Geological and Geomorphological Studies in Parts of Angkola Sangkunur District, South Tapanuli Regency, North Sumatra

Mohammad Fachri Azzaenuri [1], Mega Fatimah Rosana [1], Cecep Yandri Sunarie [1] Muhammad Eko Angga Syahputra[2], and Ardiansyah Marbun[2]

[1] Faculty of Geological Engineering, Padjadjaran University

[2]Agincourt Resources

Corresponding author: mohammad19022@mail.unpad.ac.id

ABSTRACT

This research focuses on studying geological conditions that develop in the research area which is based on studies related to geomorphology, stratigraphy and geological structures that develop in the research area. In this research, the data used comes from mapping and taking surface data in a research area with an area of 12.5 km2, followed by petrographic analysis to determine the types of rocks found in the research area. The research area is divided into three geomorphological units, namely Sloping Volcanic-Structural Rolling Hills, Steep Volcanic-Structural Hills, and Sloping Volcanic-Structural Rolling Hills. The drainage pattern in the research area consists of parallel patterns in almost the entire area and sub-dendritic flow patterns in the central part of the area. The research area is composed of 3 lithologies, from old to young, namely, andesite, diorite which was formed as an intrusion, and breccia which consists of polymic and monomic breccia with fragments in the form of andesite, diorite, quartz fragments and carbon. The structures in the study area have the main directions northwest-southeast and northeast-southwest, both of which influence the morphology of the study area.

Keywords: Geology, Geomorphology, Geological structure, Petrography

INTRODUCTION

Geology is the science that studies the earth and its contents. Geology discusses the materials, structure, history, and all the processes that occur both within and on the surface of the earth (Noor, 2012).

In studying geological conditions in an area, many methods can be used, one of them is geological mapping. Geological mapping aims to collect information regarding geomorphology, stratigraphy, geological structure and formation history of an area.

This research was conducted in part of Angkola Sangkunur District, South Tapanuli Regency, North Sumatra with an area of 2.5 x 2.5 km. This research aims to examine the geological conditions that developed in the research area.

RESEARCH METHODS

This research was carried out in 4 stages, namely the literature study stage, field research stage, laboratory analysis stage, and data interpretation and processing stage. Field research focuses on collecting surface data such as outcrop data, geological structures, and several other geological features.

The laboratory analysis stage is carried out after field data collection has been completed. At laboratory analysis stage, petrographic observations were carried out on some samples in the research area.

Petrographic analysis was carried out on thin sections using a polarizing microscope. In petrographic analysis, rock samples that have been collected in the field will be made into thin sections with a thickness of 0.03mm.

The results of this analysis aim to determine the mineral composition of the rock based on the optical properties of the mineral. Furthermore, petrographic analysis used to validate the rock classification.

RESULT AND DISCUSSION

Regional Geology

The Sumatra Island has a northwest-southeast physiographic orientation, located on the western part of the Sunda Shelf and south of the Eurasian plate. Sumatra Island has a unique geomorphological feature, namely the presence of the Bukit Barisan Mountains in the western part which extends along the island of Sumatra (figure 2.1).

E-ISSN : 2579 – 3136

Sumatra Island is located in the southwest part of the Sundaland Continent and is a convergent route between the Indian-Australian Plate which is intruding to the west of the Eurasian Plate. Plate convergence results subduction along the Sunda Trench and right-lateral movement of the Sumatran Fault System. Subduction of the Indian-Australian Plate with the Asian Plate boundary in the Paleogene caused rotation of Sumatra resulting in a change in Sumatra's position from initially heading west-east to northwest-southeast.

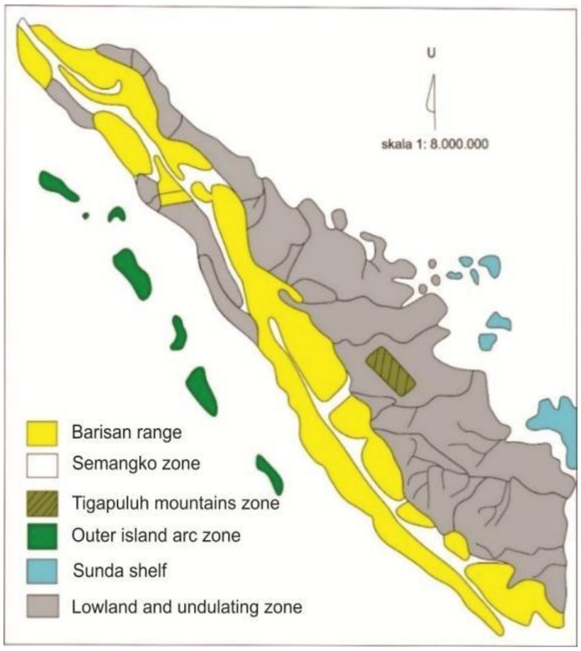


Figure 1 Regional physiography of Sumatra Island (Van Bemmelen, 1949)

The Martabe area is in the Sumatran Fault System which is locally known as the Sibolga Fault and the Angkola-Gadis Fault and is in a structural uplift zone.

This Sumatran fault system has been active since the Oligocene, but in some segments, it is estimated to have been formed as a result of the reactivation of the northwestern movement zone which is currently moving. Offsets are often difficult to find along faults, this is thought to be the result of very large offsets that can reach hundreds of kilometers (Page et al., 1979).

Geomorphology

The geomorphological analysis is aimed at studying the appearance of land forms as evidence of geological processes operating in an area, both endogenous and exogenous processes. This geomorphological analysis is carried out by looking at several aspects such as morphometry, landforms, morphogenetics, and drainage patterns that develop in an area.

Three factors influence the formation of a natural landscape, namely structure, process and stages of formation (Davies, 2002). The structure here is not limited to folds or faults. Furthermore, it is related to the rocks sequence that developed in an area.

The formation stages of a geomorphological feature can be divided into youth, mature, and old stages where each stage has certain characteristics of a land form.

