Bulletin of the Geological Society of Malaysia, Volume 75, May 2023, pp. 25 - 36
DOI: https://doi.org/10.7186/bgsm75202304

Physical characterization of the weathering profile over a sheared, biotite-muscovite granite in Peninsular Malaysia

John Kuna Raj

No. 83, Jalan Burhanuddin Helmi 2, Taman Tun Dr. Ismail, 60000 Kuala Lumpur, Malaysia
Author email address: jkr.ttdi.tmc@gmail.com

Abstract: The weathering profile can be separated into an upper, 11.8 m thick pedological soil (zone I) comprising gravelly clayey sands and a lower, >31.9 m thick saprock (zone II) consisting of gravelly silty sands with distinct preservation of the minerals, textures and structures of the original granitic bedrock material and mass. Zone I can be separated into A, B and C soil horizons, whilst zone II can be differentiated into sub-zones IIA, IIB, IIC and IID based on differences in preservation of relict structures and content of core-boulders. The earth materials of zone I represent rock mass weathering grade VI, whilst those of sub-zones IIA and IIB represent grade V, and those of sub-zones IIC and IID represent grades IV and III respectively. Constant volume samples show the earth materials to have variable dry unit weights (11.98 to 17.66 kN/m^3), but a limited range in specific gravity (2.62 to 2.70) due to similar primary and secondary minerals. The zone I earth materials have relatively large clay contents (>19%) and are more porous (33% to 55%) than those of zone II (36% to 44%) which have large silt contents (>23%). Sand contents are more variable (23% to 44%) though relatively large total sand and gravel contents (37% to 68%) point to the original, coarse grained granitic bedrock. Increasing clay contents (of kaolinite and illite) up the profile, and a corresponding decrease in silt contents (of mainly sericite), reflect increasing alteration of the bedrock; a feature also shown by increasing values of the textural weathering index (I_w). Distinct preservation of granitic textures and structures in saprock (zone II) indicate *in situ* alteration of bedrock; weathering resulting from gradual lowering of an unconfined groundwater table.

Keywords: Sheared biotite-muscovite granite, weathering profile characterization, pedological soil, saprock

INTRODUCTION

Several classification schemes have been proposed for the weathering of rock mass; one of the earliest by Moye (1955) who used seven recognition factors, as staining of joints and absence of original texture, to distinguish six grades or degrees of weathering of granite in Australia. Closely similar recognition factors were also applied to differentiating six grades of weathering of granite in the Batang Padang Hydro-electric Scheme in Cameron Highlands in Malaysia (CEB, 1962). In Hong Kong, Ruxton & Berry (1957) differentiated four weathering zones within an idealized weathering profile over granite on the basis of the absence of original texture, staining of fractures and percentage occurrence of core-stones. Several other characterizations of weathering profiles over granite, as those by Little (1969), Deere & Patton (1971), Lan *et al.* (2003) and Rahardjo *et al.* (2004) have also involved the differentiation of weathering zones based on essentially morphological criteria.

Some criticism has been levelled at the use of weathering zones for geotechnical purposes as their recognition is said to be based on criteria that are not quantitative nor related to mechanical properties or engineering behavior of material (Dearman, 1974). Stages of weathering of granitic rock material were then differentiated and used to define weathering grades in weathering profiles; the grades, in reality, applied to weathering zones (Dearman, 1974; 1976; Irfan & Dearman, 1978). The assignment of weathering grades is somewhat problematical for different stages of weathering of rock material are present at similar levels in weathering profiles, as in the concentrically developed stages of weathering of rock material around core-stones and core-boulders (Dearman, 1974). It was thus noted that the assignment of rock mass weathering grades is an averaging process dependent upon mapping scale; the resultant grades being proportions of different materials (ie. rock materials at different stages of weathering) (Baynes *et al.*, 1978).

