

Petrographic study and its implication to the uniaxial strength of weathered volcanic rocks from Tawau, Sabah

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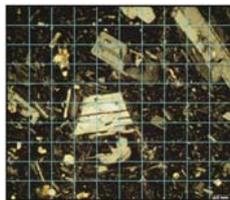
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GRAPHICAL ABSTRACT



ABSTRACT

This paper discussed the petrographic study and its effect to the uniaxial strength of weathered volcanic rocks from Tawau, Sabah, Malaysia. The volcanic rock consists of associated dacite, andesite and basalt rocks with the age of Pliocene to Quaternary. In this study the Murphy (1985) classification were used to determine the weathering grade of volcanic rocks. The uniaxial strength value were obtained from the Point Load Test and also estimated calculation from Uniaxial Compressive Strength test. The microstructures and identification of altered minerals were analysed using scanning electron microscope (SEM) and polarized microscope, respectively. The result of analysis indicated that the uniaxial strength of volcanic rocks decreased with the degree of weathering grades where the uniaxial strength decreased from 122.2 to 15.8 MPa for dacite, 143.4 to 10.1 MPa for basalt and 181.2 to 26.8 MPa for andesite. This result is due to the different percentages of quartz and feldspar minerals in the rock samples as well as formation of secondary minerals in weathered rocks. Microstructures study showed the appearance of micro fractures with narrow apertures in the minerals also influenced the uniaxial strength of the rocks.

Keywords: Micro fractures, Petrographic study, Uniaxial strength, Volcanic rocks, Weathering

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1. INTRODUCTION

The strength of rocks varies depending on the rock type, discontinuities and weathering. The effect of weathering on the engineering properties of rocks has been studied by previous researchers and various weathering classification have been proposed [1, 2, 3]. Weathering process consists of chemical, physical and biological dynamic process with agents such as water, air, organism and climate [4]. Chemical weathering is defined as a decomposed process of rocks caused by reactions to water, carbon dioxide and humidity of mineralogy composition [4]. Whereas, physical weathering is a slaking and disintegration process caused by force of water movements, temperature and inner stress changes [5]. Continuous weathering process that occurred has contributed to the decrease of rock physical characteristics [2]. High humidity resulted to extensive chemical weathering process and decrease the physical behaviour [6]. Earth materials can be categorized into five layers according to the weathering grade which does not only limit to the rock surface.

Weathering grade can be classified from Grade II (slightly weathered) to Grade V (completely weathered) based on certain parameters such as color changes, strength

index, rocks-soils ratio (RSR) and micro-index (micro-petrography, I_{mp} , and micro-fractures, I_{fr} , index) [7]. In tropical area the weathering profile can be observed from completely weathered on the surface to fresh rocks at the bottom of the profile. According to Fookes [8], Grade I and II classified as fresh rocks, Grade III and IV as combination of rock and soil, whereas Grade V and VI as soil. However, Irfan and Dearman [3] modified Fookes's classification and can be used for all types of rocks. Weathering processes effects to the strength of rocks due to the formation of soil material and increasing of porosity [6]. The decreasing of strength occurred when the bond between minerals particles is break apart thus forming micro cracks and new minerals during weathering [5]. Therefore, the objective of this research is to study the petrographic and its implication to the uniaxial strength of weathered volcanic rocks, collected from Tawau, Sabah.

The study area is located at Tawau, Sabah which one of the area in east of Sabah has experienced with active volcanic activity. The age of volcanic rocks at the study area is estimated from Pliocene to Quaternary [9]. The Pliocene volcanic rocks are situated at Mt. Magdalena, Mt. Wullersdorf, Mt. Pock, and Mt Lucia while Quaternary volcanic rocks can be found at Mt. Maria, Bombalai Hill, Tiger Hill and Mostyn Hill (Figure 1). The rock

distributions situated around Tawau town from Apas-Balung in the eastern part and Brantian in the western part of Tawau district.

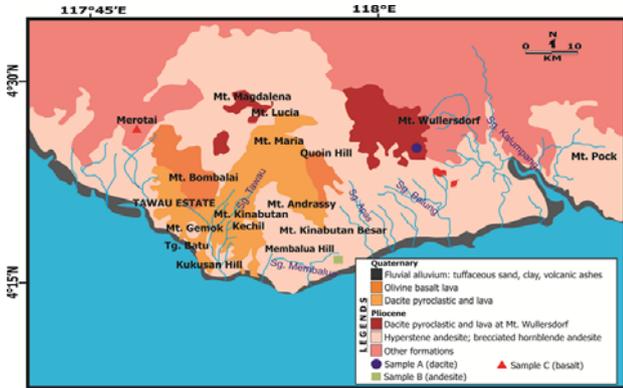


Fig. 1 Geological map of Balung to Merotai, Sabah (modified from Kirk (1962)).

