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RESEARCH ARTICLE

Control Structure On Damage Zone and Fault Plane to Geometry Of Quartz Veins and Calcite In Muaradua Ogan Komering Ulu Selatan, South Sumatra, Indonesia

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Abstract

Geological mapping was carried out on the Gilas and Malau rivers in the Muaradua area, South Ogan Komering Ulu Regency, South Sumatra by observing the presence of joints, faults, and veins in the granite and phyllite rock outcrops of the Tarap Formation. Research on pattern geometry and vein type in the crushing zone is focused on measuring the direction (trend) of veins and joints. The measurement results are then analyzed to obtain a general pattern of quartz and calcite veins so that the orientation of their development can be known. The method used in this study is in the form of determining the orientation and geometry of the veins based on classifications that refer to several studies, then an analysis is carried out using DemNAS data to determine the general direction of the straightness pattern of the study area. The quartz veins that developed in the study area have an extensional fracture type with the geometry found in the form of isolated, abutting, cutting, mutually-cutting, and crosscutting. The veins that develop in the research area are relatively north-south and west-east and indicated the presence of a fault and traces of deformation that occurred in the study area. With the help of veins and joints found in the study area, it is possible to determine the structural control of the presence of a crushing zone in the fault plane.

Keywords: Structural Geology, Quartz and Calcite Veins, Geometry, Shear Zone, Muaradua

1. Introduction

Geologically, Muaradua and its surroundings have a very diverse distribution of rocks and are dominated by basement rocks that are Pre-Tertiary aged. The basement rocks of the South Sumatra Basin consist of metamorphic rocks, plutonic rocks, and volcanic rocks. In addition to complex bedrock, some sediment depositions are deposited in harmony afterward.

The research area is in Ogan Komering Ulu Regency (OKU) South, South Sumatra (Figure 1). Tarap Formation (PCt) research area has a Carbon-Permian age consisting of the lithology of Phyllite, Granite, and Quartzite rocks. It then deposited sedimentary rock formations in a misaligned or nonconformity at tertiary age. In Tarap Formation, many quartz and calcite veins develop in Phyllite, Granite, and Quartzite rocks. This is an encouraging factor for studies on the development of veins in the research area.

Veins are strongly related to the fracture mechanism where the mineral fills the fracture's space and helps determine stress, strain, pressure, temperature, fluid composition, and fluid origin during their formation (Bons, et al., 2012). Fracture is used in geology, interpreted as a fault, joint, and vein. Fractures can format a single deformation or form simultaneously with different deformation phases (Peacock & Sanderson, 2018). Then observations were made to see the development of the fractures and the geometric patterns of the veins that developed in the research area.

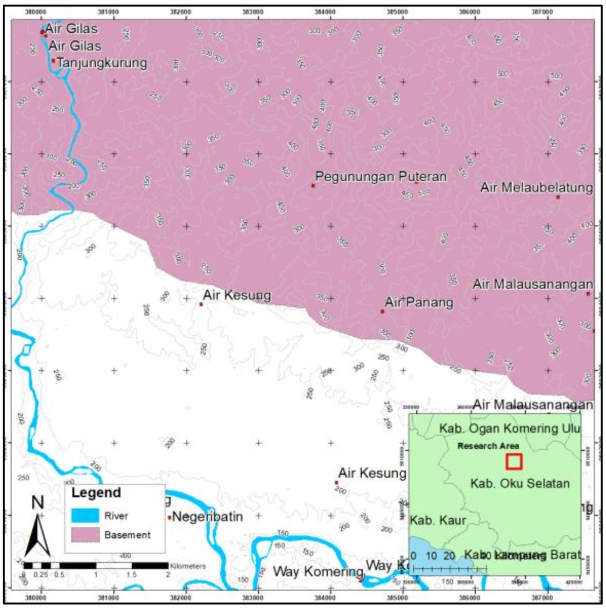

Fig 1. Administrative Map of Ogan Komering Ulu Selatan Regency (Pemerintahan OKU Selatan Pusdata, 2012)

1.1 Regional Geology

The tectonic order of the South Sumatra Basin (Figure 2) is closely related to tectonic events that occurred on the Island of Sumatra. Sumatra Island is a western suburb of Sundaland, and its tectonic history took place during the

Paleozoic – Mesozoic, which was formed from a combination of several blocks through various subduction and Collision processes. The island of Sumatra belongs to the East Malaya – Indochina Block, which originated in Gondwana in the Devone period, and at that time, subduction occurred in the western part of Sundaland. (Barber, 2005) (Hall, 2009).

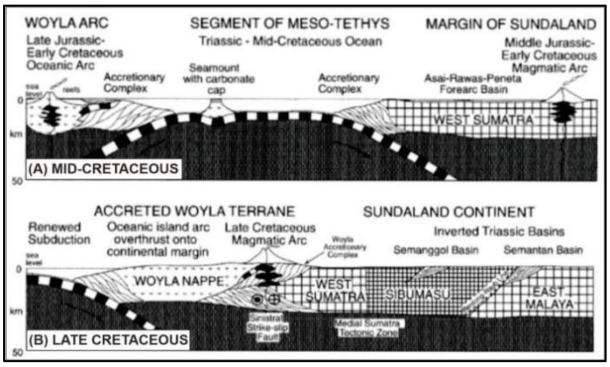

Fig 2. Formation of Sumatra Block and Woyla Block Alignment Process in the form of Accretion Zone (Barber, 2005)

Basement rocks that are Pre-Tertiary aged have been formed simultaneously as the formation of Sumatra Island, such as the Tarap Formation and Garba Formation, until the occurrence of granitic intrusion, namely Granit Garba. Then, there is tectonic activity, namely the extensional phase in the Early Eocene to the Early Miocene. ((Hall, 2012)). The tectonic process formed the Lahat Group in Kikim Formation and Telisa Group consisting of Talangakar Formation, Baturaja Formation, and Gumai Formation. From the Early Miocene to the early Pliocene, tectonic events were relatively calm and ended with an oblique compression phase in the Pliocene to Pleistocene, which contained volcanic deposits, including the Kasai Formation and Ranau Formation.

