

EFFECT OF MICRO-FABRICS ON UNIAXIAL STRENGTH OF WEATHERED VOLCANIC ROCKS FROM TAWAU, SABAH

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ABSTRACT. *This paper discusses the effect of micro-fabrics on uniaxial strength of weathered volcanic rocks from Tawau, Sabah. Volcanic rocks consist of basalt and andesite, aged from Pliocene to Quaternary. Weathered rock samples with grade range from slightly weathered (II) to completely weathered (VI) were collected from the road-cut slopes. Micro-fabric analysis was performed using polarizing microscope and Scanning Electron Microscope (SEM) techniques. Uniaxial strength analysis involved Point Load Test index (PLT) and Unconfined Compression Strength (UCS) test. The petrography analysis of basalt showed the domination of plagioclase with existence of orthoclase and pyroxene in aphanite texture. Meanwhile andesite consists of plagioclase, feldspar and amphibole in porphyritic matrix. Basalt samples with weathering grade from II to V showed the alteration of primary minerals from 12% to 55% and Imp (micro-petrography index) value ranging from 8.8 to < 0.2. Meanwhile andesite showed alteration of primary minerals ranging from 15% to 60% with Imp value of 4.9 to < 0.4. Andesite contains 16.8% stable minerals of quartz and feldspar phenocrysts that remain intact throughout the weathering process. Uniaxial strength results indicated that andesite exhibited a higher strength with value from 181.2 to 87.7 MPa while basalt showed 127.2 to 35 MPa. The porosity of andesite with Grade II to V was 4.1% to 49.5% whereas basalt ranged from 2.5% to 47.8%. The uniaxial strength of Grade V showed basalt is slightly higher than andesite with 0.3 MPa and 0.2 MPa respectively. This is due to the presence of more clay minerals in basaltic soil (75.1%) than in andesite soil (65.2%). This study showed that the weathering process is able to alter the micro-fabric characteristics of rocks which contributes to the decrement of the strength of volcanic rocks.*

KEYWORDS. Micro-fabrics, uniaxial strength, volcanic rocks, weathering.

INTRODUCTION

The micro-fabric aspect of rocks such as type of minerals, mineral orientation, grain shape and micro-scale change zones could have an effect on rocks' mechanical strength, permeability and other physical properties. The micro-fabric study entailed detailed microscopic examination of certain parts of materials which represented the whole materials themselves. Micro-fabric is measured at a scale of 100 μm to 1 μm and 1000-8000 times of expansion. Micro-fabric study consisted of research of mineralogy, texture and microstructure in rock mass, which is not visible to the naked eye, including pores and mineral orientation (Shamshuddin & Nik, 1985).

The micro-fabric of rock will change due to the weathering process, which consists of chemical, physical and biological processes with agents such as water, air, organisms and climate before exposed rocks decompose on the earth's surface to produce regolith or soils (Tjia, 1987). The weathering grade can be classified from Grade II (slightly weathered) to Grade V (residual soils) based on certain parameters such as colour changes, strength index, rock-soil ratio (RSR) and micro-index (micro-petrography, I_{mp} , and micro-fractures, I_{fr} , index) (Beavis, 1985; Brand, 1990). Weathering grade may change from completely weathered rocks on the surface to fresh rocks at the bottom of the profile. Therefore, the objective of this research is to study the effect of micro-fabric on the strength of weathered volcanic rocks, collected from Tawau, Sabah.

GEOLOGICAL BACKGROUND

The study area is located at Tawau in the eastern part of Sabah which has experienced active volcanic activity involving lava flows and pyroclastic deposits. The age of volcanic rocks at the study area is

estimated from Pliocene to Quaternary (Kirk, 1962; Tjia *et al.*, 1992). 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).