2. MATERIALS AND METHODS

Three types of volcanic rocks consist of dacite, andesite and basalt were collected from the study area, which are widely distributed around Balung and Merotai area of Tawau, Sabah (Figure 1). The active weathering process resulted to thick soil profile up to 5 meters in most of the volcanic profiles. The colour is controlled by mineral composition which alter the primary minerals to secondary minerals throughout the weathering Grade II (slightly weathered) to V (completely weathered).

Petrography plays an important role as volcanic rocks exhibited various mineral composition and texture. Thus, it is crucial to observe how weathering can affect on uniaxial strength of different petrography of volcanic rocks. The classification of rocks samples were done based on QAP diagram to which used to classify volcanic rocks [10].

In this study, weathering grade classification by Murphy [11] (Table 1) is used. Murphy’s classification was modified to include the sound and feel of the square end of a rock hammer hitting the rock, though it depends on many external factors including the strength of the person wielding the hammer and the weight of the hammer itself [2]. In-situ sampling was conducted where volcanic rock samples with Grade II to IV of cubic size (20 cm x 20 cm x 15 cm) were collected, except for Grade V where sampling was difficult to be done due to its very weak materials. Grade I was unable to be collected due to its depth and condition for sampling. All samples were then inserted into sample bag and labelled before proceed for laboratory analysis.

Weathering degree also been able to identify with the condition of joints on the surface of rocks. Grade II showed closed joints with minor color changes; while the opening will increase and filled with calcite and kaolinite in Grade III. At this point half of the volcanic rocks samples had degraded to a residual soil. In highly weathered volcanic rocks (Grade IV), the joint opening increased and

the spacing decreased with clay was the common filling. Whereas, Grade V showed nearly 90% of the material turned to residual soil with clay as main mineral due to hydrolysis of abundance of feldspars in volcanic rocks.

Table 1 Weathering grade classification by Murphy [11]

Weathering Grade	Description
Fresh (I)	No visible signs of weathering. Rock is fresh. Crystals are bright. The rock hammer rings and bounces back.
Slightly Weathered (II)	Discontinuities are stained or discolored and may contain a thin filling of altered material. Discoloration may extend into the rock from the discontinuity to a distance of 20% of the discontinuity spacing. The rock hammer rings and bounces back.
Moderately Weathered (III)	Slight discoloration extends from discontinuity planes for a distance of more than 20% of the discontinuity spacing. Discontinuities may contain filling of altered material. Partial opening of grain boundaries observed. The hammer ‘thuds’.
Highly Weathered (IV)	Discoloration extends throughout the rock, and the rock material is partly friable. The original texture of the rock has mainly been preserved, but separation of the grains has occurred. The hammer ‘thuds’ and fragments of rock and individual mineral grains on the surface can easily be broken or rubbed off by hand.
Completely Weathered (V)	The rock is totally discolored and decomposed and in friable condition. The external appearance is that of a soil. Internally, the rock texture is partly preserved, but the grains have been completely separated. The pick end of the hammer easily enters the rock.
Residual Soil (VI)	Not included.

Uniaxial compressive strength analysis involved of Point Load Test (PLT) and Unconfined Compression Test (UCT) [12] for intact rocks samples. The PLT is an accepted rock mechanics testing method used for the calculation of an intact rock strength index. Also, PLT is a versatile field based index method capable of deriving values. The data obtained can be used to correlate the PLT index (Is_{50}) with the uniaxial compressive strength (UCS) [13] and to propose appropriate Is_{50} to UCS conversion factors [12] (Table 2) for volcanic rocks samples. The changes of microstructures in volcanic rocks throughout the weathering process were observed using polarized light microscope model Carl Zeiss and the scanning electron microscope (SEM) technique model Philips XL40 with 60 psi pressure and 15 to 20 kV voltages. The observation of mineral is include of alteration of composition mineral, the existence of micro-fractures and the increment of pore spaces. Mineral percentage is counted using gridding technique of 10 mm x 10 mm (Figure 2).