Pre-Tertiary Complex is a bedrock (Basement Rock) Basin of Central Sumatra and South Sumatra that is newly composed of Mesozoic igneous rocks, Paleozoic-Mesozoic metamorphic rocks, and carbonate rocks (Figure 3). In addition, some places in the research area found early carbon-aged rocks with low-degree metamorphic rocks in the form of phyllite derived from the microcontinent of West Sumatra. (Koesoemadinata and Matasak, 1981).

Furthermore, the formation of Sumatra Island is the formation of volcanic arcs, and South Sumatra Basins formed through several tectonic events ranging from Pre-Tertiary to Early Tertiary (Pulunggono, et al., 1992) (Figure 4). In the first Compression Phase, the formation of right horizontal faults with the Northwest - Southeast (WNW – ESE) direction and the direction of the trend that is directed at the South-North and accompanied by granite intrusion, in Pre-Tertiary in late Jura – Early Cretaceous. The Extensional Phase produces a Normal Fault or fault descending in the direction of SW – NE. Sedimentation processes fill the Sumatran basin above the bedrock or basement along with the volcanic activity. The first formation to fill the Sumatran Basin was the Lahat Formation. This phase formed graben and depression in The Gulley Mind, which began from the Late Cretaceous - The Beginning of Tertiary. The last phase identified deformation with the compressional regime at Kala Plio-Plistosen with the direction of the N 006°E express resulting in the formation of the Fold Structure. The fault flattens and reactivates the Paleogene-aged structure. The process also resulted in the Air Benakat Formation turning into an eroded height, and volcanism activity occurred in this basin.

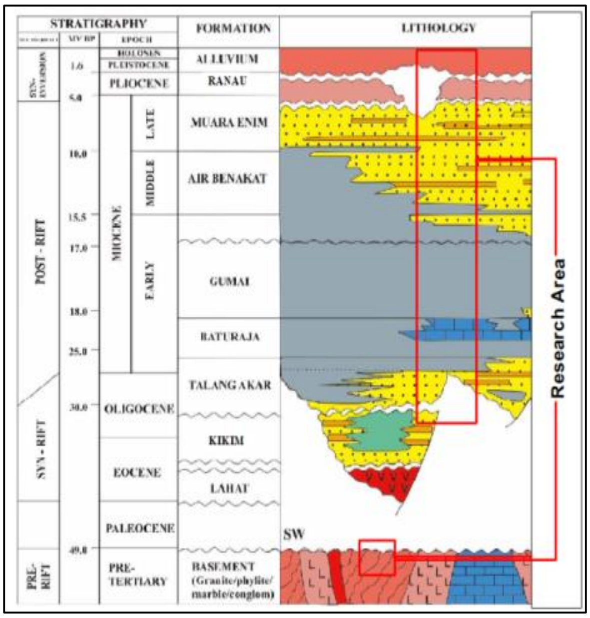

Fig 3. Stratigraphy of the South Sumatra Basin (Syaifudin, 2018)

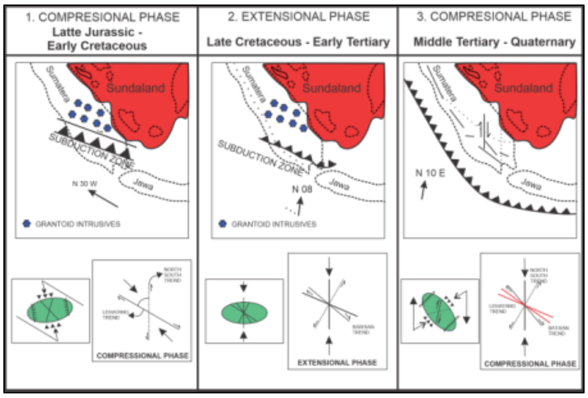

Fig 4. Tectonic Phase of the South Sumatra Basin (Pulunggono, et al., 1992)

1.2 Relationship Between Control Structure and Vein Distribution

According to Firmansyah et al (2007), Sumatra Island has a dominant structural pattern consisting of three main directions, namely NW – SE as the Sumatra Pattern, the NE – SW direction Jambi pattern, and N – S as the Sunda pattern where the three patterns are caused by the presence of compression regime plate collision. (Oo et al., 2021) have the same assumptions regarding the development of the structure and the evolution of the basin where the structure on the island of Sumatra has a complex development. The transitional phase results in the formation of a releasing bend pattern which is characterized by the presence of an opening mode. Where the zone opens a gap which is then filled by fluid as the beginning of the formation of veins in the mineralized zone. Field observations show that most of the veins are syn-kinematic in the process of formation although some veins appear to be of post-kinematic origin. Where each - each vein has a relationship with the deformation process that took place before or after controlled by the structure in the study area (Akawy, 2007).

2. Materials & Methods

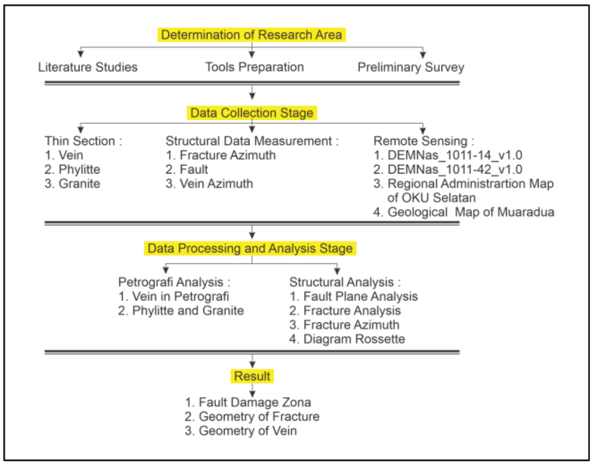

Fig 5. Materials and Methods in Diagram Flow

2. 1. Fracture

Fractures are depicted on the surface of rocks, but on a specific scale, can involve thickness, where based on Fossen (2010) divide fractures into three, namely, shear fracture, extension fracture, and contraction joint (Figure 6). A shear fracture has a slight movement on a small scale, where the movement is formed when the rock body is caused by the main force (σ1), and the minimum force (σ1) unevenly presses the rock that it experiences movement. In contrast, extension fracture indicates the movement of extensions, where the joint has little or no movement. When fluid fills an extension fracture, it is called a fissure and when filled by a mineral called a vein or vein (Chauvet, 2019). Finally, contractional fractures are formed perpendicular to the main force, where the fracture formed will be parallel to the minimum force and develop as a stylolite.