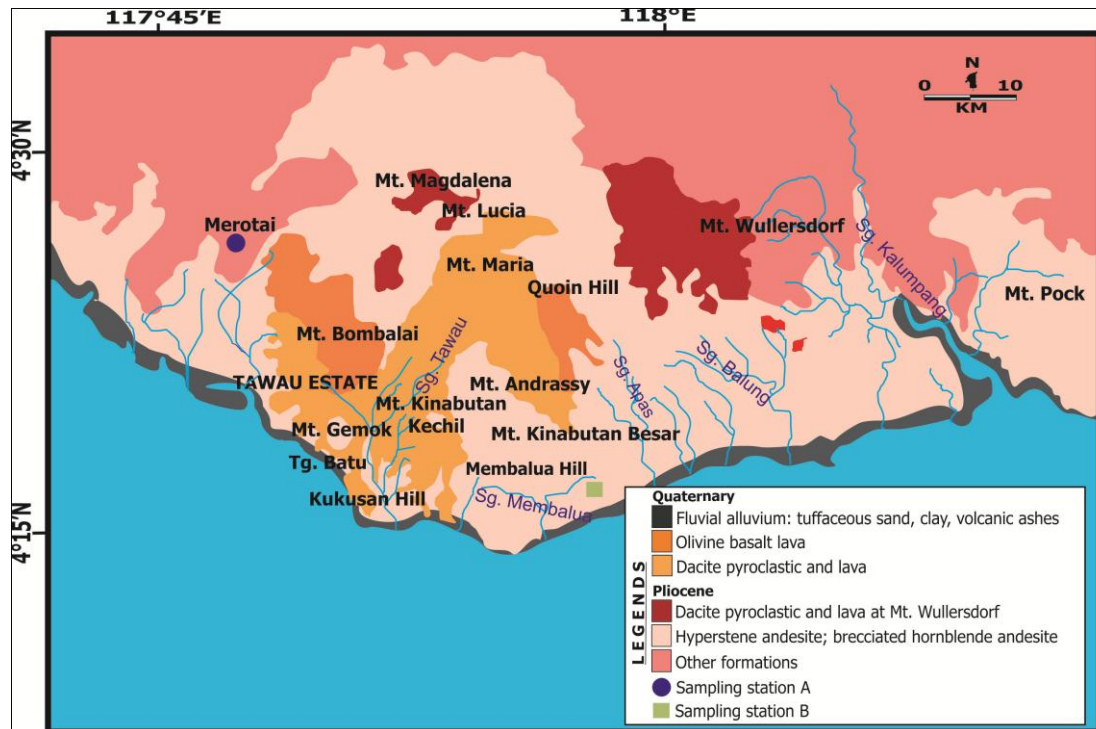


Figure 1. Geological map of Balung to Merotai, Sabah (modified from Kirk (1962)).

Volcanic rock consisting of basalt and andesite which are widely distributed around Balung and Merotai area of Tawau, Sabah were collected from the study area, (Figure 1). Basalt is basic volcanic rock while andesite is classified as intermediate volcanic rock based on its mineral composition percentage. Petrography played an important role as volcanic rock exhibited various mineral compositions and textures. Thus, it is crucial to observe how micro-fabric can affect strength of different petrography of volcanic rocks.

The distribution of volcanic rock begins at Apas-Balung and ends when it encounters Kuamut Formation (mélange) near Brantian. The active weathering process resulted in a thick soil profile of up to 5 meters in most of the volcanic profiles. The colour is controlled by mineral composition which alters the primary minerals to secondary minerals throughout the weathering Grade II (slightly weathered) to V (completely weathered). The field observation of basalt exhibited separated columnar structure of 15 cm diameter due to perpendicularly-cut joints (Figure 2A). The hand samples of basaltic soil show yellow-reddish to whitish in colour due to the existence of iron oxide minerals (goethite and hematite) and kaolinite (Baba *et al.*, 2008). Basalt is the youngest volcanic rock in the study area with the estimated age of Late Quaternary (Takashima *et al.*, 2004; 2007). Andesite, on the other hand, was erupted during Late Miocene to Pliocene and is distributed along Tawau River. Andesite is blackish-gray with 1.5 cm to 5 cm of edgy blocky and prismatic structure (Figure 2B). The andesite outcrop generally has been coated with yellow-brownish ferum oxide. The classification of rock samples was based on QAP diagram (Streckeisen, 1978).

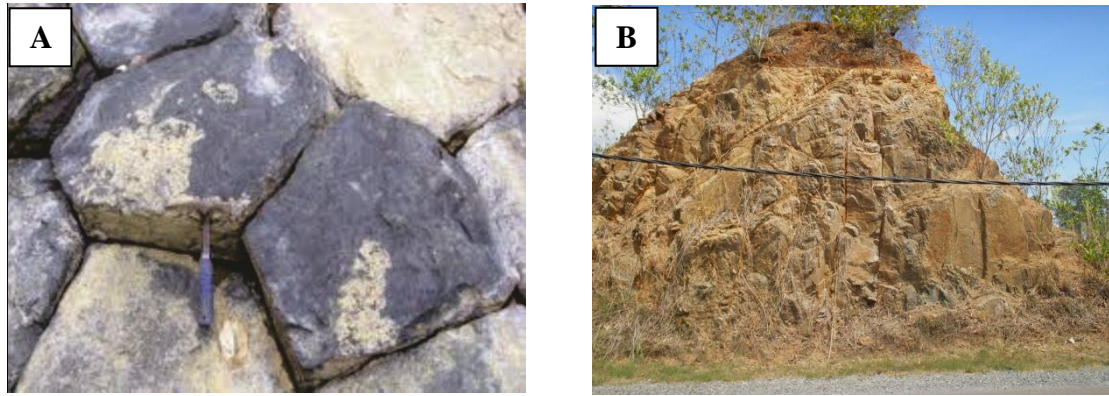


Figure 2. Field observations showed (A) columnar structure of weathered basalt and (B) edgy blocky structure of weathered andesite.