Process factors are closely related to the weathering and erosion that occurs in an area. Each type of rock has a different level of resistance to erosion and weathering processes. Relatively resistant rocks will result a high relief with relatively tight contours when compared to areas composed of less resistant rocks.

Landform

The landform map was created based on the classification of landforms by Zuidam (1985), where landforms are divided into several classifications based on slope percentage and elevation different that occur in an area (Table 2.1):

Table 1 Classification of relief units (Zuidam, 1985)

Relief Classification	Slope Percentage	Elevation Different
Flat / Almost Flat	0 – 2	<5
Undulating	3 – 7	5 – 50
Undulating Rolling	8 – 13	50 – 75
Roling Hilly	14 – 20	75 – 200
Hilly Steeply Dissected	21 – 55	200 – 500
Steeply Dissected Mountainous	56 – 140	500 – 1000
Mountainous	>140	>1000

Based on the classification above, the research area can be divided into three landforms, namely Hilly Steeply Dissected, Roling Hilly, and Undulating. In general, the research area is dominated by landforms that have steep hilly relief, with parts of the central part of the research area having rolling hilly relief and the northeastern part having undulating relief (figure 2.2).

E-ISSN : 2579 – 3136

The shape of the valley that develops in the research area can be influenced by several aspects such as the level of erosion, slope percentage, and also the type of lithology. In the research, there are 2 valley shapes, V and U shapes. The valleys in the study area are dominated by V-shaped valleys, where these valleys are characterized by narrow and relatively steep valleys which develop mainly on steep hilly landforms. Meanwhile, U-shaped valleys are characterized by valleys that are relatively wide and located in relatively flat areas, especially on rolling hilly land forms.

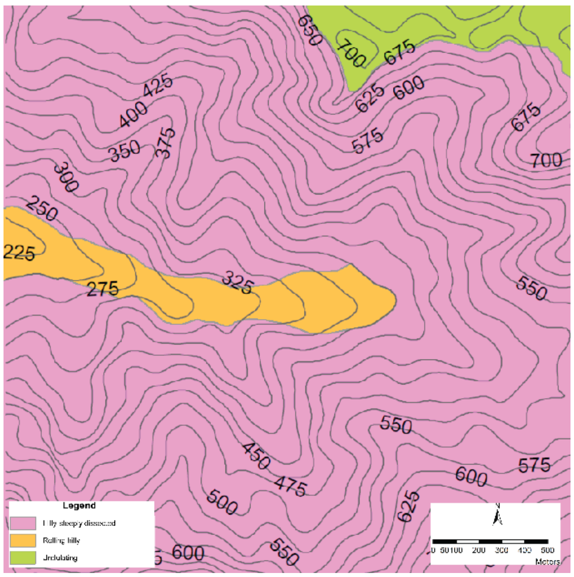


Figure 2 Landform map

Morphometry

The morphometric analysis was related to the slope percentage in the research area. The determination of slope percentage used in this research is based on the Van Zuidam classification (1985) where Van Zuidam divides the slope measurements into (Table 2.2):

Table 2 Measurement of Slope Percentage (Zuidam, 1985)

Slope Percentage	Slope Classification
0-2	Flat – almost flat
3-7	Gently sloping
8-13	Sloping
14-20	Moderately steep
21-55	Steep
56-140	Very Steep
>140	Extremely Steep

Based on the results of the slope analysis, the research area is divided into 6 slope classes where is dominated by steep – very steep slopes which develop in almost the entire research area, especially in the northern and southern area. Meanwhile, the sloping – gently sloping class develops in the central part of the research area and slightly in the northeastern region of the research area (figure 2.3).

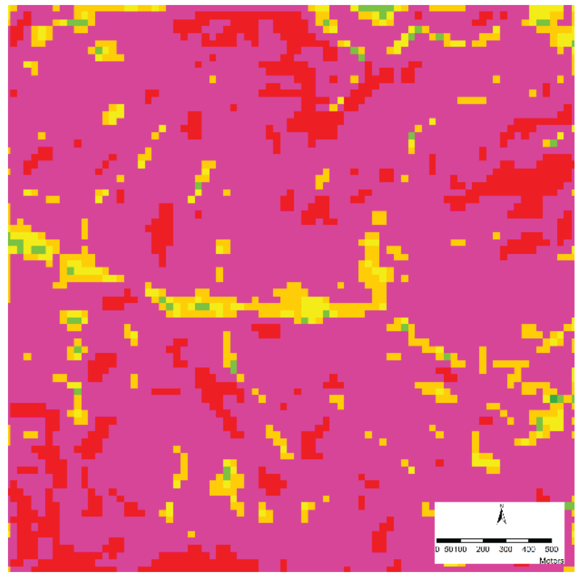


Figure 3 Slope percentage map

Morphogenetic

Morphogenetics examines geological processes influence the formation of a particular area. Based on the analysis and data collection in the field, it was found that the research area was influenced by endogenous and exogenous processes. The exogenous processes that occur are relatively destructive, such as erosion, oxidation, alteration and weathering that occur in the study area (Figure 2.4).

Endogenous processes that occur are more dominant in influencing the formation of the relief of the research area. Processes such as intrusions and structures that develop greatly influence the landforms, alignments and drainage patterns that develop in the research area.

E-ISSN : 2579 – 3136

Figure 4 Weathering and oxidation on outcrops in the study area

Drainage Pattern

The drainage pattern is a pattern formed by the presence of some river flows that develop in an area. Analysis related to drainage patterns is an aid in interpreting the geological structure and characteristics of rocks that developed in the research area. Based on Howard (1967), every existing river flow pattern can be formed by a certain type of structure or by the presence of certain characteristics of a certain type of rock.

The drainage pattern can be divided into basic and modified pattern. The basic drainage pattern is the most common pattern formed in a region and is generally influenced by regional structures. Meanwhile, a modified drainage pattern is a basic drainage pattern that changes due to the influence of characteristics of an area, these changes can be in the form of river flow density levels and other things like that. There are 2 river drainage patterns that develop in the research area (figure 2.5), namely:

a. Parallel

Parallel drainage patterns generally develop in areas with medium to steep slopes. This drainage pattern is generally straight and formed following the direction of the slope. This drainage pattern develops in the north and south of the research area.

b. Sub-dendritic

The sub-dendritic drainage pattern is a modified drainage pattern of the dendritic drainage pattern. This drainage pattern develops in areas with relatively gentle slopes with a uniform level of rock hardness. In contrast to the dendritic drainage pattern, the formation of the sub-dendritic drainage pattern is influenced by the structure that develops in an area.