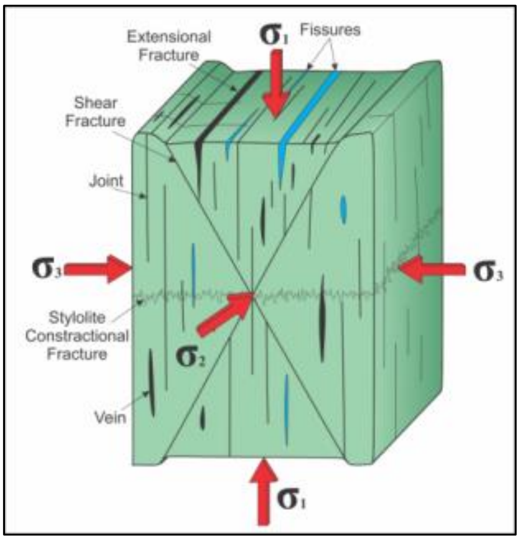

Fig 6. The mechanism of forming fractures and their relationship to principal stress (Fossen, 2010)

In analysis, fractures divide into three fracture modes (figure 7), namely mode I, opening mode is a fracture with a motion perpendicular to the forces that work, such as veins and joints, mode II in-plane shear where fractures with this mode have movements parallel to the surface. Finally, mode III out-of-plane shear is a fracture with a parallel movement to the plane or called a combined fracture that develops from joints and shears (Scholz, 2019).

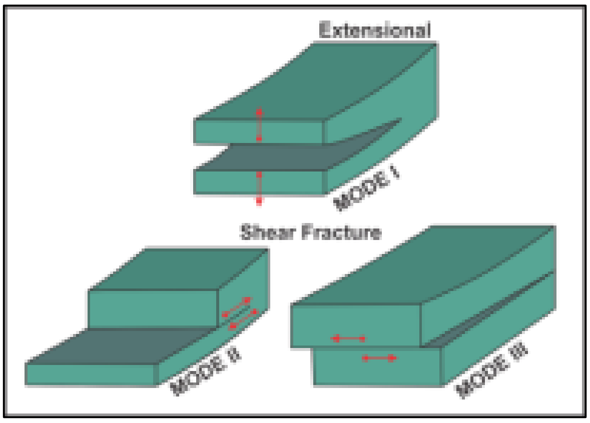

Fig 7. Fracture division is based on the relationship of its openings to rock movements (Scholz, 2019)

Type and Geometry in Fracture (Figure 7) are divided into two parts, namely Joint Type and Joint Geometry Pattern. Fracture types of divides are based on the rock body's movements in response to the force affecting the rock (Peacock & Sanderson, 2018). First Extension Fracture was in the form of a joint that was not filled with minerals (Bons, et al., 2012). Then shearing-mode fracture, in which the field of movement produces fractures on the rock surface. Following contractional fractures in which closed fracture movements can be stylolite (Fletcher & Pollard, 1981), where the presence of stylolite in a deformation helps analyze the mechanism of movement and direction of stretching force as the weakest field when deformed. A combined fracture is a combination of two or more fracture types.

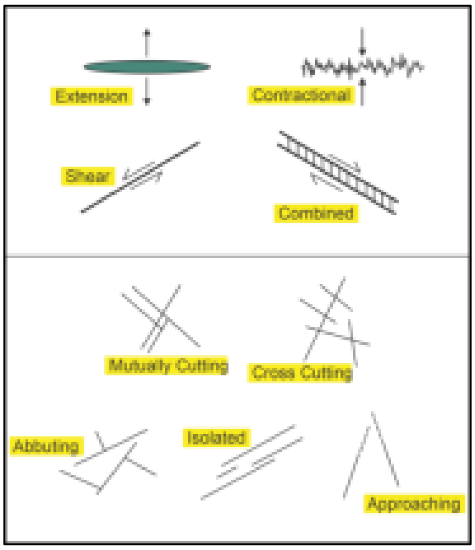

Fig 8. Type dan Geometry Fracture (modification (Peacock & Sanderson, 2018)

Fracture geometry (Figure 8) is divided into five geometries, namely Isolated, where fractures geometrically have no other geometry and have distances between fractures and tend to be the same. Approaching is a geometry that shows the relationship between a joint close to each other but not connected and has a small distance between joints. Abutting has joint geometry that meets each other, Cutting joint geometry (old) cut by other joint (young), and finally is mutually cutting where the joint that cuts with many other joints.

The presence of fractures indicates the presence of a fault and traces of deformation that occurs in an area. In addition, fracture analysis can determine the direction of the force that hits the rock and explain the type of deformation that occurs.

2. 2. Fault Damage Zone

The division of the ruined zone indicates various geometries and joint types (Kim, 2004). Faults damage zone is a body of rocks that are deformed around the fault plane or along the fault. The classification of the destroyed zone is based on the geometry of the fault, the location of the fault, and the structure that develops within the destroyed zone. For example, extension fractures and veins that develop in the crush zone can be a clue to the movement of a fault so that the angle between the extension fracture controls the geometry of this crush zone to the main fault with a large angle of ±45° (Kim, et al., 2004) (Figure 9).

