



Study Petrogenesis and Phase of Rock Formation in the Sibaganding Area, Girsang Sipangan Bolon District, Simalungun Regency, North Sumatra Province

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Abstract. The study site is located in the Sibaganding area of North Sumatra, which has complex geological conditions that form the background for this research. Sumatra is an island topographically oriented from northwest to southeast. The island is in the southwestern part of the Sunda Shelf, south of the Eurasian Plate. This study aims to characterize and determine petrogenesis and analyze the phase sequence of the formation of existing rocks. The research method used megascopic and microscopic analysis of rocks. Petrographically, the types of rocks distributed in the study area are igneous, metamorphic, pyroclastic, and clastic and non-clastic sedimentary rocks. With rock naming in the form of quartz diorite, quartzolite as an intrusion that tends to be rich in silica, hornfels as a result of contact metamorphism, slate formed as a result of regional metamorphism, mylonite as a result of the milonitization process, crystal tuff, vitric tuff which are both a result of volcanic processes and there are limestones, claystone, very fine sandstone to conglomerate stones which all characterize different depositional sedimentation processes. Each rock characterizes the phase of formation that occurred. This sequence illustrates a complex geological history, with metamorphism phases such as basement formation, shallow marine environment phases, milonitization processes, depositional environment transition phases, magmatic activity, and volcanic activity. All of these phases occurred during the pre-Tertiary to Quaternary periods.

Keywords: Magmatism, Petrogenesis, Petrography, Rock characteristics.

1 Introduction

This research was conducted in an area of 22 km² in Sibaganding Village, Girsang Sipangan Bolon District, Simalungun Regency, North Sumatra. Regionally, the research area is located on the geological map of Sidikalang and (Partly) Sinabang sheets, which consists of 6 formation sections namely the Bohorok Formation, Kualu Formation Sibaganding Limestone Member, Peutu Formation Parapat Member, Microdiorite Parapat Formation, Haranggaol Volcano Formation, and Toba Tuff Formation [1]. Regional geology can be used as a general description of geological conditions in the study area

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and as an essential reference for the initial interpretation of geological factors that affect geological conditions in the study area.

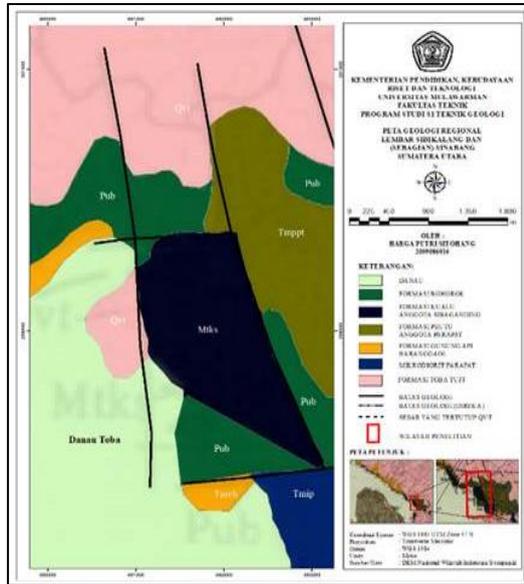


Fig. 1. Regional Geological Map of the Mapping Area (Sidikalang and (Partial) Sinabang sheets [1])

The study area has diverse rock units ranging from igneous, metamorphic, and pyroclastic to clastic and non-clastic sedimentary rocks. With the diversity of rock units in a relatively small area, it is interesting to study. This research is based on the lack of research on petrogenesis studies and rock formation phases in the research area. This research aims to obtain an overview of the petrogenesis conditions and the phase of rock formation using megascopic and microscopic analysis of rocks.

2 Materials and Methods

In this research, the object studied is the characteristics of rocks in megascopic and microscopic terms, focusing on the form of mineral groups that make up the rock. Several things must be done in the research stages to get good, correct, and accurate data. The stages in this research are divided into pre-field, field and post-field stages.

2.1 Pre-Field Stages

As a first step before starting the research, preparations were made in advance, including a literature review. In addition, additional data such as regional geology and DEM data are also needed to make basic maps such as topographic maps.

2.2 Field Stages

A simple random sampling method was used. This sampling represents each rock unit in the study area.

2.3 Post-Field Stages

This stage is the stage of data processing for both primary and secondary data.