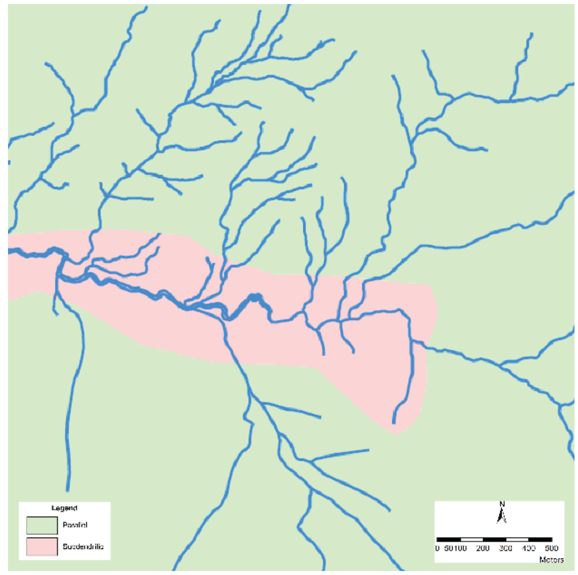


Figure 5 Drainage pattern map

Geomorphological Unit

The determination of geomorphological units is based on landform, slope and morphogenetic analysis. Based on these several aspects, the research area is divided into 3 geomorphological units (figure2.6), namely:

a. Sloping volcanic undulating

This geomorphological unit develops in the northeastern region of the research area. Located at an altitude of 675-715 meters above sea level with a relatively gentle slope. In this geomorphological unit, a parallel drainage pattern with V-shaped valleys develops. In its formation, this unit was influenced by volcanic activity in the form of diorite intrusions. The diorite is more resistant compared to other lithologies around it, resulting in the formation of high relief in this area.

b. Steep Volcanic-Structural Hills

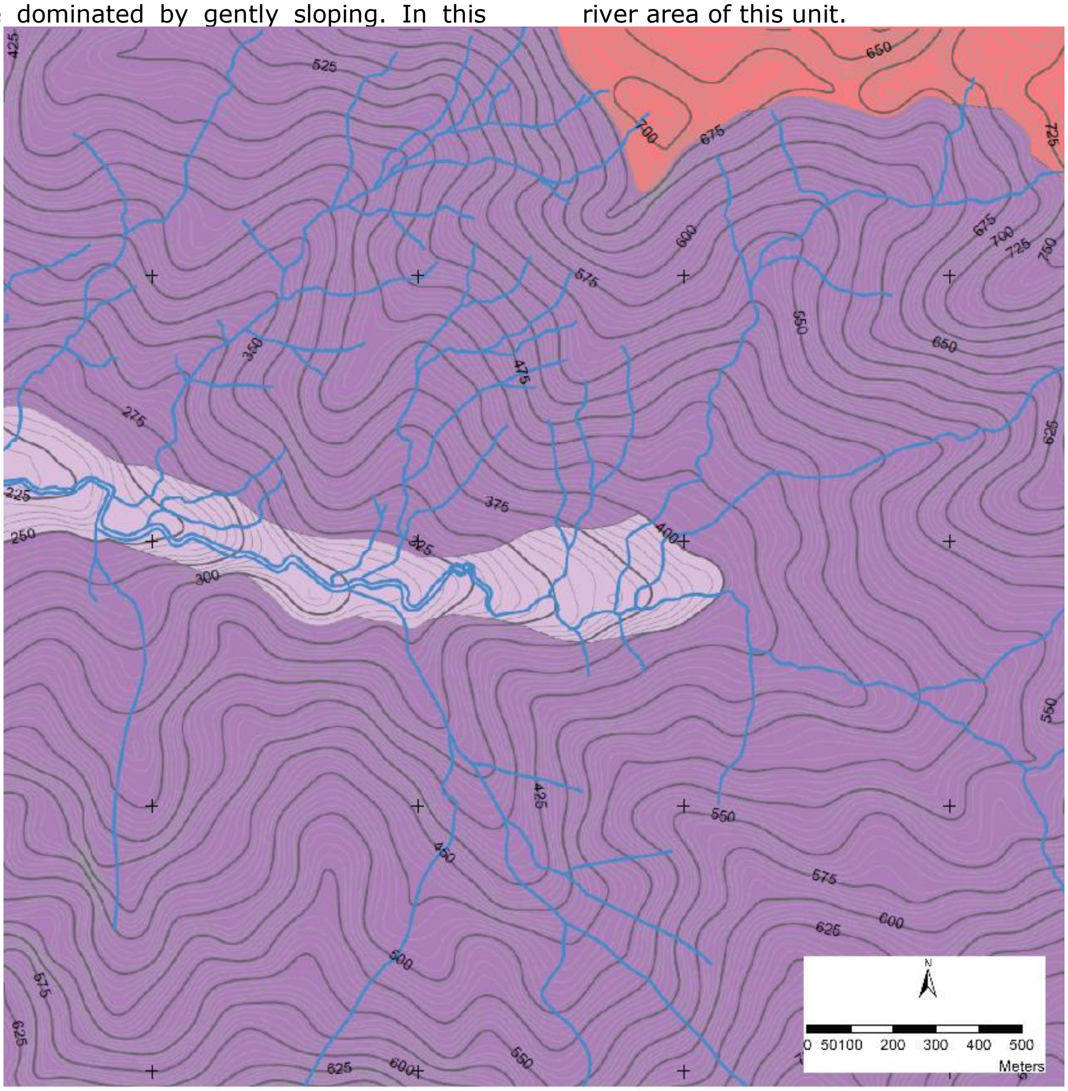
This geomorphological unit is formed in almost the entire study area. Located at an altitude of 270-756 meters above sea level with slopes dominated by steep slopes. In this geomorphological unit, a parallel river drainage pattern with V-shaped valleys develops. In its formation, this unit was influenced by volcanic and structural activity that developed in the area. Volcanic activity resulted in the formation of lithology in the form of andesite, breccia and diorite in this unit. Evidence of the presence of structures in this unit is quite diverse, in this unit slicken side can be found in the northwestern part, and in the southern part