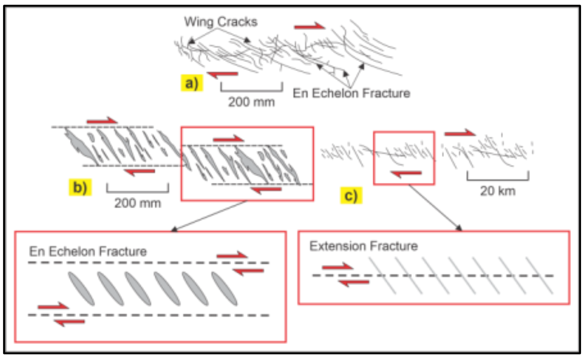

Fig 9. Scheme showing Fracture in fault field destruction zone (Modification Kim, 2004)

The concept of a crush zone helps connect the deformation zone with the structure that forms it, where the crush zone is the area affected by stress so that deformation occurs, and the structure has a different frequency and orientation (Peacock & Sanderson, 2018). First, the division of the destruction zone is depicted by showing the type of destruction zone and fracture formed in the ruined zone (Figure 10). On the left is the product breakdown zone of contractional stress characterized by the presence of stylolite. Then, the right side describes the product destruction zone of extensional stress characterized by joints or veins (Table 1).

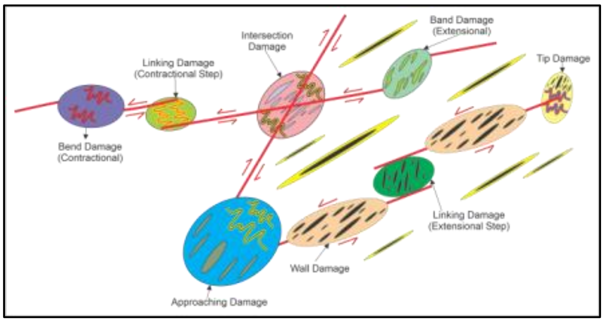

Fig 10. Shear zone scheme around fault area (Peacock & Sanderson, 2018)

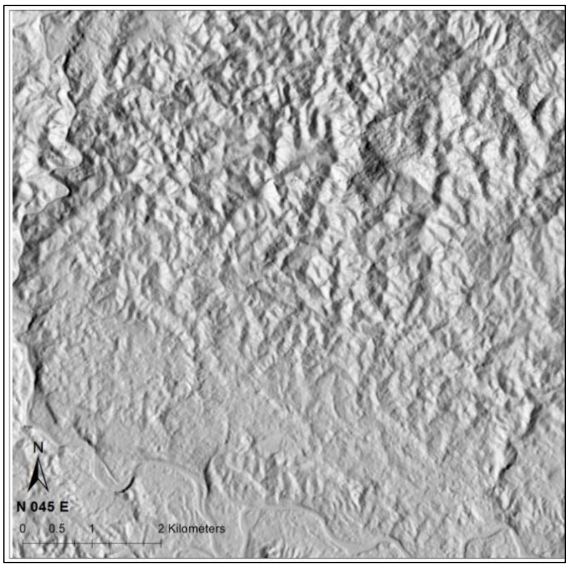

Fig 11. Hill shades with Sun Azimuth

Table 1. Classification of damaged zones in fault fields based (Peacock & Sanderson, 2018)

Shear Zone	Explanation
Distributed	The first area is destroyed when the rocks experience movement
Tip	Areas that are directly affected by stress, in the form of pulls and stylistic releases. So, there are extension products of stress and constructional stress.
Wall	The area where the wall rock movement type can be read from the fracture formed.
Linking	Meeting area of two fields with misaligned patterns
Approaching	Areas by forming a pattern of aligning and approaching each other
Intersection	The destruction zone formed because of the hardness of the fault field in different directions due to the direction of the force responsible
Fault Bend	Areas formed due to fault fields that are moving

2. 3. Remote Sensing

Remote sensing is used to obtain straightness data, illustrating the direction of structures that develop in the research area. This depiction of straightness using DEM (Digital Elevation Model) data shows the formation of the earth's surface (Wirastuti Widyatmanti, Ikhsan Wicaksono, 2016). The use of DEM affects the level of resolution with a specific scale and density that will show a regionally projected straightness pattern with different contour patterns at significant elevations with lighting (Amir, 2014). The straightness map is created using DEMNas data and using the ArcGIS application, using sun azimuth 45° with a sun altitude of 45° (Figure 11).

3. Result and Discussion

3. 1. DemNAS interpretation using Remote Sensing

In conducting the structural analysis, an interpretation of the straightness pattern was used using DemNAS data. Lineament is a reflection of the morphology observed on the earth's surface, which is observed based on the straightness of the ridge (positive lineament) and the straightness of the valley (negative lineament). This lineament indicates the presence of a form that is interpreted as an element of geological structure.

The results of the analysis group the lineament patterns based on the orientation direction. Furthermore, the orientation of the lineament is modeled in the form of a rosette diagram, so that a general pattern is obtained, namely Northwest – Southeast, and the dominant pattern is obtained in the study area with a direction of N 123° E.

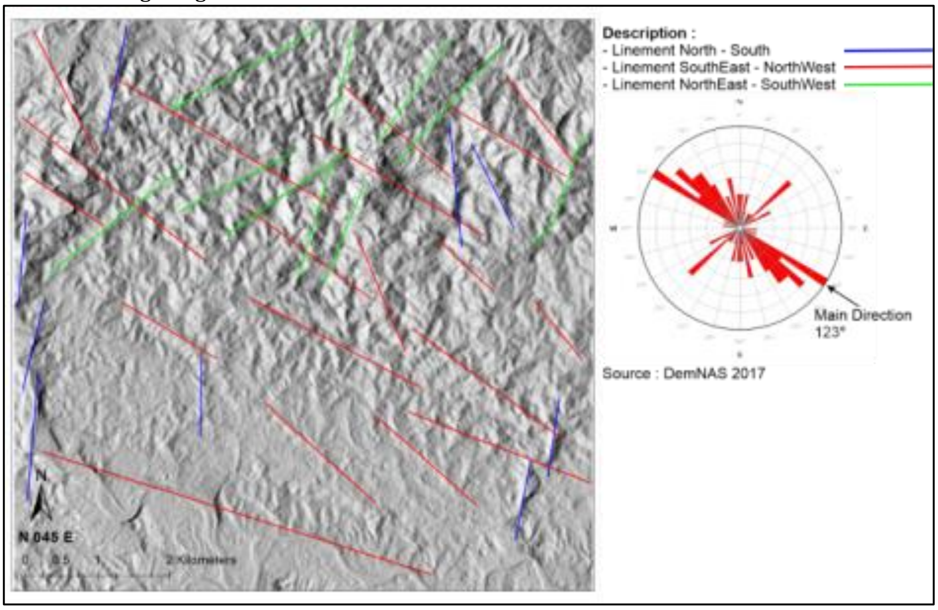

Fig. 19. The straightness interpretation of the DemNAS data with the General Direction of Lineament N 123° E.