SAMPLING AND METHODOLOGY

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, whereas Grade V samples were collected vertically on horizon A of outcrop profile. All samples were then inserted into sample bags and labelled for laboratory analysis.

The changes of micro-fabric in basalt and andesite throughout the weathering process were observed using polarized light microscope model Carl Zeiss and the scanning electron microscope (SEM) model Philips XL40 with 60 psi pressure and 15 to 20 kV voltages. The observation of mineral for micro-fabrics included alteration of composition mineral, the existence of micro-fractures and the increment of pore spaces. Mineral percentage was counted using grid technique of 10 mm x 10 mm whereas the number of micro-fractures was counted in a centimetre thin section.

Uniaxial compressive strength analysis involved of Point Load Test (PLT) for intact rocks samples whereas Unconfined Compression Test (UCT) (ISRM, 1985) was applied for soil samples. The PLT is an accepted rock mechanics testing method used for the calculation of an intact rock strength index. The data obtained can be used to correlate the PLT index (Is_{50}) with the uniaxial compressive strength (UCS) and to propose appropriate Is_{50} to UCS conversion factors (ISRM, 1985) (Table 1) for volcanic rock samples. For grade IV to V, UCT is done on cylindrical shape (diameter, $D = 50$ mm; height, $H = 100$ mm) for which the amount of sample needed is based on maximum dry density and optimum moisture content obtained from Proctor Compaction Test (BS1377: Part 4: 1990). The sample mixture was then inserted in cylinder mould and compacted before uniaxial compression stress was applied on it to measure its compressive strength.

Table 1. Classification of rock strength (ISRM, 1985)

Classification	Is_{50} (MPa)	Equivalent UCS (MPa)
Extremely Weak	Generally does not apply	< 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

RESULTS AND DISCUSSION

Volcanic Rock Classification

Volcanic rock samples in the study area were collected based on hand specimen observation and previous references which showed the distribution of volcanic rock types. To prove the first assumption and interpretation of the type of volcanic rocks collected, further analysis was performed using QAP diagram (Streckeisen, 1978) to classify the volcanic rock samples. The percentage of quartz, alkali-feldspar and plagioclase feldspar was counted (Table 2) using gridding technique. The percentages were then plotted into the triangle which showed the classification of volcanic rock samples. Based on Figure 3, volcanic rock samples were classified as basalt and andesite.

The petrography features of basalt showed the domination of plagioclase (90%) and presence of orthoclase (9%) with a minor amount of pyroxene and olivine in aphanite texture (Figure 4A). Meanwhile, the petrography features of andesite showed 70% plagioclase phenocrysts, 22% orthoclase with a small amount of quartz (8%), pyroxene and amphibole in porphyritic texture (Figure 6A).

Table 2. Rock classification based on major mineral composition of volcanic rock samples

	Quartz, Q (%)	Feldspar, A (%)	Plagioclase, P (%)	Rock Classification (Streckeisen, 1978)
Sample A	1	7	92	Basalt
Sample B	8	22	70	Andesite

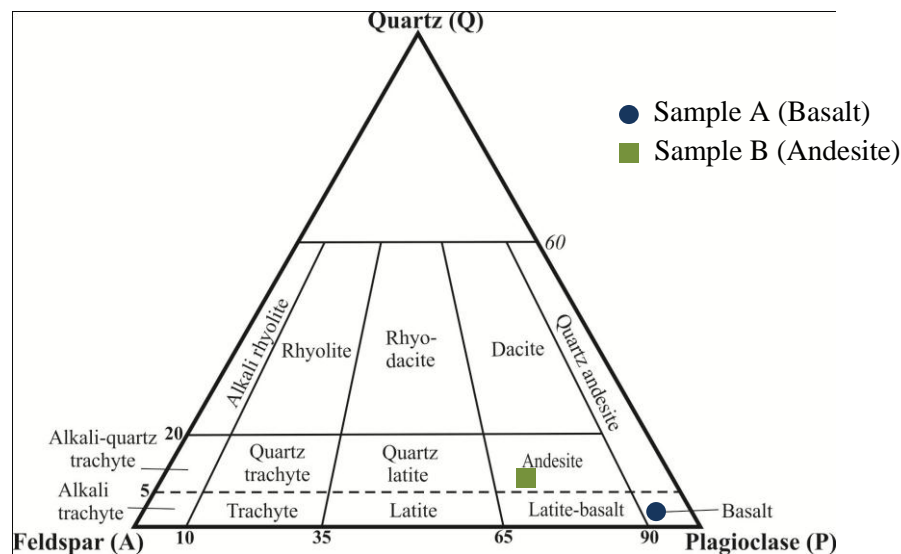


Figure 3. QAP diagram for volcanic rock classification (Streckeisen, 1978)