E-ISSN : 2579 – 3136

quartz veins and evidence of faults in the form of clay gouges.

c. Sloping Volcanic-Structural Rolling Hills

This geomorphological unit develops in the central part of the study area. Located at an altitude of 217-400 meters above sea level with a slope dominated by gently sloping. In this geomorphological unit, a sub-dendritic drainage pattern generally develops. In its formation, this unit was influenced by volcanic and structural activity that developed in the area. The existence of volcanic activity is proven by the lithology that makes up this unit, which is andesite. Fault were also found in the eastern river area of this unit.



Geomorphological Unit	Symbol	Morphography			Morphometry			Morphogenetic		
		Drainage Pattern	Relief	Valley Shape	Elevation (m)	Slope Class	Slope %	Endogen	Exogen	Material
Sloping volcanic undulating		Parallel	Undulating	V	675-715	Sloping	3 – 20	Volcanic	Weathering and Erosion	Diorite
Steep Volcanic-Structural Hills		Parallel	Hilly-steeply dissected	V	270-756	Steep	21 55	Volcanic-Structural	Weathering and Erosion	Andesite, Diorite, Breccia
Sloping Volcanic-Structural Rolling Hills		Subdendritic	Rolling hilly	U	217-400	Sloping	8 – 20	Volcanic-Structural	Weathering and Erosion	Andesite

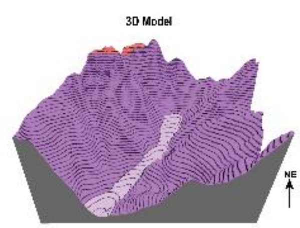


Figure 6 Geomorphological Map

Stratigraphy

The division of stratigraphic units in the research area uses lithostratigraphic units where the grouping of rock units is based on rock texture, mineral composition, types of constituent fragments, and several other things. Interpretation regarding the relationship of each rock unit is carried out by looking at evidence in the field, reconstructing geological cross-sections, and carrying out regional comparisons using the Regional Geological Map of Padang Sidempuan and Sibolga, Sumatra (Aspden et al., 1982)

Based on the mapping results, the lithology that develops in the research area consists of andesite, diorite intrusions and breccia (figure 2.7). The order of formation of lithological units in the research area from old to young:

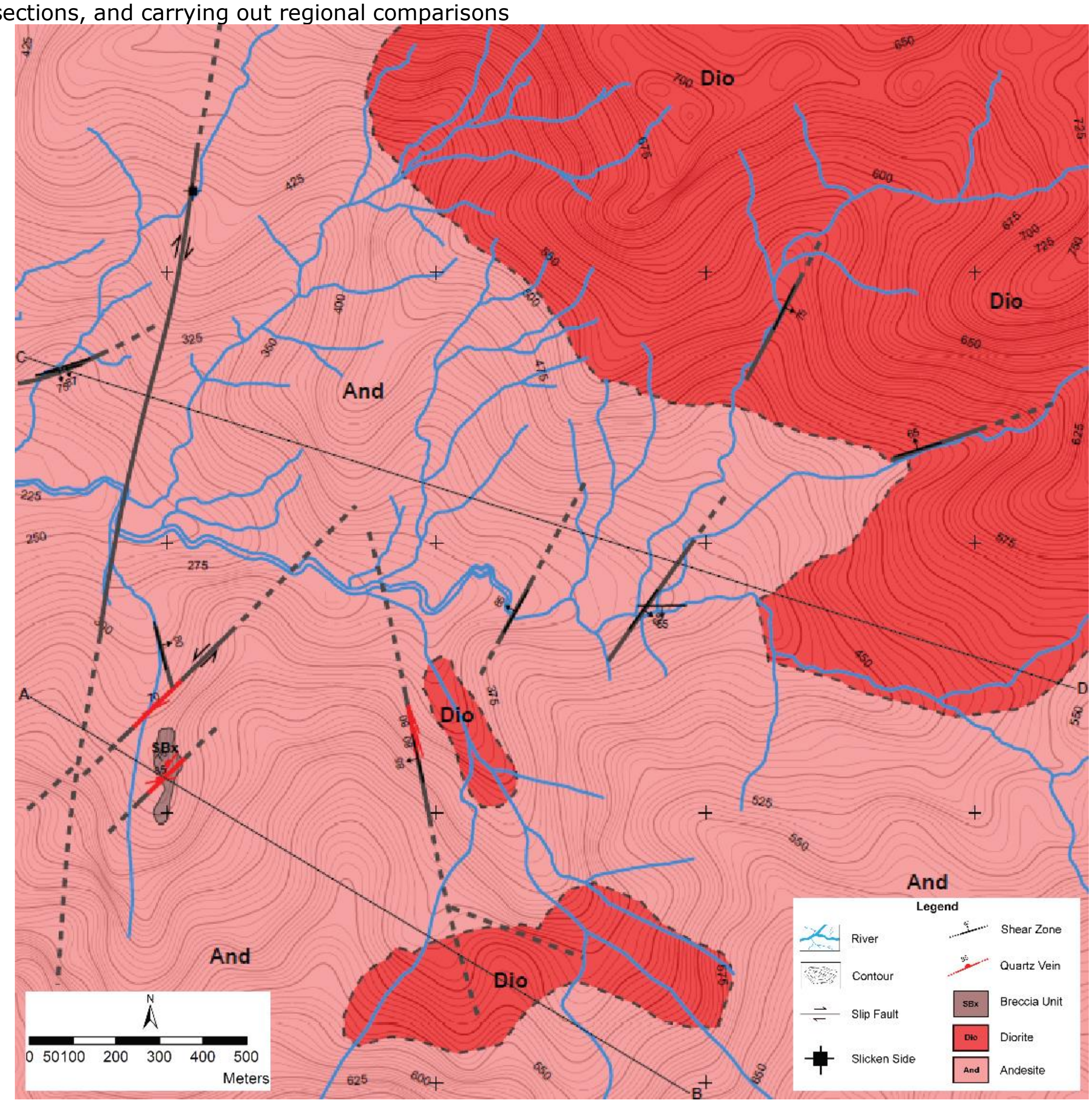


Figure 7 Geological Map

E-ISSN : 2579 – 3136

a. Andesite (And)