Based on the results of the interpretation of the lineament pattern, then it is correlated with the results of field observations of geological structures in the form of faults and joints. Many structural elements in the study area were found in the form of displacements, fractures in the form of extensional joints and shear fractures.

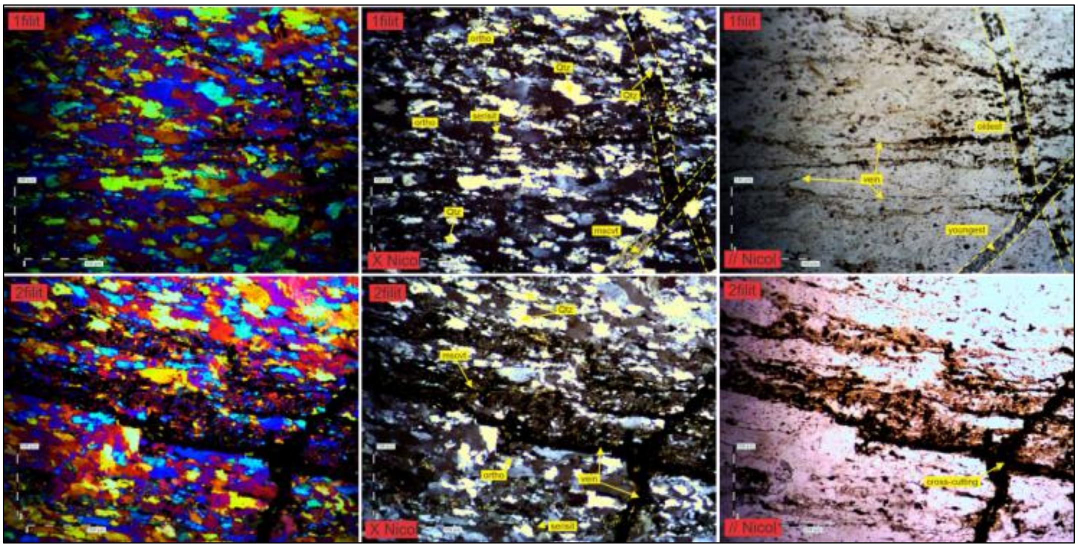

Fig 12. The appearance of Quartz veins and calcite in Phyllite Rocks in the Tarap Formation

3. 2. Petrography

Observation of petrography analysis of Phyllite and Granite Rocks in Tarap Formations to find the availability of quartz veins in rocks by looking at the minerals that fill the rocks. Microscopic appearance can indicate the development of quartz and calcite veins in Phyllite and Granite rocks. The Termination results show mineral complexity in Phyllite rocks in Quartz, Plagioclase, Calcite Veins, Sericite. (Figure 12). The Phyllite rock incision found the appearance of pieces of veins with cutting geometry by showing the presence of older quartz veins cut by younger calcite veins. The incision indicates the presence of several constituent minerals that wean and undergo the alignment indicated by the presence of Phyllite foliation structure. Then the petrography incision of Phyllite rocks is classified in the form of Phyllite (IUGS, 2007 Robertson, 1999)

Then the composition of minerals in granite rocks in the form of Quartz, Plagioclase, Orthoclase, Calcite Veins, Quartz Veins, Sericite (Figure 13). Based on the results of petrography analysis of igneous rocks, namely granite, various geometries show the pattern of veins. There are constituent minerals such as quartz and calcite. The geometric pattern shown reflects the distribution of quartz veins and calcite with geometry in the form of cross-cutting. Microscopically, holocrystalline's degree of crystallization can be seen and has a relationship in the form of equigranularity, or the size between minerals is the same. It has an equigranularity relationship and has plagioclases with albite twins. Based on the composition of mineral constituents classified into granite igneous rocks (Streckeisen, 1978).

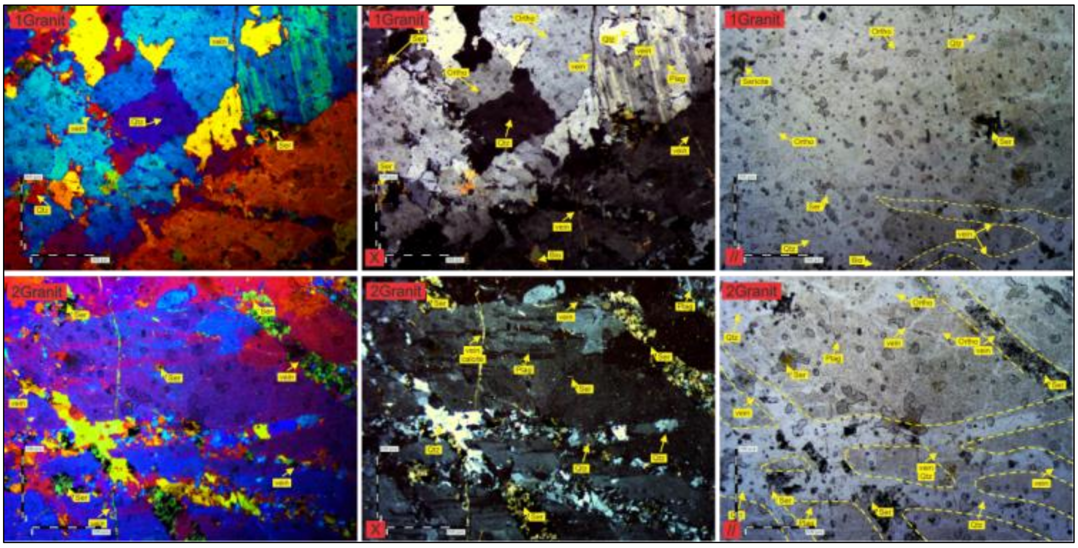

Fig 13. The appearance of Quartz veins and calcite in Granite Rocks in the Tarap Formation

Table 2. Results of Directional Orientation Analysis on Quartz and Calcite Veins with Rose Diagram and Joint geometry patterns and veins of research areas according to Peacock and Sanderson (2018).