Table 2 Classification of rock strength [12]

Classification	Is_{50} (MPa)	Equivalent UCS (MPa)
Extremely Weak	Generally do not applies	< 0.5
Very Weak		0.5 – 1.25
Weak		1.25 – 5.0
Moderately Weak	0.2 – 0.5	5.0 – 12.5
Moderately Strong	0.5 – 2.0	12.5 – 50
Strong	2.0 – 4.0	50 – 100
Very Strong	4.0 – 8.0	100 – 200
Extremely Strong	> 8.0	> 200

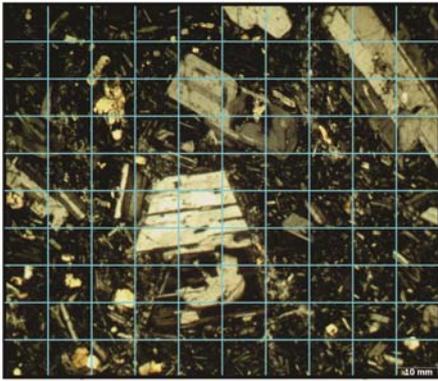


Fig. 2 Gridding technique to count the percentage of minerals exist in rock samples (unscaled).

3. RESULTS AND DISCUSSION

3.1 Volcanic Rocks Classification

Volcanic rocks samples in the study area were collected based on hand specimen observation and previous references which showed the distribution of volcanic rocks types. To prove the first assumption and interpretation of the type of volcanic rocks collected, further analysis has been done by using QAP diagram [10] to classify the volcanic rocks samples. The percentage of quartz, alkali-feldspar and plagioclase feldspar was counted (Table 3) using gridding technique. The percentages of minerals were then plotted into the triangular chart for the classification of rocks samples. Based on Figure 3, it is found that the volcanic rocks were classified as dacite (Sample A), andesite (Sample B) and basalt (Sample C).

Dacite consists mostly 45% of plagioclase feldspar with minor appearance of biotite and pyroxene along with rounded quartz (40%) and phenocrysts. Dacite is intermediate in composition between andesite and rhyolite which the groundmass is composed of plagioclase and quartz (Figure 4A). The petrography features of andesite showed 70% of plagioclase phenocrysts, 22% of orthoclase with small amount of quartz (8%), pyroxene and amphibole in porphyritic texture (Figure 4B). Meanwhile, the petrography features of basalt showed the domination of plagioclase (90%) and presence of orthoclase (9%) with minor amount of clinopyroxene and olivine in aphanite texture (Figure 4C).

Table 3 Rock classification based on major mineral composition of volcanic rock samples

	Sample A	Sample B	Sample C
Quartz, Q (%)	40	8	1
Feldspar, F (%)	15	22	7
Plagioclase, P (%)	45	70	92
Rock Classification (Strecheisen, 1978)	Dacite	Andesite	Basalt

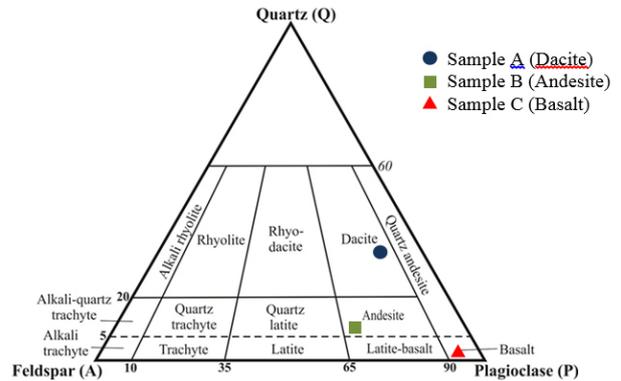


Fig. 3 QAP diagram for volcanic rocks classification

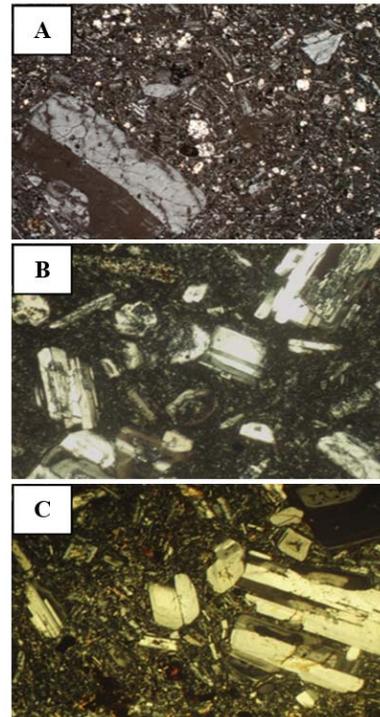


Fig. 4 Photomicrographs show (A) dacite with groundmass is composed of plagioclase and quartz; (B) andesite with plagioclase phenocrysts in porphyritic texture; and (C) and basalt with domination of plagioclase in glassy matrix (20X, XPL).