Weathered Basalt

The petrography features of Grade II basalt showed the domination of plagioclase (90%) and presence of orthoclase (9%) with minor amounts of pyroxene and olivine in aphanite texture and glassy matrix (Figure 4A) which produced 2.5% porosity. Feldspar then reduced by up to 35% and altered to form 30% of clay minerals and sericite, along cleavage axis and fractures on grains, thus increased the porosity to 6.3%, for Grade III. Quartz and plagioclase showed uneven micro-fractures in this grade (Figure 4B). Most olivine and pyroxene had changed to form chlorite, oxide minerals and 60% clay minerals in Grade IV. Orthoclase experienced small dissolution while quartz was still unaffected but showed slight changes on the inter connected edges among grains (Figure 4C). Micro-fractures appeared abundantly in this grade to form 9.3% pore spaces some of which were filled with clay minerals. On Grade V, the rock has completely weathered and decomposed to form soils. Almost 90%

of feldspar has altered to form clay minerals, while pyroxene and olivine have changed to secondary minerals, and the porosity increased up to 47.8%. The X-ray diffractogram of weathered basalt sample showed the appearance of kaolinite and montmorillonite (Figure 5) where the edges have eroded and rounded due to the dissolution process (Figure 4D). The alteration of 12% to 55% of primary minerals and formation up to 75.1% of secondary minerals showed the I_{mp} value of basalt ranged from 8.8 to < 0.2 for Grade II to V respectively.