The andesite is the oldest unit in the research area. This unit is formed in almost the entire study area. Based on field observations, the andesite found in the study area has an aphanitic - porphyritic texture with an inequigranular crystal shape, the phenocrysts are dominated by plagioclase. Some sampe are paramagnetic – ferromagnetic.

Based on the petrographic analysis (figure 2.8), andesite has a porphyritic - aphanitic texture with the ground mass and phenocrysts being dominated by plagioclase, some phenocryst are also quartz, k-feldspar and opaque minerals. Alteration minerals were also found in the form of quartz microliths, clay minerals, epidote and chlorite which changed or replaced the groundmass and phenocrysts.

In this unit, the age formation reconstruction is based on regional comparisons from Regional Geological Map of Padang Sidempuan and Sibolga, Sumatra (Aspden et al., 1982) where this andesite unit is included in the Gunung Angkola Formation (Tmvak) which is composed of andesite, agglomerate and basalt. This formation was formed during the Early Miocene - Late Miocene.

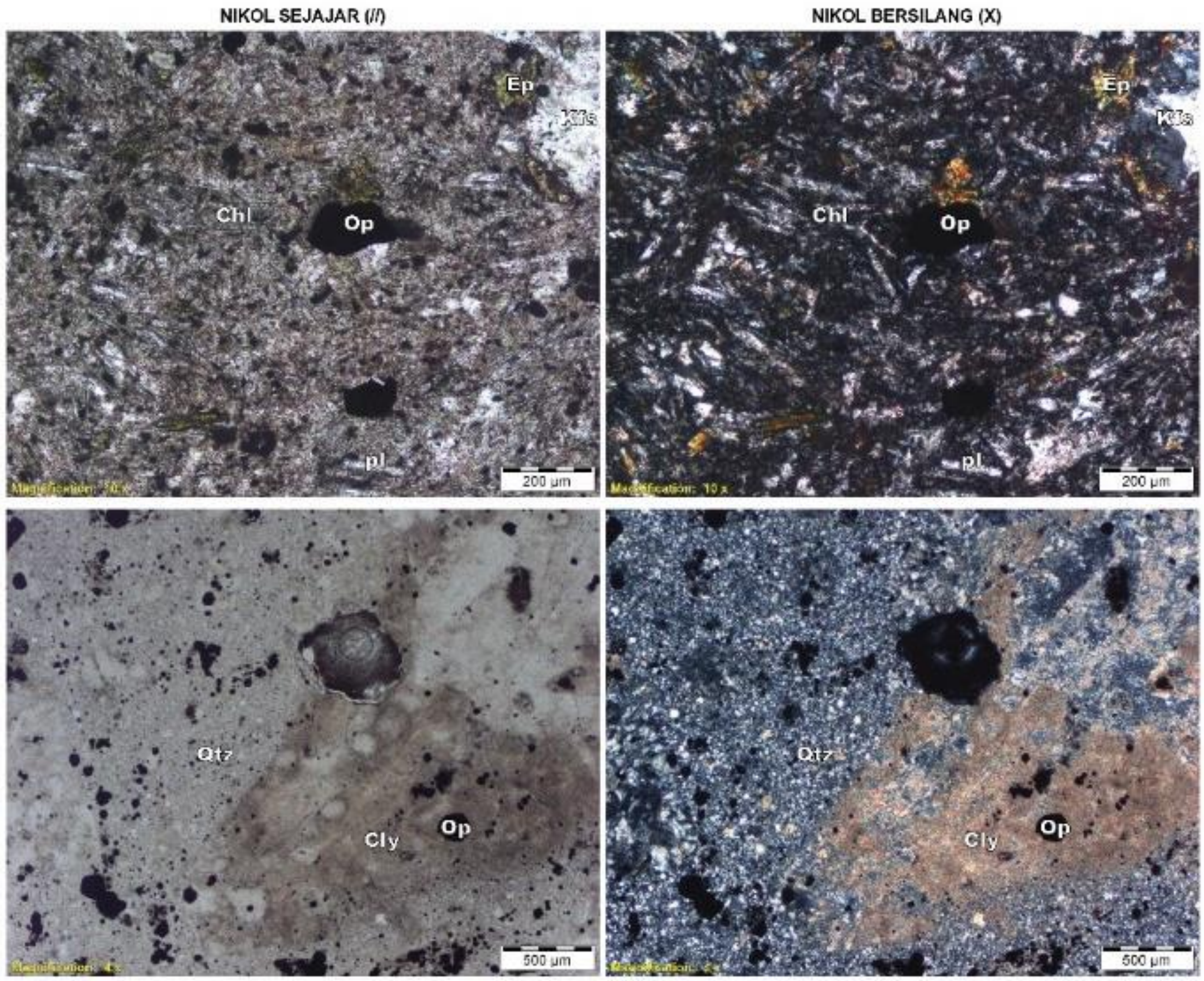


Figure 8 Petrographic analysis of andesite: opaque (Op), chlorite (Chl), Quartz (Qtz), plagioclase (Pl), epidote (Ep), k-feldspar (Kfs), clay minerals (Cly) (Streckeisen, 1976)

b. Diorite (Dio)

Diorite was formed after the andesite unit, this unit spreads in the northeastern and southern parts of the study area as an intrusion. Based on observations on hand specimens, diorite has a porphyritic - phaneritic texture with inequigranular crystal sizes, the mineral composition is dominated by plagioclase with a

E-ISSN : 2579 – 3136

small addition of quartz, hornblende and K-feldspar minerals. In this unit, there is diorite samples were found which had andesit xenoliths in it

Based on the petrographic analysis (figure 2.9), the diorite in this unit has a porphyritic texture. Phenocrysts are dominated by plagioclase minerals with small additions in the form of quartz, k-feldspar, amphibole and opaque minerals with some being changed or replaced by clay minerals, chlorite and epidote. While the groundmass is mainly composed of plagioclase minerals, in several samples the groundmass was also found to have been changed or replaced by clay minerals, quartz and chlorite.