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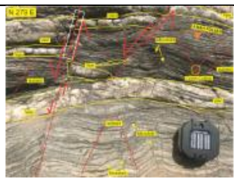
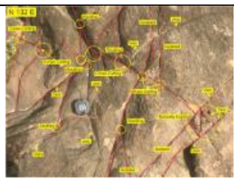
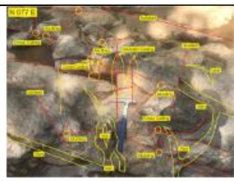
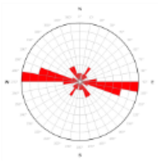
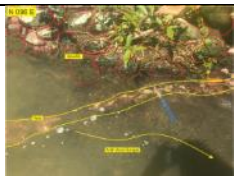
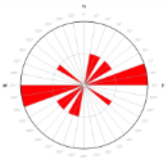
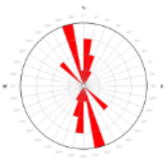
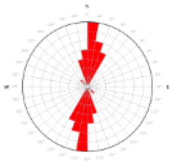
				
				
Abutting, Isolated, Mutually Cutting, Crosscutting	Abutting, Isolated, Cutting	Abutting, Isolated, Cross-cutting	Abutting, Isolated	Abutting, Isolated, cutting
LP 6	LP 7	LP8	LP 9	LP 10
				
				
Abutting, Isolated, Mutually Cutting, Crosscutting	Abutting, Isolated, cutting	Abutting, Isolated	Abutting, Isolated, Cross-cutting	Abutting, Isolated, Mutually Cutting, Crosscutting

3. 3. Geometry

A joint structure is formed due to the force acting on rocks (Peacock, 2018), where the joint has no or relatively little shift in the field of rock. Many joint structures were found in the research area, then measured joint data to determine the general direction of the force working in the research area. Data obtained in the form of joint position data or fractures from shear and gash fractures and measurements of the direction of brecciation. Kinematically and dynamically, elements are used to determine the main force produced so that it can be known the direction of the maximum express or sigma 1 (σ1), the direction of the average or sigma 2 (σ2), and the direction of the minimum express or sigma 3 (σ3). This joint analysis can also determine extensional joints and release joints and determine the type of fault by naming faults, namely Fossen (2010) and Rickard (1972).

In analyzing extensional fractures in the form of veins, the thing to do is to determine the direction of geometry and type in quartz veins and calcite, which then analyzes the direction of development of the veins. Ten observation sites show the development of veins based on field observations with a North-South and West-East orientation shown in the rose diagram.

The direction of each vein orientation is done by the geometry and the type of veins that develop. Physically the developing veins are not connected, shown in the Isolated type, and then the cross-cutting can develop simultaneously and show the X node pattern and have an extensional fracture type. The general direction is relative to the North-south and West-East. It is interpreted that the force affecting the distribution of veins comes from the Compressional and Extensional Forces (Pulunggono, 1992). Then at some locations, it was found that abutting geometry showed the physical appearance between interconnected veins and formed T and Y knots (Peacock and Sanderson, 2018), where the relationship between the two formed together at the same deformation but not until it was intersected.

3. 4. Fault Damage Zone

Based on the spread of veins that developed at the research site became the basis for examining the relationship of urate patterns to the destruction zone in the fault field. The geological structure develops in the form of fractures that have been filled with minerals or are still in the form of joints, and there are fault zones such as fractures and fault mirrors.

Analysis of the destroyed zone is done to determine the fractures found that can explain the location or traces of deformation in the research area. Based on the interpretation of developed veins, geometry is a type of extensional fracture and is a joint formed when the rock is exposed to a force parallel to the direction of the fracture. In addition, quartz veins that develop in the research area describe the existence of a tip damage zone where this area is an area that is directly affected by stress to produce fractures.

Fault structure obtained in the research area was analyzed through field observations and field structure measurements. The research area is divided into two segments: the Gilas Segment and the Malau Segment. The analysis of the fault structure was analyzed using the Stereographic method and correlated with DEMNas data of the research area to find out the direction of the straightness of the structure that developed in the research area, namely on the Gilas Fault directed at E-W while on the fault of Malau directed NE-SW.

The fault is identified based on the results of geological processes found in the field in the form of line scratches or slickenside and some joints or fractures around the site of observation of the structure. The classification used in naming faults is based on Fossen's (2010) and Rickard's (1972) classification.

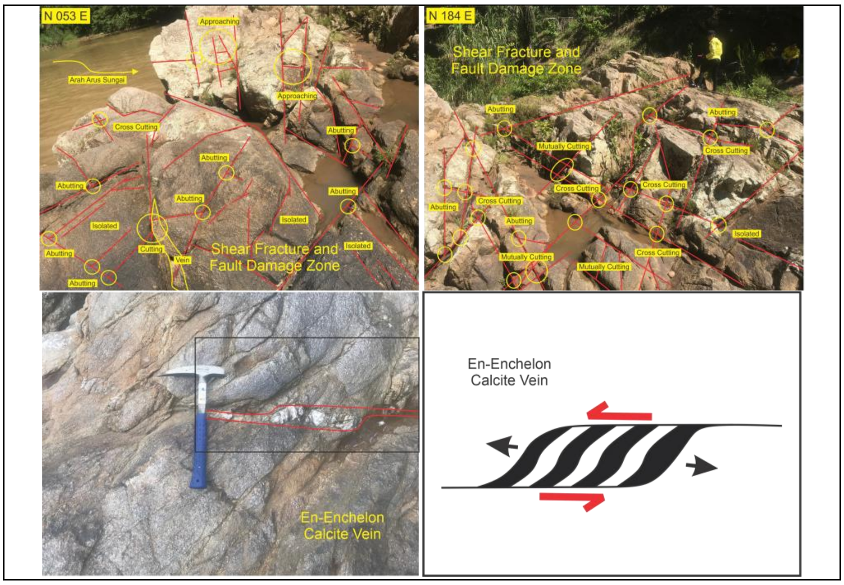


Fig 14. Shear Fracture shows the existence of Cross-Cutting geometry that forms an angle of 48° - 55°, Abutting, and Isolated geometry. Shear Fracture and Fault Damage Zone from En-Echelon in Calcite Veins