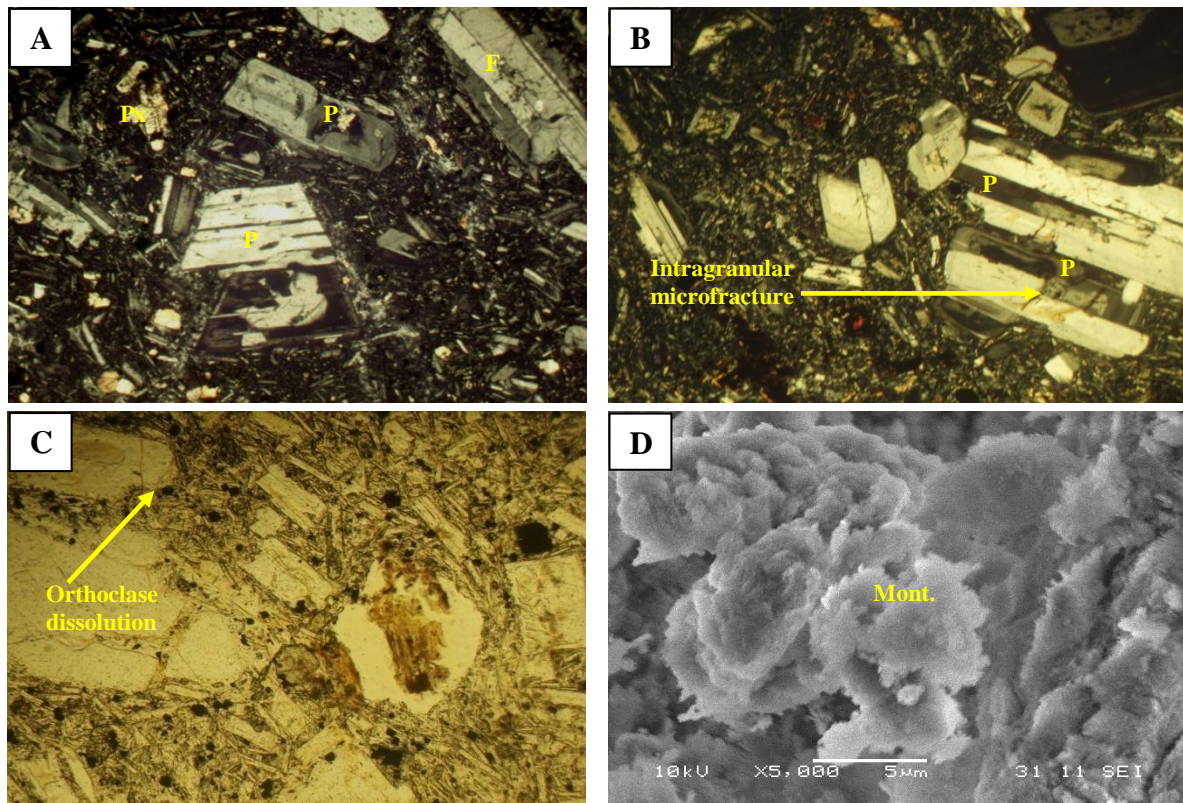


Figure 4. Photomicrographs of weathered basalt showed (A) the domination of plagioclase (P), orthoclase feldspar (F) with pyroxene (Px) in aphanite and glassy matrix (20X, XPL); (B) intra-granular micro-fractures in plagioclase (20X, XPL); (C) small dissolution of orthoclase with altered quartz on interconnected axis among grains (20X, PPL); and (D) the appearance of montmorillonite with flaky-shaped aggregate in weathered basalt (5000X).

Weathered Andesite

The petrography features of the Grade II andesite showed 70% plagioclase phenocrysts, 22% orthoclase with a small amount of quartz (8%), pyroxene and amphibole in porphyritic texture (Figure 6A). This contributed to 4.1% higher porosity than basalt. Less than 10% of plagioclase and 25% of orthoclase were altered to form sericite. Quartz and plagioclase remained intact but slightly eroded at inter-grains and produced micro-fractures (which increased porosity to 7.3%) some of which were filled with clay minerals in Grade III (Figure 6B). Most plagioclase (85%) was altered into clay minerals while 65% to 75% of hornblende and pyroxene had changed to chlorite and ferum oxide in Grade IV (Figure 6C). The existence of micro-fractures with bigger interconnections thus increased the porosity to 10%. On Grade V, almost all feldspars had altered to form clay minerals to dominate about 75% of the whole mineral composition. The X-ray diffractogram of weathered andesite (Figure 7) shows the abundance of kaolinite (Figure 6D). The porosity was 49.5% due to random arrangements of clay minerals. The I_{mp} value of andesite ranged from 4.9 to < 0.36 with alteration of primary minerals from 15% to 60% to form 65% of secondary minerals from Grade II to V respectively.

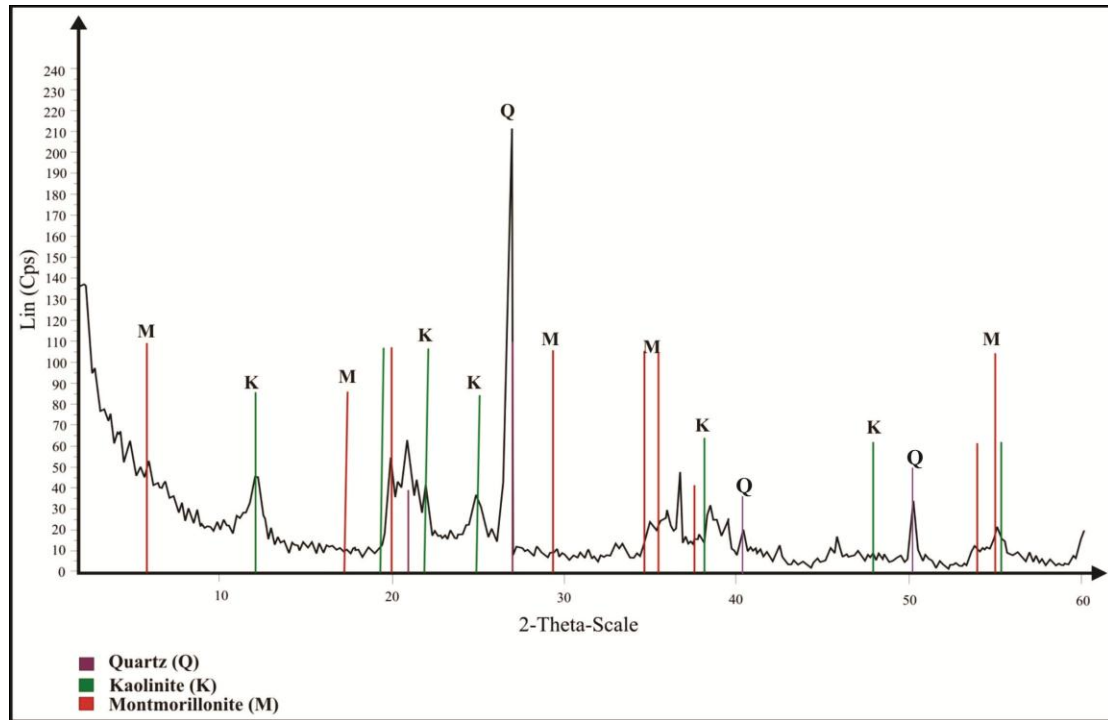


Figure 5. The X-ray diffractogram of weathered basalt shows the abundance of kaolinite and montmorillonite.