3.2 Uniaxial Compression Strength

Table 4 summarizes the result of uniaxial compression strength test on dacite, andesite and basalt. The result of uniaxial strength of rocks showed that the strength is decreased with the increment of both weathering grade (Table 4). The existence of pores in the inter granular of minerals and micro fractures reduced the strength of rock [14, 15, 16]. However the reduction of uniaxial strength is non-linear with the increment of weathering grade (Figure 5). Failure in the form of fractures resulted in uneven fracture planes in the rock samples.

Based on Figure 5, the relation shown by graphs clearly exhibited higher strength of andesite compare to

dacite and basalt. Andesite showed higher strength with 181.2 MPa in Grade II; due to the existence of plagioclase phenocrysts and interlocking quartz. This has contributed to high frictional angle which able to cause firmer collision thus increased the strength of particles in andesite [17]. While basalt, gained its 143.4 MPa because of aphanitic texture where fine-grained were tightly packed and dacite with 122.2 MPa due to the dominance of quartz and glassy matrix in this grade. In Grade III, the increment of intra granular micro fractures has decreased the strength of andesite to 104.6 MPa. This, however, still classified andesite as very strong rock [12] due to its porphyritic texture where angular quartz in fine-grained matrix gave higher bonded degree to andesite (Figure 6). Basalt and dacite, meanwhile, showed significant drop of strength to 87.4 MPa and 73.4 MPa respectively, due to the formation of porosity (Figure 7) which caused particles to apart and easy failure.

Table 4. Effect of weathering grade uniaxial strength of volcanic rocks samples

Grade	Dacite		Andesite		Basalt	
	MPa	Class	MPa	Class	MPa	Class
II	122.2	Very Strong	181.2	Very Strong	143.4	Very Strong
III	73.4	Strong	104.6	Very Strong	87.4	Strong
IV	39.4	Moderately Strong	87.7	Strong	35.0	Moderately Strong
V	15.8	Moderately Weak	26.8	Moderately Strong	10.1	Moderately Weak

* II-slightly weathered, III-moderately weathered, IV-highly weathered, V-completely weathered, MPa-strength unit, class-classification of strength

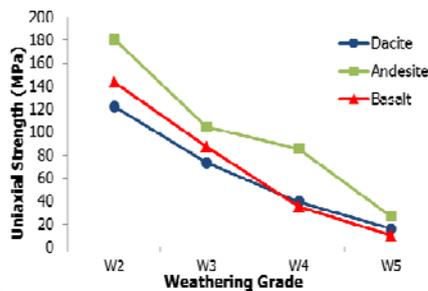


Fig. 5 Relation between uniaxial strength and weathering grade of volcanic rocks which weathering process is able to decrease the strength.

In Grade IV, the uniaxial strength of andesite continue to decrease to 87.7 MPa but still classified as strong, while dacite and basalt showed moderately strong value with 39.4 MPa and 35.0 MPa respectively. This is due to the existence of clay minerals (57.9 % to 60.2%) originated from the weathering of feldspars which yielded to increased porosity. Clay minerals reduced the friction angle to 4° [17, 18] which able to affect the initial frictional angle. The formations of micro-fractures caused particles to slide along the failure axis thus decreased the uniaxial strength for volcanic rocks samples in Grade IV.

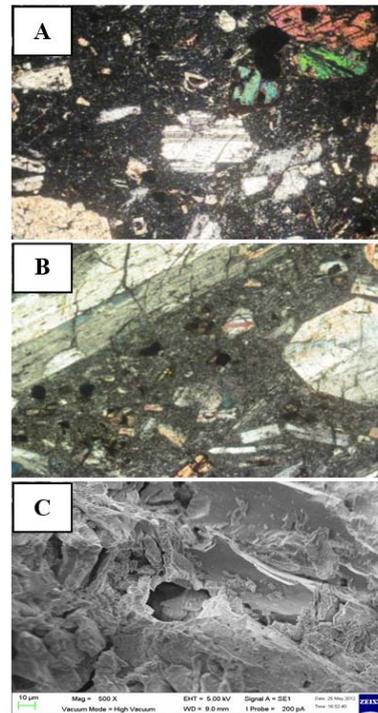


Fig. 6 Andesite showed the existence of (A) interlocking quartz which contributed to high frictional angle. Continuous weathering produces (B) abundance of micro-fractures and (C) porosity which caused particles to slide along the failure axis.