In this unit, age determination is based on regional comparisons based on the Regional Geological Map Sheet of Padang Sidempuan and Sibolga, Sumatra (Aspden et al., 1982) where this unit is included in the Tmi Formation which is an unnamed granodiorite formation, diorite, and volcanic sub-intrusion. This formation was formed during the Middle Miocene - Late Miocene.

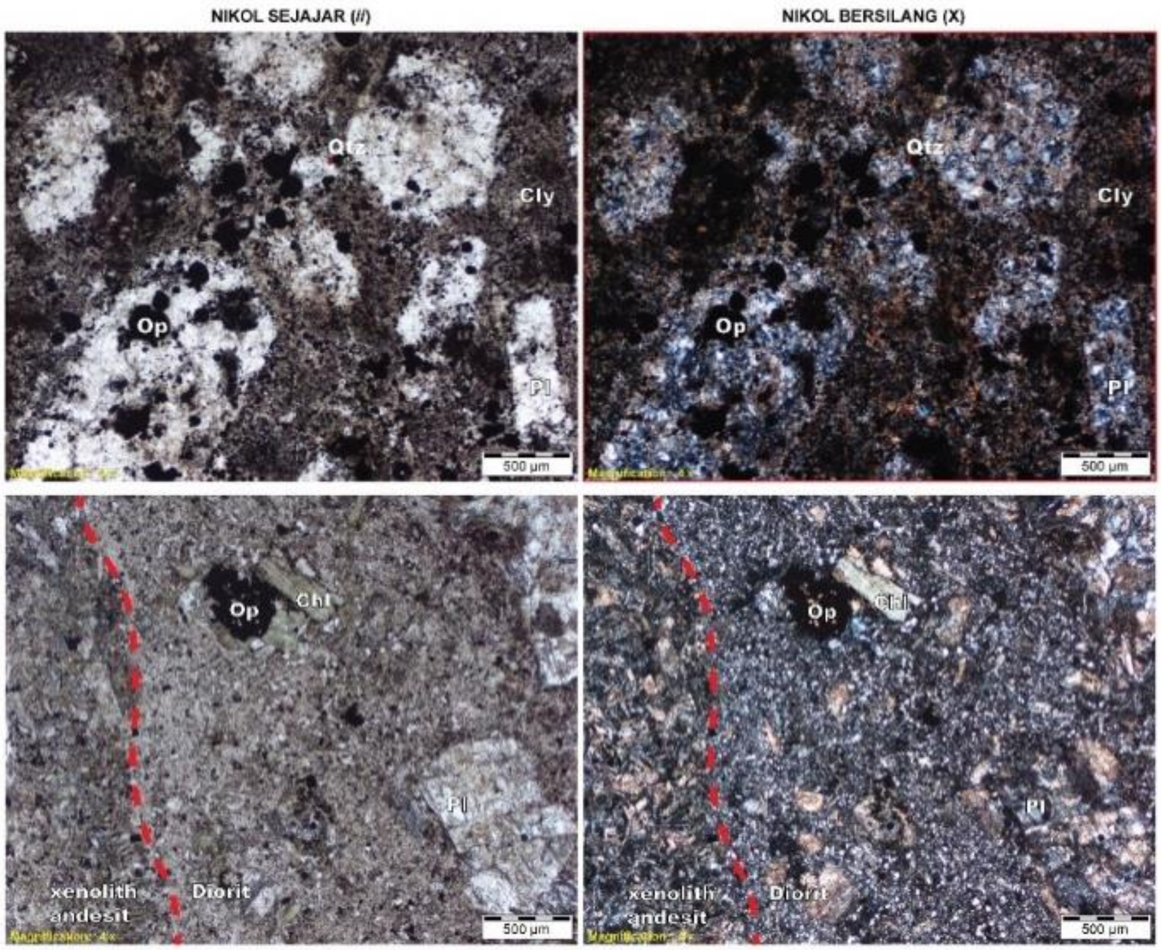


Figure 9 Petrographic analysis of diorite samples. The bottom shows the presence of andesite xenoliths in the diorite; opaque (Op), quartz (Qtz), clay minerals (Cly), chlorite (Chl), Plagioclase (Pl)

E-ISSN : 2579 – 3136

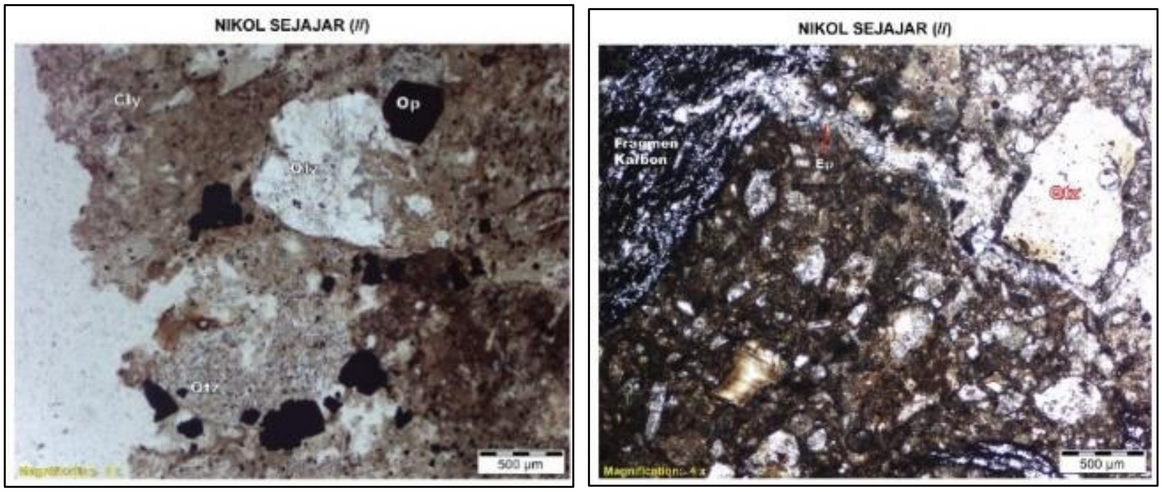


Figure 10 Petrographic analysis of breccia matrix; opaque (Op), quartz (Qtz), epidote (Ep)

c. Breccia Unit (SBx)