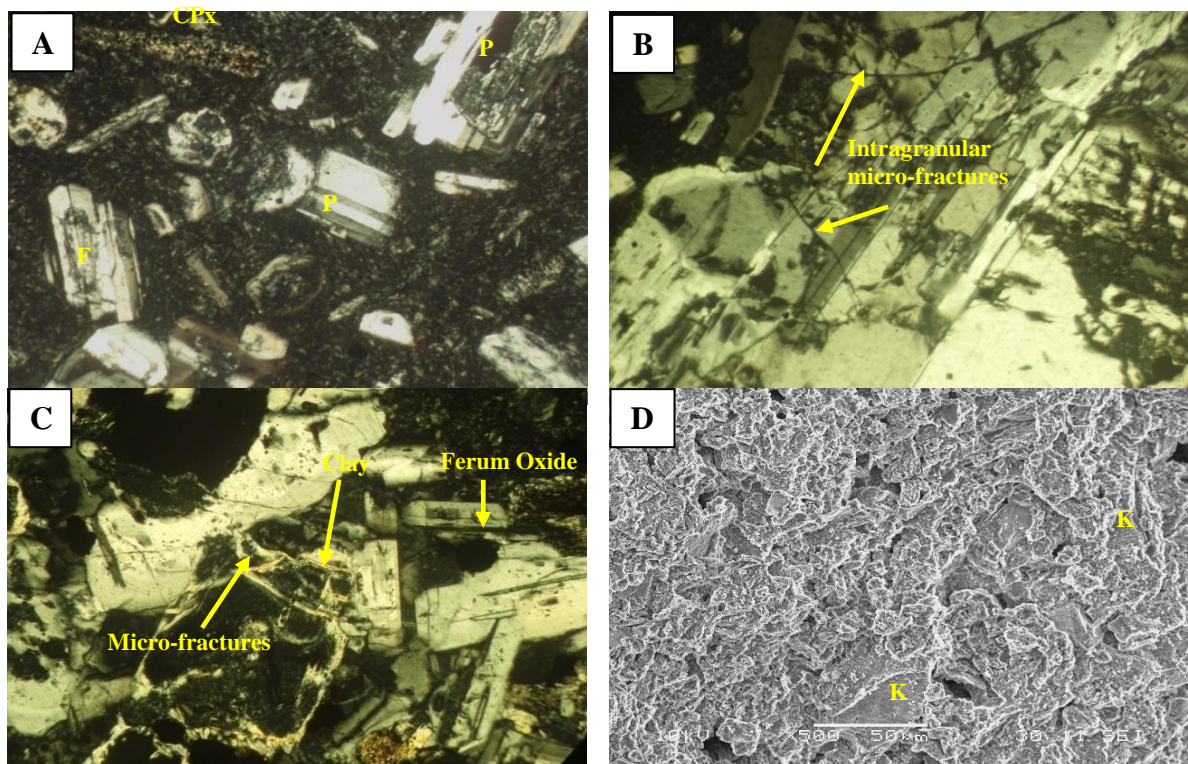


Figure 6. Photomicrographs of weathered andesite show (A) the existence of plagioclase (P), clinopyroxene (CPx), hornblende and feldspar (F) in porphyritic texture (20X, XPL); (B) intragranular micro-fractures of plagioclase (20X, XPL); (C) filled micro-fractures with clay minerals (20X, XPL); and (D) the appearance of kaolinite as dominant clay minerals in weathered andesite (500X).