Rock Characteristic Analysis Stage. At this stage, it is carried out to determine the characteristics of rocks in the laboratory. This stage uses a polarizing microscope for two analyses, namely megascopic and microscopic. At this stage, the percentage of mineral content in rocks is also calculated using plotting and grid software so that the percentage generated is more accurate. Determining the name of the rock is carried out based on the classification. This determination uses several classifications, namely the QAPF classification for plutonic or volcanic igneous rocks, the Schmid classification (1981) for pyroclastic rock types, Wentworth (1922) for clastic sedimentary types, Dunham classification (1962) for determining the name of carbonate rock types.

Phase Analysis of Rock Petrogenesis. They were conducted to determine the petrogenesis of rocks in the research area. This stage also refers to the classification of rock naming.

Phase Analysis of Rock Formation. This stage connects all data and analysis to determine the phase of rock formation in the study area.

3 Results

The data analyzed were three rocks without thin sections and ten thin-section samples representing each rock unit.

3.1 Rock Characteristics and Petrogenesis of Rocks

Rock characteristics can be known by analyzing rocks with megascopic and microscopic analysis.



Fig. 2. Sample quartz diorite (a) Sample hand specimen (b) Thin section, XPL

It is exposed around the southeast of the study area. The sample has greenish ash in color with a massive structure. It has the texture of holocrystalline crystallization level, euhedral crystal shape, phaneritic granularity, and granular panidiomorphic intercrystalline relationship.

Table 1. Calculation of percentage of mineral composition in quartz diorite samples

Mineral	Calculation	Normalization
Hornblende	20.1249	-
Plagioclase	67.0101	90.0422
Alkali Feldspar	1.0818	1.4536
Quartz	6.3288	8.5040
Biotite	2.2537	-
opaque	3.2003	-

The second sample has blackish ash in color with a hypocrystalline texture, euhedral-subhedral crystal shape, micro-phaneritic granularity, and equigranular grain uniformity.

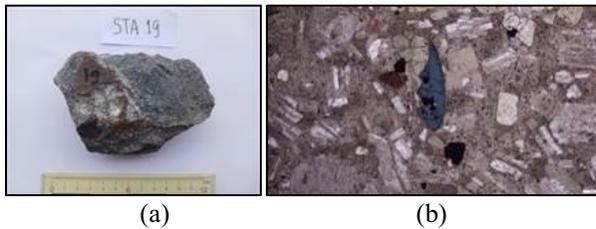


Fig. 3. Sample quartz diorite (2) (a) Sample hand specimen (b) Thin section, XPL

Table 2. Calculation of the percentage of mineral composition in quartz diorite samples (2)

Mineral	Calculation	Normalization
Plagioclase	41.7576	86.208
Pyroxene	22.9748	-
Quartz	6.68	13.791
Hornblende	1.19	-
Opaque	3.34	-
Base Mass	24.0566	-

The formation of quartz diorite occurs in tectonic environments that allow magmas rich in silica and other minerals to rise and cool slowly within the upper crust. The quartz diorite in the second sample is formed from magma that cooled more rapidly, probably at a shallower depth, resulting in smaller (micro-phaneritic) crystals. Based on regional geology, this rock is located in the Parapat microdiorite formation, which is middle to late Miocene.

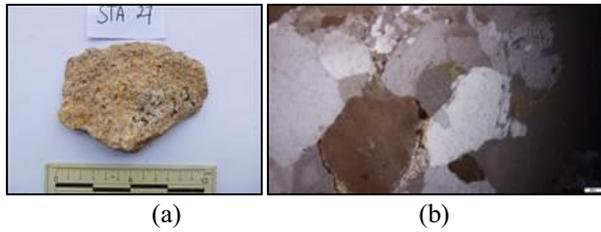


Fig. 4. Sample quartzolite (a) Sample hand specimen (b) Thin section, XPL

The following sample is greyish white with holocrystalline texture, phaneritic granularity, subhedral to anhedral mineral shape, and equigranular grain uniformity. Quartzolite is formed from the melting of silica-rich magma. Silica-rich magma can undergo gradual crystallization, where other minerals such as plagioclase and feldspar crystallize first, leaving an increasingly quartz-rich magma that will cool slowly.