3.4.1. Segment of Sungai Gilas

Joint Gilas is found in the Gilas river with the discovery of shear joints and tension joints with Cross-Cutting geometry that forms an angle of about 48 ° - 55 ° with the position of Calcite veins of N 061 ° E / 83 ° with igneous rock lithology, namely Granite (Figure 12). This fracture type in Joint Gilas indicates a visible age difference from the pattern that cuts each other. Then other joint patterns at the research site are abutting and isolated that are not physically connected (Peacock and Sanderson, 2018). Then joint at this location is processed to show the direction of the firmness and know the development of release joints and extension joints in the research area (Figure 14).

In addition, it was also found that the Gilas Fault with an adjacent location was exposed to the Gilas river. Gilas Fault is in Gilas River Tanjung Kurung Village, where he found a rock outcrop with Granite lithology and identified the existence of a fault structure in the form of slickenside and fault fields measured while in the field (Figure 15). Based on field data with the position of the Gilas Fault field N 052° E/82° with the direction of the line scratch from rough to smooth directed NE. Based on the results of the analysis using the stereographic method, it is known that the maximum express direction (σ1) 08°, N 008° E, minimum express (σ3) 11°, N 276° E, with a net slip of 22°, N 049°E, and rake/pitch of 08°. Kinematically to see the movement pattern of the fault on the Gilas Fault in the form of a left horizontal fault. Based on data that has been analyzed and carried out, the naming of faults on the Gilas Fault, including the Strike-Slip Dominated Fault (Fossen, 2010) and the Left Slip Fault (Rickard, 1972). Then the withdrawal of the Gilas fault structure on the geological map is carried out based on the structure's durability connected with the straightness pattern or lineament of the DEMNas image map.

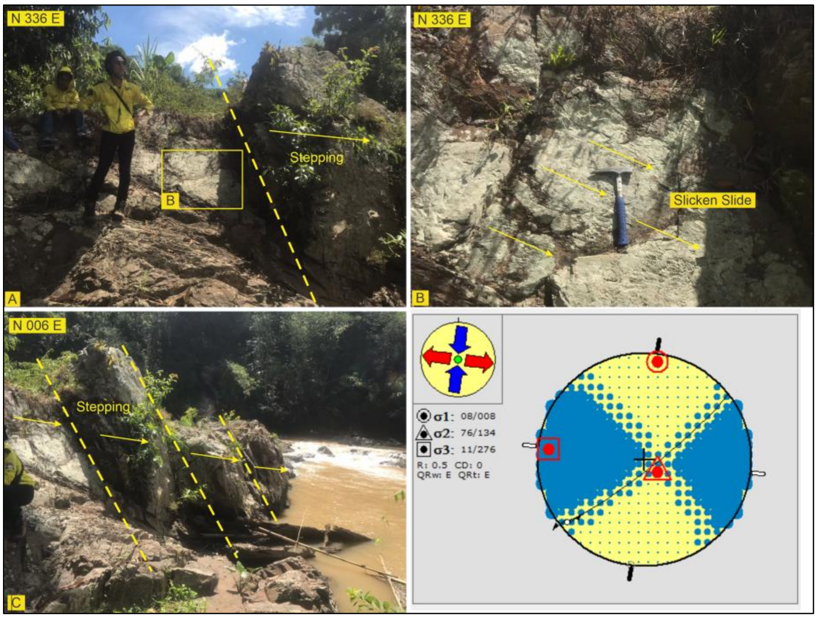


Fig 15. Destruction Zone in the Research Area in the form of Gilas Fault

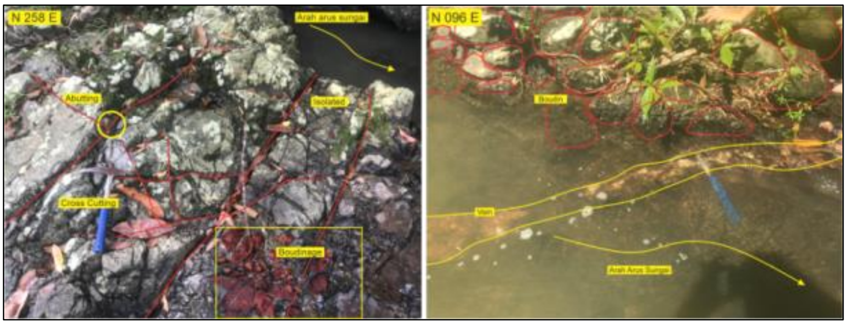


Fig 16. Shear fracture in the Malaubelatung Segment shows the cross-cutting geometry that forms an angle of 61° - 88°. Abutting and Isolated geometry has quartz veins and shear fracture and Fault Damage Zone forming boudinage on Phyllite rocks.

3. 4. 2. Segment of Sungai Malau

Malau River has found many joint and cesarean found in the research area, namely the Malaubelatung joint and Malausarangan joint. The availability of shear joints and tension joints with Cross-Cutting geometry forms an angle of about 61° - 88° with the lithology of Phyllite rocks (Figure 16). This type of fracture in the Malaubelatung Joint shows the age difference seen from the pattern cutting each other. Then other joint patterns at the research site are abutting and isolated that are not physically connected (Peacock & Sanderson, 2018). Then joint at this location is processed to show the direction of firmness and know the development of release joints and extension joints in the research area (Figure 16). Based on analysis using stereographic methods showed that the maximum express direction (σ1) produced was 23°, N 358° E, and the minimum express direction (σ3) was 07°, N 091°E. Based on the results of stereographic analysis, reconstruction obtained the naming of the type of fault included in strike-slip dominated fault (Fossen, 2010) and Normal Right Slip Fault (Rickard, 1972).