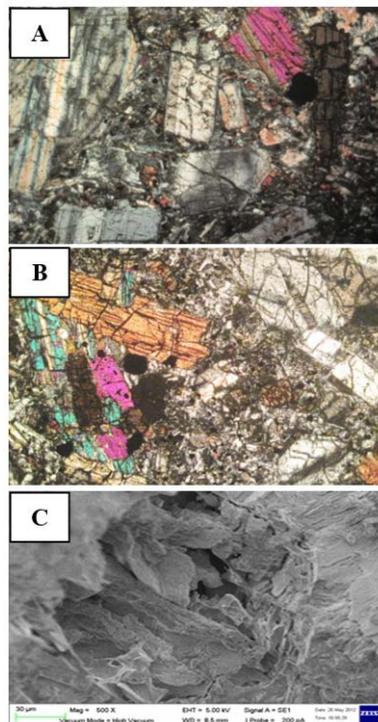


Fig. 7 Dominance of (A) quartz and glassy matrix gave high strength on dacite before decreased due to the (B) increment of intragranular micro-fractures and (C) inter-pores in higher weathering grade.

All volcanic rocks showed the least uniaxial strength with 26.8 MPa, 15.8 MPa and 10.1 MPa for andesite, dacite and basalt respectively. Both basalt and dacite showed similar strength classification of moderately weak while andesite showed moderately strong value in Grade V. This is due to the homogeneous texture and fine-grained with more than 65% clay domination (Figure 8). Rounded grains initiated easy collision among them thus resulted in low internal friction angle. Basalt showed a higher strength than andesite due to the existence of kaolinite and montmorillonite which played a role as a cohesive material between grains.

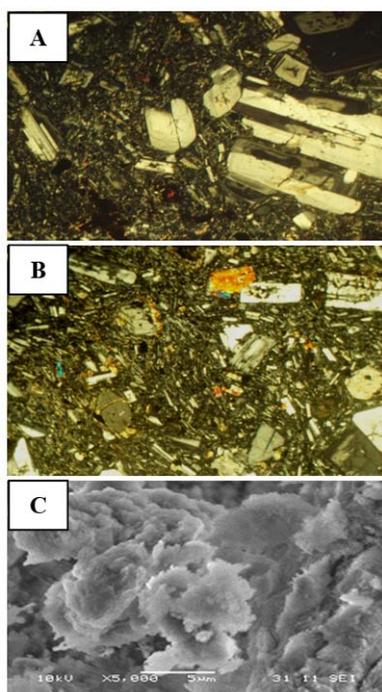


Fig. 8 Decrease in strength due to the existence of clay minerals which reduced the friction angle and produced porosity in basalt.

Slightly weathered rock (Grade II) showed discoloration and 50 – 60% of fresh rock strength. 50% of rock structure will start to disintegrated to possess approximately 30% of fresh rock strength in moderately weathered grade. It will disintegrate greater up to more than 50% of structure with less than 15% of fresh rock strength in highly weathered grade [3]. Under the influence of weathering, the strength, density and volumetric stability of the rock will be reduced, whilst deformability, porosity and weatherability is increased. This can lead to significant reduction in rock strength [19].

4. CONCLUSION

Chemical weathering has altered the rock forming minerals in andesite, dacite and basalt volcanic rocks. The weathered rocks formed secondary minerals and pore spaces between mineral grains. The presence of pore spaces, micro fractures and secondary minerals due to the

weathering processes affected the uniaxial compressive strength of rocks. Andesite rock with Grade II to IV showed the decrease of strength from 181.2 to 26.8 MPa; basalt decreased in strength from 143.4 to 10.1 MPa; whereas dacite strength decreased from 122.2 to 15.8 MPa.

The primary minerals in volcanic rocks such as quartz and plagioclase which is resistant to the weathering exhibited higher strength of the rocks. However, in weathered volcanic rock the appearance of clay minerals from plagioclase minerals will reduce the strength of the samples. As a conclusion, the weathering process is able to alter the rock forming minerals and micro fabrics of rocks thus reduced the uniaxial strength of the volcanic rocks.

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