Table 3. Calculation of the percentage of mineral composition in quartzolite

Mineral	Calculation	Normalization
Lithic	10.919	-
Quartz	89.08	100

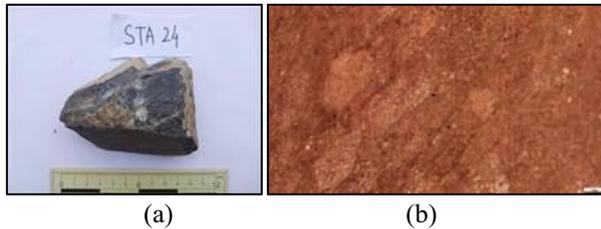


Fig. 5. Sample hornfels (a) Sample hand specimen (b) Thin section, XPL

Metamorphic rock, with non-foliation texture in the form of hornfels, metamorphism facies in contact metamorphism, brownish grey ash in color, grain shape found to be semi-rounded (sub-rounded). The process of hornfel formation is due to contact with intrusive rocks that generate high heat so that the minerals contained in the original rock change chemically and structurally.

Table 4. Calculation of the percentage of mineral composition in hornfels

Mineral	Calculation
Quartz	16.587
Matrix	82.33
Opaque	1.081

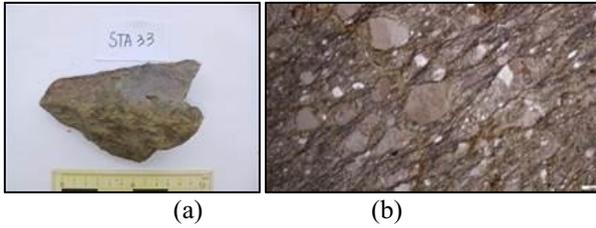


Fig. 6. Sample mylonite (a) Sample hand specimen (b) Thin section, XPL

Rocks have a grey to brownish grey color, cataclastic metamorphism type, and porphyroclastic textures. Mylonite is a metamorphic rock that undergoes intense plastic deformation in the shear zone, resulting in a fine-grained texture or directional fibres. The formation process is referred to as millonitic deformation. Regionally, the fault structure in the study area has a dominant Southeast - Northwest deformation direction [1].

Table 5. Calculation of the percentage of mineral composition in mylonite

Mineral	Calculation
Porfiroclast	17.866
Quartz	7.5
Lithic	73.511
Opaque	1.121
Total (%)	99.998

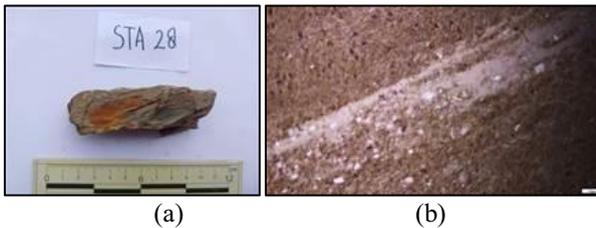


Fig. 7. Sample slate (a) Sample hand specimen (b) Thin section, XPL

Rocks have a brownish color foliation texture in the form of slaty cleavage. The high pressure causes the reorientation of the clay minerals in the original rock into alignment, resulting in foliation. These rocks will recrystallize the clay minerals into fine mica minerals, minor quartz, and feldspar.

Table 6. Calculation of the percentage of mineral composition in slate

Mineral	Calculation
Quartz	20.0268
Matrix	73.5494
Opaque	6.4228
Total (%)	99.999

Based on regional geology, this rock is located in the Bohorok formation, which is pre-Tertiary age. According to Barber et al., the bohorok formation is characterized by pebbly mudstone, slaty mudstone, conglomerate and sandstone. Pebbly mudstone, in this case, was formed in a glacio-marine environment [2]. The Bohorok Formation has generally been affected by low-level metamorphism.

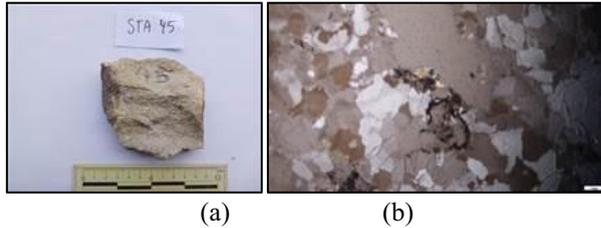


Fig. 8. Sample crystal tuff (a) Sample hand specimen (b) Thin section, XPL

Pyroclastic rock, with ash-tuff grain size, open packing, relatively good sorting, and grain shape, was found to be semi-rounded (sub-rounded). Crystal tuff is formed from magma that cools and crystallizes before being thrown into the air as pyroclastic fragments. These crystalline fragments are then thrown into the air during volcanic eruptions. Afterwards, these fragments are diagenesis and consolidated into crystalline tuff rock.