In a review of the classifications of weathering of rock mass proposed by IAEG (1981) and ISRM (1981), Martin & Hencher (1986) noted the lack of definition or guidance for the description of rock material grades; in particular, the inadequate definition of the terms ‘rock’ and ‘soil’ and pointed out that not all rocks are characterized by the presence of core-stones when they weather. Martin & Hencher (1986) were also critical of the way in which the term ‘grade’ was used to describe a stage of weathering

0126-6187; 2637-109X / Published by the Geological Society of Malaysia.

of rock material as well as classify a zone of weathered heterogeneous rock mass. Lee & de Freitas (1989) then proposed that the term 'weathering zone' be used to distinguish the character of material en-masse, while the term 'weathering grade' is used to describe material from which the mass is formed. Lee & de Freitas (1989) also concluded from a study of weathered granite in Korea that it is necessary to combine geological descriptions with mechanical evaluation to describe weathered materials; this necessity being especially important in identification of relict geological structures as joint and fault planes (Aydin, 2006; Raj, 2009).

In the humid tropics, as Peninsular Malaysia, deep weathering profiles are found over a variety of bedrock and have developed as a result of prolonged sub-aerial exposure throughout a larger part of the Cenozoic era (Thomas, 1974; Raj, 2009). These deep profiles have thick saprolites (C soil horizons) that are relatively poor in nutrients and thus only marginally suitable or even unsuitable for the cultivation of perennial crops (Hamdan & Burnham, 1997). Physical characterization of two of these weathering profiles has already been described; the first over a porphyritic biotite granite (Raj, 1985), and the second over rhyolite (Raj, 2018). In this paper is described the characterization of a deep weathering profile over a biotite-muscovite granite.

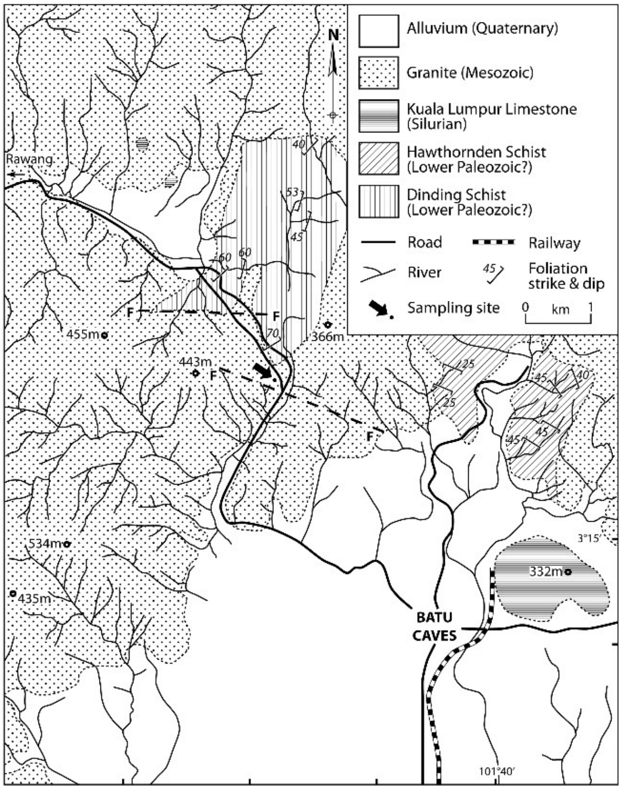

Figure 1: Geological sketch map of the Batu Caves area, Kuala Lumpur (after Gobbett, 1965; Yusari, 1993).

GEOLOGICAL SETTING OF INVESTIGATED WEATHERING PROFILE

The profile is located at a slope cut close to milestone 10 (Km 16) of the Kuala Lumpur - Ipoh trunk road (Federal Route 1) and was exposed during excavation work for its widening (Figure 1 and 2). The cut, at an elevation of 120 m above sea-level, is located in a fluvially dissected hilly terrain of moderate to steep ground slopes with narrow to broad, flat-bottomed valleys, some 3.5 km to the northwest of Batu Caves in Kuala Lumpur (Figure 1). Granitic and meta-sedimentary rocks are present in the general area; the meta-sediments mapped as the Dinding Schist, Hawthornden Schist, and Kuala Lumpur Limestone (Gobbett, 1965). The granites are part of the Kuala Lumpur Pluton which is a large body of irregular shape comprising two lobes located on the western side of the Main Range of Peninsular Malaysia (Cobbing *et al*., 1992). The Pluton has considerable textural and mineralogical variations and mapping of the different lithological variants is difficult (Cobbing *et al*., 1992).