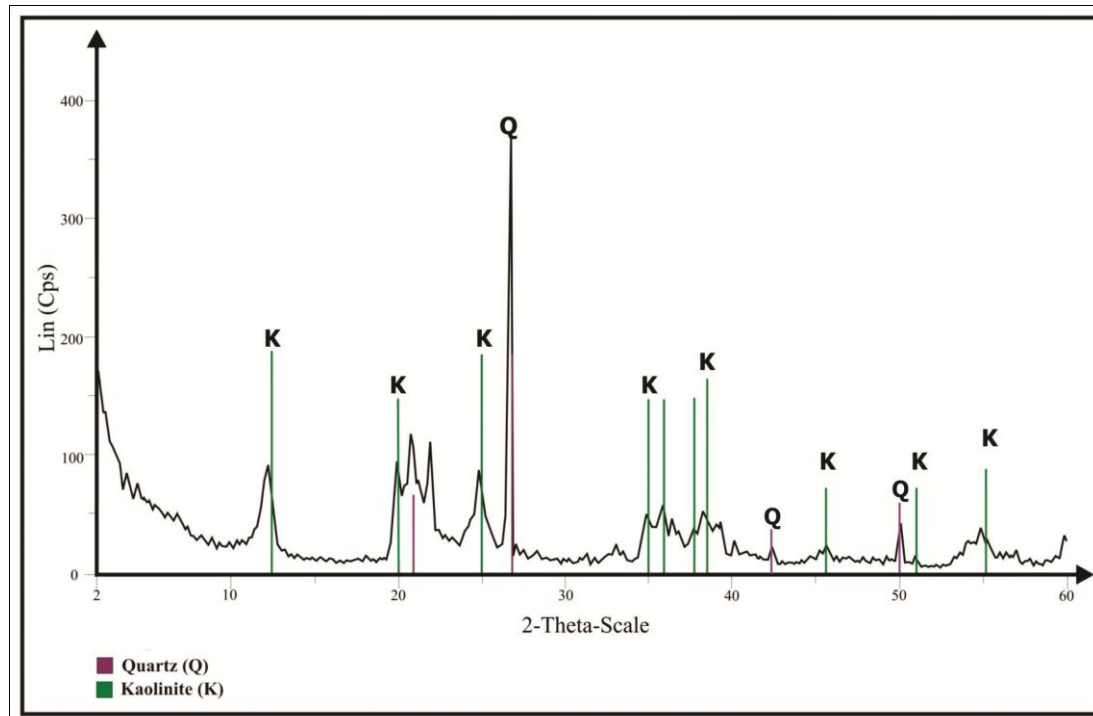


Figure 7. The X-ray diffractogram of completely weathered andesite shows the abundance of kaolinite and small amount of quartz.

Uniaxial Strength Characteristics

The measurement of uniaxial strength of rocks showed that the strength decreased with the increment of both weathering grade and porosity (Table 3). The existence of inter granular pores in the minerals and micro-fractures reduced the strength of rock (Hudyma *et al.*, 2004; Chang *et al.*, 2006; Hennie & Baba, 2010) of rocks. However the reduction of uniaxial strength is non-linear with the increment of total porosity (Figure 8) and weathering grade (Figure 9). Failure in the form of fractures resulted in uneven fracture planes which cracked the rock along the part with higher percentage of macro-pores.

Table 3. Weathering grade affect on the strength of volcanic rocks from the study area

Weathering Grade	Rocks-Soils Ratio (RSR) (Brand, 1990)	Index Micro-petrography (I_{mp})		Porosity (%)		Strength (MPa)	
	Remarks	Basalt	Andesite	Basalt	Andesite	Basalt	Andesite
Fresh (I)	An amount of soil in major joints	NA	NA	NA	NA	NA	NA
Slightly Weathered (II)	An amount of soil in all joints	7.3 – 8.8	2.3 – 4.9	2.51	4.08	127.2	181.2
Moderately Weathered (III)	All joints weathered, the existence of bigger core	2.3 – 3.1	1.2 – 2.5	6.27	7.25	39.4	104.6
Highly Weathered (IV)	Small core in soil mass	0.8 – 1.2	0.8 – 1.2	9.56	10.04	35.0	87.7
Completely Weathered (V)	Small core and hardly found (decomposed to soil)	< 0.2	< 0.35	47.76	49.50	0.3	0.2

*NA: Not Applicable

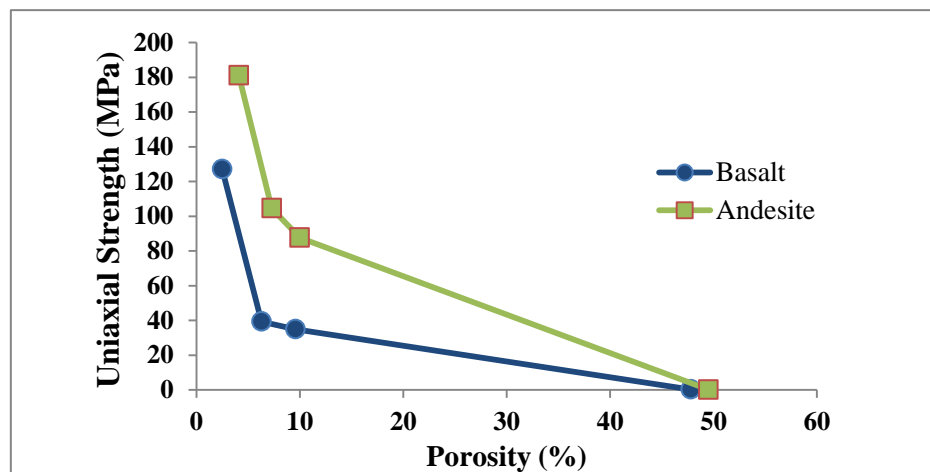


Figure 8. Graph shows the relation between uniaxial strength and porosity exhibiting decrement in strength within crease in pore spaces.