Table 7. Calculation of the percentage of mineral composition in crystal tuff

Mineral	Calculation
Quartz	52.4786667
Lithic	19.7990333
Opaque	0.55188333
Base Mass	27.1686667

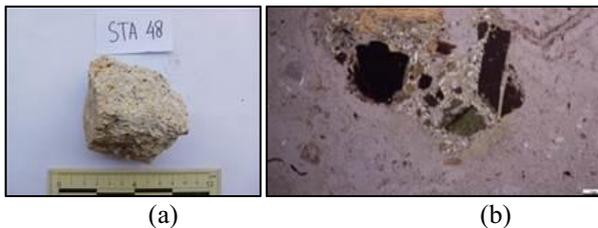


Fig. 9. Sample vitric tuff (a) Sample hand specimen (b) Thin section, XPL

Pyroclastic rocks, with ash-tuff grain size, open packing, relatively moderate - poor sorting, grain shape found to be semi-rounded (sub-rounded), and vitrophyric texture. During an eruption, volcanic material melts most of it, resulting in volcanic ash that is rich in glassy material and precipitates, cools rapidly and forms glassy material.

Table 8. Calculation of the percentage of mineral composition in vitric tuff

Mineral	Calculation
Quartz	12.1925
Biotite	15.5055
Plagioclase	7.2116
Base Mass	65.0886

In addition, vitric tuff samples comprise basic masses and minerals such as quartz, biotite and plagioclase. The combined presence of quartz, plagioclase and biotite in pyroclastic deposits may indicate an eruptive process involving a mixture of felsic and mafic to intermediate igneous rocks. This condition could describe complex volcanic conditions, where magmas of various compositions and sources were involved in the eruption. Based on regional geology, this rock is located in the Pleistocene-aged Tuff toba formation.

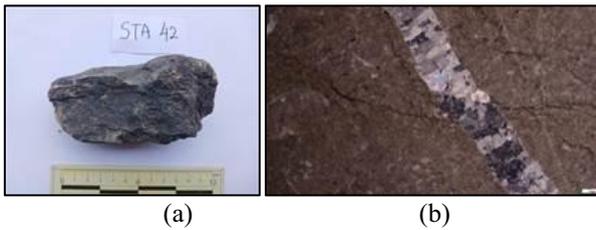


Fig. 10. Sample mudstone (a) Sample hand specimen (b) Thin section, XPL

It has a clastic texture and is subhedral to anhedral shape. This rock has a brownish ash absorption color and a brownish interference color. It is dominated by 83.178% micrite. This thin section also contains calcite minerals, part of the vein (fracture cavity filler), but there are also voids and opaqueness.

Mudstone limestones form in calm marine environments or relatively shallow water. Based on regional geology, this rock is in the Kualu Formation, a member of the Sibaganding limestone from the late Permian to late Triassic age.

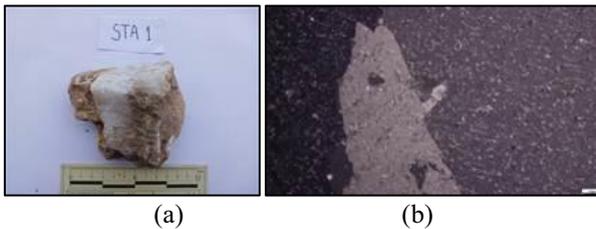


Fig. 11. Sample crystalline limestone (a) Sample hand specimen (b) Thin section, XPL

In prismatic crystal shape, the relationship between crystals is supported by grain. This sample consists of calcite minerals and opaque minerals. Crystalline limestone is formed through a natural process called diagenesis. The process of diagenesis can

change the structure of the stone to become more crystalline. Based on regional geology, this rock is in the Kualu Formation, a member of the Sibaganding limestone from the late Permian to late Triassic age.



Fig. 12. Sample hand specimen claystone

Brown in color with clay grain size, texture in the form of excellent sorting, degree of rounding, and closed packing. This rock consists of a matrix of clay-sized minerals. Cement is non-carbonaceous. Claystones form in quieter environments with shallow depositional energy, allowing fine clay particles to settle.



Fig. 13. Sample hand specimen very fine sandstone

This rock is brownish grey in color. This rock has a reasonable degree of sorting texture and a rounded degree of rounding, and the grain size is very fine sand. This rock has no rock structure (massive). Sandstones indicate formation in medium-energy environments such as deltas, beaches, or river channels, where the strong water currents or waves deposit sand particles.