Core-boulders at the cut and nearby outcrops show the bedrock to be a biotite-muscovite granite that has been sheared and strongly fractured as it is located within the Kuala Lumpur Fault Zone. The Kuala Lumpur Fault Zone is some 15 km wide and extends in a general southeast-northwest direction over some 100 km (Ng, 1992). The granite is characterized by mega-crysts of coarse rounded quartz and feldspars set in a groundmass of dark grey, medium to coarse grained, equigranular mosaic of quartz and feldspars and fine biotite and muscovite flakes (Ng *et al*., 2013). Minor late phase differentiates such as microgranite, aplite and pegmatites are sometimes seen as dykes and small

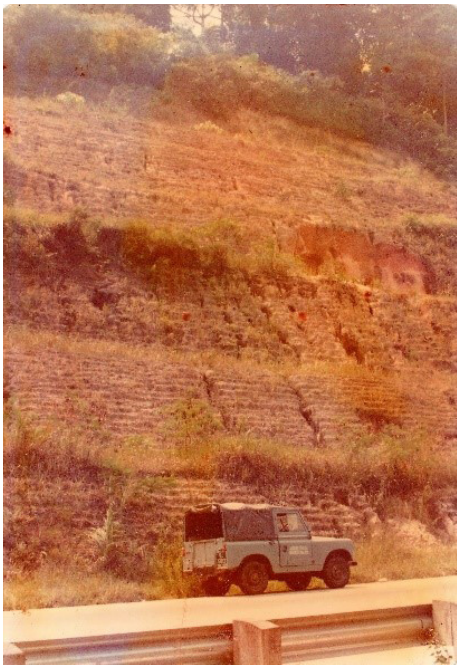

Figure 2: View of exposed weathering profile.

Table 1: Modal analysis of biotite-muscovite granite (Yusari, 1993).

Quartz (%)	Alkali feldspar (AF1) (%)	Plagio-clase (P1) (%)	Mafics (%)	Total feldspar (TF) (%)	(P1/TF) x 100 (%)
27.82	57.14	14.29	0.75	71.43	20

Recalculate to 100%			(AF2/TF) * 100 (%)
Quartz	Alkali feldspar (AF2)	Plagio-clase (P2)	
28.03	57.53	14.39	80

lenticular bodies (Yusari, 1993). A modal analysis based on the counting of 1,000 points of a stained rock slab confirms the biotite-muscovite granite classification (Table 1).

In thin-sections, the granite is holocrystalline with hypidiomorphic to allotriomorphic grains; the primary minerals being quartz, alkali feldspar, plagioclase, muscovite and biotite (Yusari, 1993). The accessory minerals include tourmaline, apatite and opaques, whilst chlorite and epidote are seen as secondary minerals. Quartz occurs as anhedral to subhedral crystals, both as phenocrysts and in the groundmass, and often shows a wavy extinction. Inclusions present include zircon, apatite and muscovite. The alkali feldspars include orthoclase and microcline and are found as euhedral to subhedral crystals, both as phenocrysts and in the groundmass. Plagioclase feldspars generally occur as euhedral to subhedral, tabular crystals that exhibit lamellar albite twins. Extensive sericitization has occurred in the plagioclases as well as in some of the alkali feldspars (Yusari, 1993).

Both primary and secondary muscovite is present; the primary variety occurring as individual, anhedral to subhedral grains, or as aggregates, whilst the secondary variety occurs as fine grains in feldspars due to sericitization. Biotite occurs as anhedral to euhedral individual flakes or as aggregates; some of them having been chloritized. Inclusions of zircon occur as euhedral to subhedral grains in the biotite and feldspars, whilst apatite is sometimes seen in quartz, feldspars and biotite (Yusari, 1993).