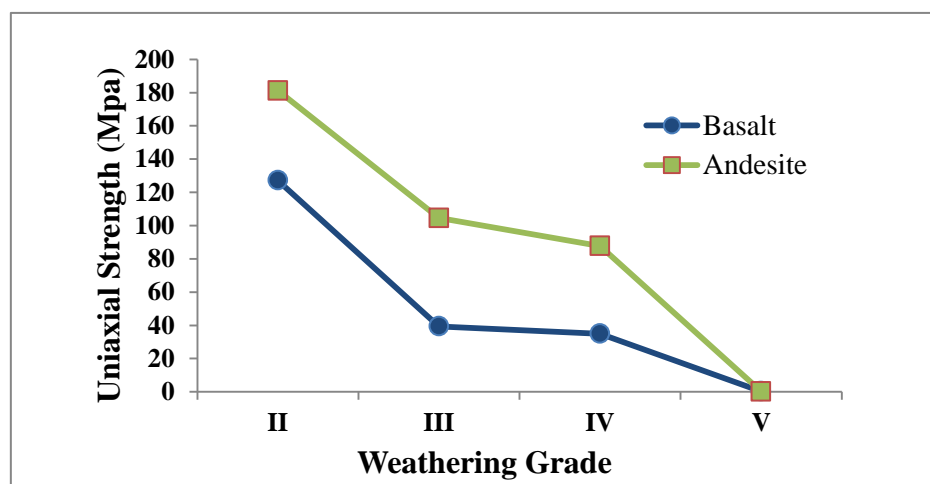


Figure 9. Graph shows the relation between uniaxial strength and weathering grade of volcanic rock where weathering decreases the strength.

Graphs Figure 8 and Figure 9 clearly exhibit higher strength of andesite compared to basalt. Andesite shows higher strength with 181.2 MPa in Grade II; due to the existence of plagioclase phenocrysts and interlocking quartz. This contributes to a high frictional angle which causes firmer collision thus increasing the strength of particles in andesite (Sassa *et al.*, 2007). While basalt, gained its 127.2 MPa because of aphanitic texture where fine grains were tightly packed. In Grade III, the increment of 7.3% porosity (intra-granular micro-fractures) has decreased the strength of andesite to 104.6 MPa. This, however, still classifies andesite as very strong rock (ISRM, 1985) due to its porphyritic texture where angular quartz in fine-grained matrix gives a higher bonded degree to andesite. Basalt, meanwhile, shows significant drop of strength to 39.4 MPa due to the formation of 6.27% porosity which causes particles to separate and easily fail.

In Grade IV, the uniaxial strength of basalt and andesite continue to decrease to 35.0 MPa and 87.7 MPa respectively. This is due to the existence of clay minerals (57.9 % to 60.2%) originating from the weathering of feldspars which yield to increased porosity. Clay minerals reduce the friction angle to 4° (Al-Shayea, 2001, Sassa *et al.*, 2007) which affects the initial frictional angle. The formations of micro-fractures cause particles to slide along the failure axis thus decreasing the uniaxial strength of both basalt and andesite in Grade IV. Both basalt and andesite show similar strength classification of very soft with 0.3 MPa and 0.2 MPa respectively in Grade V. This is due to the homogeneous texture and fine grains with more than 65% clay domination. Rounded grains initiated easy collision thus resulting in low internal friction angle. Basalt shows a higher strength than andesite due to the existence of kaolinite and montmorillonite which act as a cohesive material between grains.

CONCLUSIONS

Chemical weathering has altered mineral grains and eventually formed pore spaces between mineral grains. This study showed that presence of 8.4% to 58.0% micro-fractures played an important role in producing the porosity and connecting pores for increase in permeability. Basalt showed a porosity range from 2.5% to 47.8% while andesite exhibited higher porosity with 4.1% to 49.5% with the increase of weathering grade.

The increase of pore spaces and secondary minerals affected the uniaxial compressive strength of basalt and andesite rocks. Andesite rock of Grade II to IV showed the decrease of strength from 181.2 to 87.7 MPa; whereas the basalt decreased in strength from 127.2 to 35.0 MPa.

Andesite consistently showed a higher strength than basalt for all weathering grades studied. However, in Grade V, basalt showed higher strength (0.30 MPa) compared to andesite (0.21 MPa). This is due to the presence of 75% clay minerals in basalt which acted as a cement matrix for the mineral grains. In conclusion, the weathering process is able to alter the micro-fabric characteristics of rocks and thus may cause the decrement of the uniaxial strength of weathered volcanic rocks.

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