The composition of this unit is dominated by monomic breccia with 1-15 cm fragment sizes, the grain shape is angular to round, grain supported, and poorly sorted. The fragments in this rock are andesite and diorite. In this unit, locally there is polymic breccia with fragments consisting of igneous rock fragments, quartz fragments and carbon fragments.

Based on microscopic observations (figure 2.10), the matrix in the breccia is dominated by rock fragments measuring 0.1mm – 5mm. Apart from that, quartz fragments were also found in the breccia matrix. Based on Schmid's (1981) classification, the matrix in breccia is included in lithic tuff.

The distribution of breccia is not widespread in the study area. breccia can be found in the west, southwest and south of the research area. Breccia was found cut in the andesite unit (figure 2.11). The genesis of the formation of this breccia is thought to be related to hydrovolcanic processes where the formation process is related to the interaction of magma with the presence of water, resulting in an eruption.

Determining the age of this unit is based on evidence in the field, the results of reconstruction of geological cross sections, and cross-cutting relationship (Steno, 1669) where the breccia unit was found cutting into the andesite unit. Apart from that, the presence of andesite monomic fragments and diorite monomic fragments in the breccia unit can be used as a basis for determining the age of this unit. where it can be concluded that this unit has the youngest age when compared to the andesite and diorite units.

Figure 11 Breccia unit that intrudes into andesite

E-ISSN : 2579 – 3136

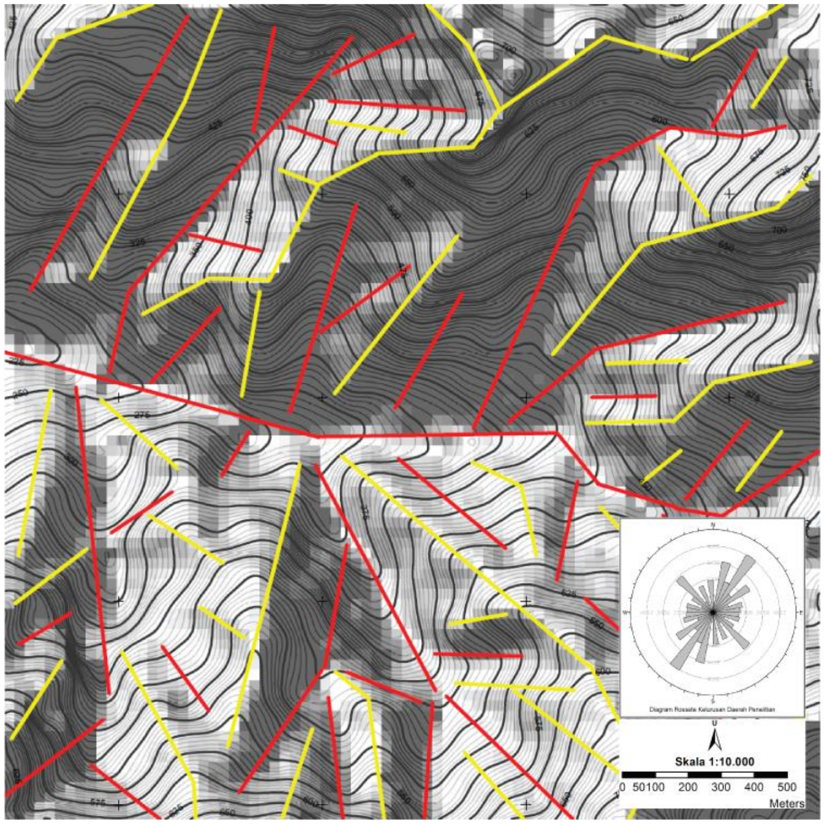


Figure 2. 12 Lineament analysis based on DEM data; yellow (ridge lineament), red (valley lineament)

Geological Structure

The analysis of structures developing in the research area is based on the results of measurements in the field and interpretation of lineament patterns created and processed from digital elevation model (DEM) data. Lineament patterns that develop in the research area will be related to the direction of stress in the research area. The lineament pattern will later be processed into a rosette diagram to see the direction of orientation of the dominant structures developing in the research area. Based on the results of the lineament pattern analysis, there are 2 dominant lineament patterns in the research area, namely in the northwest – southeast direction and also in the northeast – southwest direction (Figure 2.12). Apart from processing DEM data, structural analysis in the field is carried out by taking direct measurements of structures such as slicken side, fracture zones and quartz veins in the field. However, not all faults in the field can be measured directly, both in the direction of movement and the fault plane, some interpretations regarding the movement of structures and the direction of structural planes in the field are based on lineament analysis or based on offsets seen in river that are thought to exist. the influence of structure in its formation, especially in rivers with subdendritic patterns.

Based on the results of measurements in the field, 2 structural patterns are developing in the research area, namely in the northwest - southeast direction and also in the northeast - southwest direction. In a structure that has a northwest - southeast orientation, this structure is formed by cutting through andesite and diorite in the southern area where this structure is located, filled with quartz veins. In structures that have a northeast – southwest orientation. In general, this structure is continued by clay gouges. Apart from that, at several other observation locations, the structures of this period are filled with quartz veins (figure 2.13).

