cm. At the GT 1 scanline a total of 192 fractures consisting of 145 shears fractures and 47 joints were obtained. The shears fractures are paired and dominated by NNW - SSE direction.

The GT 4 scanline location is south of GT 3, and consists of granitic rocks with weathered conditions in black. It also consists of minerals dominated by k-feldspar, plagioclase, and quartz, with sizes of 1.2 cm. The granitic rocks are characterized by a fairly dominant k-feldspar mineral followed by plagioclase and quartz. The observed scanline length is 500 cm with a window scan width of 200 cm. At the GT 4 scanline a total of 252 fractures consisting of 211 shears fractures and 41 joints were obtained. The shear fracture orientation was paired and dominated by ENE-WSW and NNW directions.

The GT 5 scanline is located in the southwest of GT 4. The rocks obtained are granitic with weathered red conditions, which consist of minerals dominated by k-feldspar, plagioclase, and quartz, with sizes of 0.1 cm. The granitic rock has a characteristic k-feldspar mineral that is dominant with a very fine mineral size followed by plagioclase and quartz. The scanline length observed was 500 cm with a window scan width of 200 cm. At the GT 5 scanline a total of 126 fractures consisting of 85 shear fractures and 41 joints were obtained. The shear fracture orientation is paired and dominated by ENE-WSW direction followed by N - S. The distribution of shear fractures at the scanline - windows scan generally has an orientation similar to the interpretation of photogrammetric data, which is NNW-SSE, NE-SW, and ENE-WSW orientation as shown in Figure 7. This proves that on a macro scale at DOM, fracture interpretation generally approaches the pattern of shear fracture. Meanwhile, for the data joint on the scanline - windows scan has an orientation direction whose distribution is not affected by the current stress. Joint orientation is influenced by the release of pressure from the subsurface which generally does not have an irregular orientation, and grouped with several joint models [13].

3.3. *Comparison of Fracture Orientation Characteristics of DOM and Scanline - Windows scan Methods*

Generally, there is a relatively similar natural fracture orientation between DOM interpretation and at the scanline - windows scan measurements method. Shear fractures in direct measurements are similar in orientation to fractures interpreted in DOM data. Figure 8, shows that the strike vs dip plots has the same distribution pattern between the fracture interpretation in the DOM data and the direct measurement. However, the interpretation data density has a wider distribution compared to direct measurement (SL).

DOM is divided into data clusters based on the population of the strike and dip as shown in Figure 8a. The distribution of strike on the DOM has a range of 0° - 100° and a dip of 50° - 90°, while strike in SL measurements is 0° - 92° and a dip of 50° - 90°, when viewed in blue data clusters. For red data clusters, strike at DOM data distribution ranges from 140° - 185° and dip 60° - 90°, while SL measurements have a strike data range of 145° - 180° and dip 65° - 90°. In the green data cluster, the strike distribution on DOM ranges from 200° - 260° and dip 55 ° - 90 °, while the SL measurements has a strike data range of 208° - 255° and dip 52° - 90°. For the purple data cluster, the spread strike on the DOM ranges from 318° - 380° and dip 60° - 85°, while SL strike measurements have a data range of 325° - 358° and dip 58° - 87°. When viewed based on data distribution, the strike and dip histogram on DOM is almost similar to SL as shown in Figure 8b. Therefore, the result of identification of fracture orientation on DOM data measurement has the same orientation pattern with SL, with a difference of ± 8°.

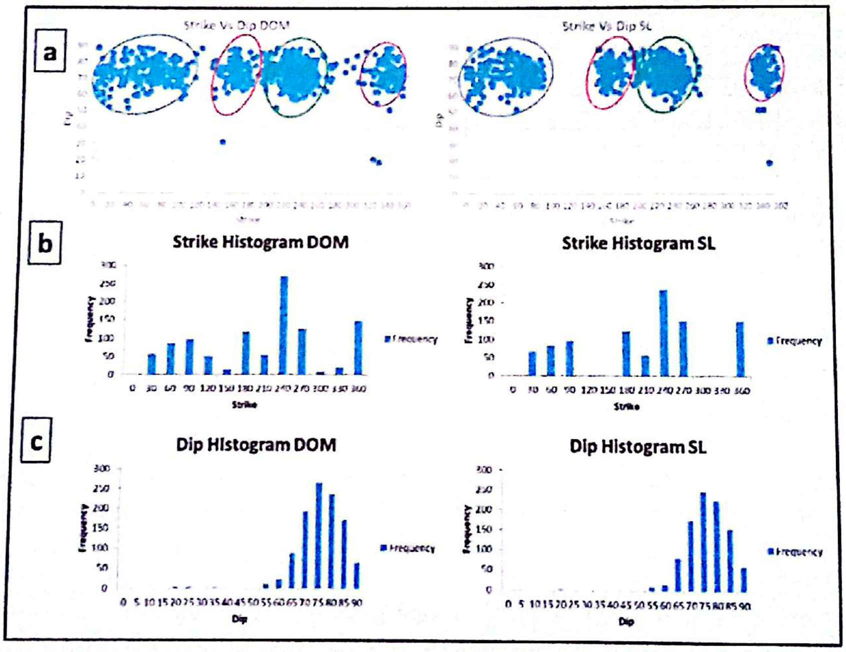

Figure 8. Identification of fracture orientation between DOM data interpretation and direct measurement (SL) shows the division of clusters with a range of data ± 8 ° (a) with same data distribution strike and dip (b and c)

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