The joint of Malausarangan (Figure 17), located in the Malau River Negeriagung Village, has a joint structure in shear fracture, gash fracture, and brecciation in phyllite rocks. Based analysis using stereographic methods showed that the maximum express direction (σ1) produced was 06°, N 053° E. Based on the results of stereographic analysis reconstruction obtained, the naming of the type of fault included in strike-slip dominated fault (Fossen, 2010) and Normal Right Slip Fault (Rickard, 1972). The next step is to analyze the straightness pattern or lineament using national Digital Elevation Model (DEMNas) data to give an idea of the withdrawal of the fault field; the pattern of straightness in this joint is directed at NW-SE.

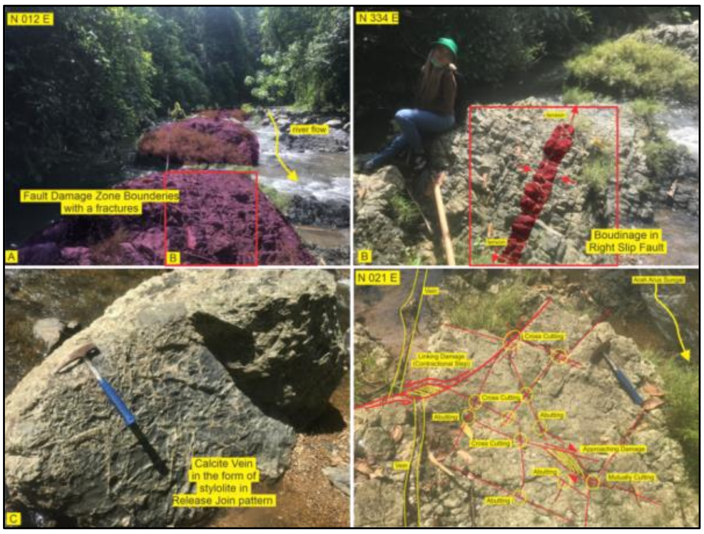


Fig 17. The appearance of fault damage zone bordering fracture zone supported by boudinage on right-slip fault, and calcite vein in the form of stylolite in release joint

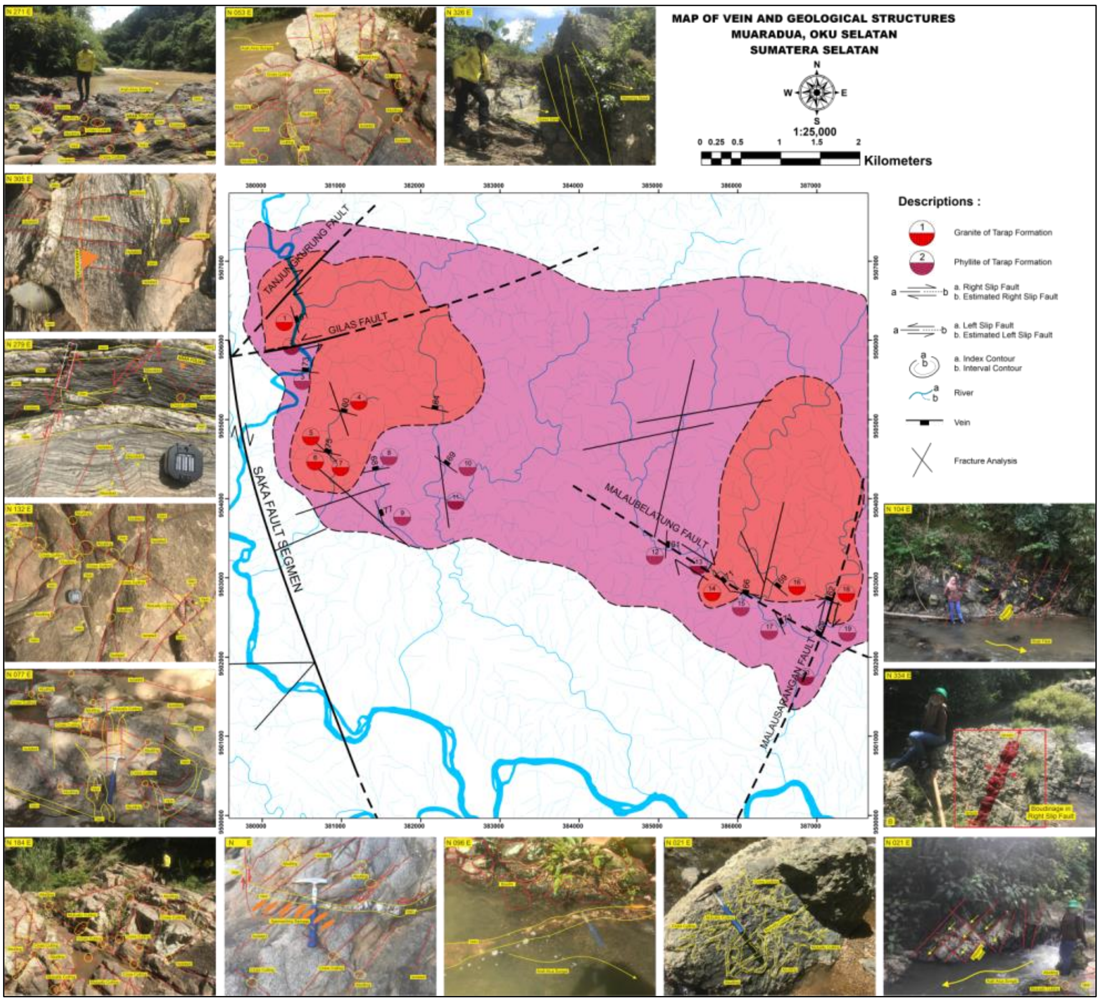


Fig 18. Schematic of Vein Distribution Map and Geological Structure in the Research Area

4. Conclusion

Based on the results of observations and data analysis can be concluded that the relationship of control of the structure of the Destruction Zone in the Fault Field to the Geometry of Quartz and Calcite Veins in the research area that the developing veins have an extensional fracture type with geometry found in the form of abutting, isolated, mutually cutting, cross-cutting with the relative direction of North-South and West-East. Therefore, the presence of fracture indicates the presence of a fault, and traces of deformation with the help of veins can determine the type of destruction zone that develops.

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