Seepage was seen at the foot of the slope cut during excavation works and indicated the presence of an unconfined groundwater table.

METHODOLOGY

Field mapping was first carried out to differentiate weathering zones, i.e. zones of earth materials with similar morphological features as color, relict bedrock minerals, textures and structures as well as litho-relicts (core-stones and core-boulders). In order to better describe the earth materials present, constant volume samples were collected at various depths (Figure 3) to determine their physical and soil index properties. Brass tubes of 4 cm length and 7.6 cm internal diameter were used to collect the samples; the tubes having a constant wall thickness of 0.3 cm except at one end where the lower half tapered to 0.15 cm thick to provide a cutting edge.

The sampling tubes were taken to the laboratory where the moisture contents, unit weights and densities of the samples were first determined before the specific gravity of the constituent mineral grains was measured using a pycnometer (ASTM, 1970). Porosities, void

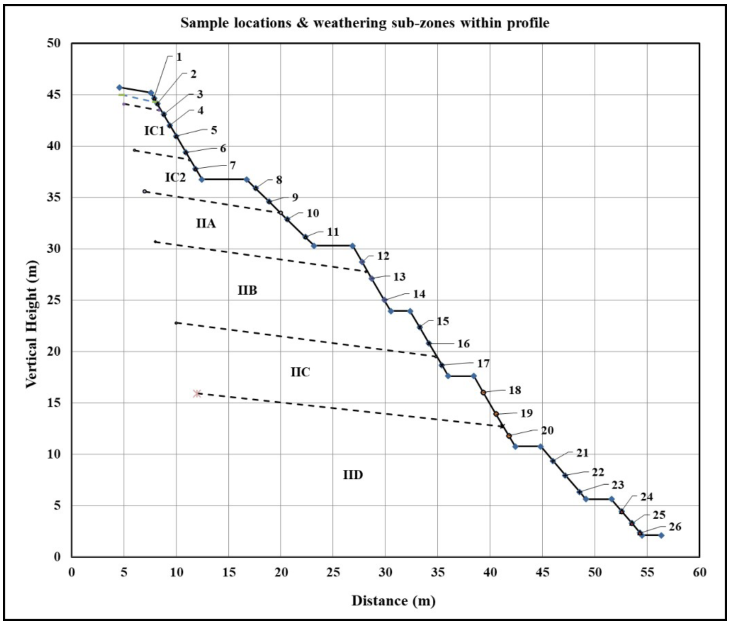

Figure 3: Sample locations and weathering sub-zones within the weathering profile.

ratios and degrees of saturation of the samples were then calculated before the plastic and liquid limits of the fine fractions (<0.42 mm size) were determined (ASTM, 1970). The particle size distributions of the samples were next determined using the sieving, and sedimentation, methods for the coarse (>0.0625 mm diameter), and fine, grained fractions respectively (ASTM, 1970). The main minerals present in the gravel, sand and silt sized fractions were then identified with the aid of a binocular microscope, whilst X-ray diffractograms of the clay fractions were prepared under normal, glycolated, and 500^{o}C heated, conditions to identify the minerals present (Thorez, 1975; Poppe *et al.,* 2001). It is to be noted that in view of a geological background, the definitions of size limits for particles follow the Wentworth (1922) Scale where gravel refers to particles with diameters between 2 and 64 mm, sand to particles with diameters between 0.0625 and 2 mm, silt to particles with diameters between 0.0039 and 0.0625 mm, and clay to particles less than 0.0039 mm in diameter.