In the research area, slicken side were also found in the western part. The fault orientation was N190°E/62° with a pitch of 7 °, this fault has a dextral movement. Based on the classification of Rickard (1972) which divides faults based on

E-ISSN : 2579 – 3136

the pitch and dip of the fault plane, this fault is included in the Right Slip Fault.

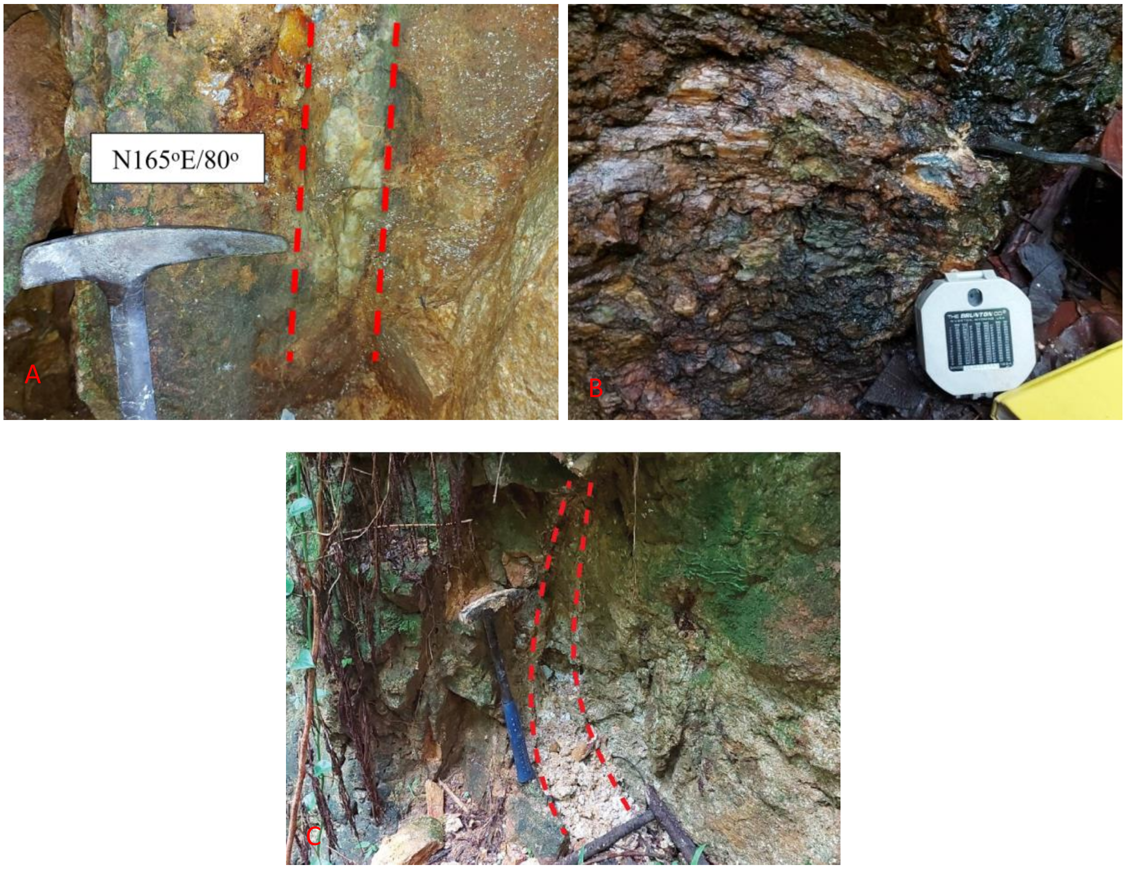


Figure 13 A. Quartz veins, B. Slicken side, C. Fault zone filled with clay gouge

CONCLUSION

a. The research area is divided into three geomorphological units, namely sloping volcanic-structural rolling hills, steep volcanic-structural hills, and sloping volcanic undulating with river drainage patterns that develop in the form of parallel and subdendritic drainage patterns.
b. The lithology that develops in the research area is divided into 3 units, namely andesite units, diorite units, and breccia units.
c. There are two dominant orientation directions in the structures developing in the research area, namely structures in the northwest - southeast and northeast - southwest directions.

ACKNOWLEDGMENT

The author would like to thank all parties who have helped in this research, especially to PT Agincourt Resources who have provided full support for this research.

REFERENCES

Aspden, J. A., Kartawa, W., Aldiss, D. T., Djunuddin, A., Diatma, D., Clarke, M. C. G., & Harahap, H. (1982). *Peta Geologi Lembar Padangsidempuan dan Sibolga*. Pusat Penelitian dan Pengembangan Geologi.

Davies, B. (2002). *Report on the Structural Review of the Martabe Project*.

Howard, A. D. (1967). Drainage analysis in geological interpretation. In *American Association of Petroleum Geologists Bulletin*.

Noor, D. (2012). *Pengantar Geologi* (Second). Program Studi Teknik Geologi, Fakultas Teknik, Universitas Pakuan.

Page, B. G. N., Bennett, J. D., Cameron, N. R., Bridge, D. M., Jeffery, D. H., Keats, W., & Thaib, J. (1979). A review of the main

E-ISSN : 2579 – 3136

structural and magmatic features of northern Sumatra. *Journal of the Geological Society*.

Rickard, M. J. (1972). Fault classification: Discussion. *Bulletin of the Geological Society of America*, *83*(8), 2545–2546.

Schmid, R. (1981). Descriptive nomenclature and classification of pyroclastic deposits and fragments: Recommendations of the IUGS Subcommission on the Systematics of Igneous Rocks. *Geology*, *9*(1), 41–43.

Steno, N. (1669). *Primera traducción completa en castellano del prodromus*.

Streckeisen. (1976). *Classification and Nomenclature of Igneous Rocks*.

Van Bemmelen, R. W. (1949). The Geology of Indonesia. General Geology of Indonesia and Adjacent Archipelagoes. In *Government Printing Office, The Hague* (hal. 1–766).

Zuidam, R. A. Van. (1985). *Aerial Photo – Interpretation Intrain Analysis and Geomorphology Mapping*. Smith Publisher.

E-ISSN : 2579 – 3136