Fig. 14. Sample hand specimen conglomerate

The greyish white color has a texture with shallow grain size, with a degree of sub-rounded rounding that distinguishes conglomerate rocks and a degree of sorting that is poorly sorted due to differences in grain size in rocks. Conglomerate rocks are formed from fragmented rock fragments, transported, deposited, and diagenized into solid rock. Conglomerate rocks are usually formed in energetic sedimentation environments, where the process of transporting and depositing sedimentary materials is very active.

4 Discussion

The tectonic setting of an area can be estimated based on the types of rocks found in the research location because every kind of rock is formed under different geological and tectonic conditions. In this study, the phase of the geological process and tectonic setting is divided into six stages, namely:

1. Metamorphism process: metamorphic rocks indicate the occurrence of metamorphism and deformation processes in the study area.
2. Shallow Marine Environment Phase, the presence of limestone in the form of mudstone or carbonate mud indicates the presence of a stabilization phase in the depositional environment in shallow seas or carbonate platforms.
3. The Milonitization phase is a stage in the rock deformation process characterized by the mylonite southeast area of the study area. Based on regional geology, the direction of the fault shift is from North-Northwest (NNW) to South-Southeast (SSE), which is interpreted to be Neogene in age.
4. In the sedimentation phase and transition of the depositional environment, there is an advanced sedimentation phase, with conglomerate, sandstone, and claystone rocks depositing in the mapping area.
5. In the Magmatic Intrusion Phase, igneous rocks as intrusions can represent magmatic activity.
6. Volcanic Activity Phase, the presence of rocks resulting from volcanic eruptions in the form of pyroclastic material crystal tuff samples rich in quartz can represent the existence of volcanic processes.

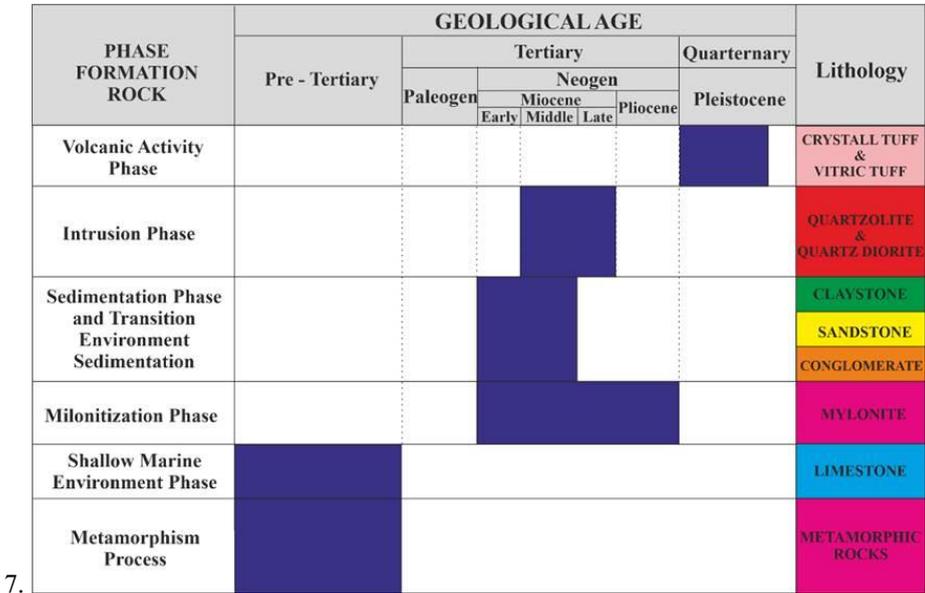


Fig. 15. Rock formation phase column

This figure explains the relationship between the phase of rock formation, the age of the phase and the rocks produced in each phase. The zonation of the milonitization process and the ages in this column also refer to the regional geological map of Sidikalang and (part of) Sinabang. This whole sequence illustrates a complex geological history.

5 Conclusions

The igneous rocks of the study area tend to be formed from magmas rich in silica. Metamorphic rocks in the study area tend to be created due to low pressure, high temperature and deformation. Crystal tuff and vitric tuff involve volcanic eruptions that release volcanic material and undergo a diagenesis process. Sedimentary rocks of the research location are formed from different sedimentation processes, ranging from quiet to intense sedimentation environments. From the characteristics and with regional geological data, the phase of geological processes can be divided into 6 phases, namely the process of metamorphism, the phase of the shallow marine environment, the milonitization phase, the sedimentation phase and the transition of the depositional environment, the phase of magmatic activity to the phase of volcanic activity.

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