WEATHERING ZONES AND ROCK MASS WEATHERING GRADES

Vertical and lateral variations in preservation of the minerals, textures and structures of the original granitic

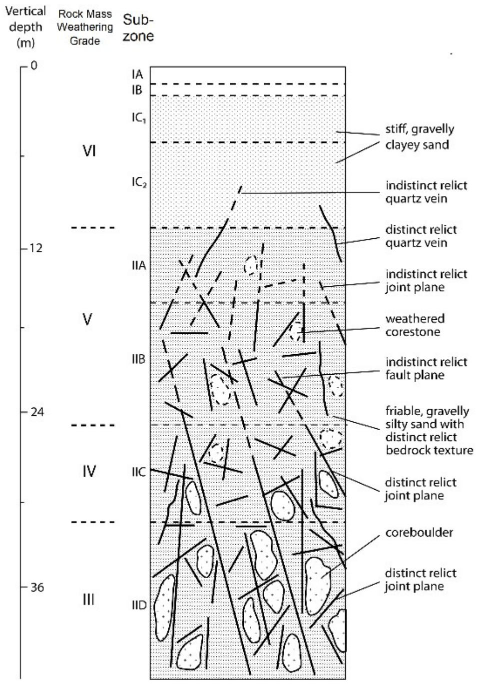

Figure 4: Schematic sketch of morphological features at the weathering profile.

Table 2: Morphological features of weathering sub-zones.

Sub-zone	Vertical depth (m)	Morphological features
IA	0.0-0.7	Yellowish brown, firm, sandy clay. Sub-angular blocky, moist. Friable dry, porous. Some roots & burrows. Boundary irregular, diffuse.
IB	0.7-1.6	Strong brown, gravelly clayey sand. Firm, sub-angular blocky, moist. Friable dry. Some roots. Boundary irregular, diffuse.
IC$_1$	1.6-6.4	Yellowish red to reddish yellow, stiff, gravelly clayey sand. Sub-angular blocky, moist. Friable dry. Boundary irregular, diffuse.
IC$_2$	6.4-11.8	Yellowish red with red & yellow mottles. Stiff, gravelly clayey sand. Sub-angular blocky, moist. Distinct relict granite texture. Indistinct relict quartz veins. Boundary irregular, diffuse.
IIA	11.8-17.5	Friable, gravelly silty sands of yellow & red colors with yellow mottles. Sub-angular blocky, moist. Distinct relict bedrock texture & quartz veins. Indistinct relict joint planes. Some thin bands & wedges of yellowish red gravelly clayey sand. Boundary irregular, diffuse.
IIB	17.5-25.9	Friable, gravelly silty sands of mainly white & yellow colors with some red mottles. Distinct relict bedrock texture, quartz veins & joint planes. Indistinct relict fault planes. Some weathered core-stones. Boundary, irregular, diffuse.
IIC	25.9-32.8	Friable, gravelly silty sands of mainly white & yellow colors. Distinct relict bedrock texture, quartz veins, joint & fault planes. Some core-boulders with weathered rims (<30% by area). Boundary irregular, diffuse.
IID	32.8-43.7	Friable, gravelly silty sands of mainly white & yellow colours. Distinct relict bedrock texture, quartz veins, joint & fault planes. Many core-boulders with weathered rims (>50% by area).

bedrock material and mass allowed differentiation of the pedological soil, and saprock, zones of the pedo-weathering profile concept of Tandarich *et al.* (2002) (Figure 4 and Table 2). The zones are developed approximately parallel to the overlying ground surface and are of maximum thickness below the ridge crest but thin towards the valley sides.

The pedological soil (zone I) is some 11.8 m thick and can be separated into A, B and C soil horizons; the A and B horizons representing the solum, and the C horizon, the saprolite (Table 2). The solum is relatively thin (1.6 m) and consists of brown, friable to firm, gravelly sandy clay, whilst the saprolite is some 10.2 thick and comprises yellowish red, stiff, gravelly clayey sands with indistinct relict granite textures. The saprolite can be separated into upper (IC_1), and lower (IC_2), sub-zones characterized by the absence, or presence, of indistinct relict quartz veins, respectively (Table 2).

The saprock (zone II) is some 31.9 m thick and consists of gravelly silty sands that indistinctly to distinctly preserve the minerals, textures and structures of the original granite; the degree of preservation increasing with depth. This zone can be subdivided into four sub-zones; the upper two sub-zones IIA and IIB consisting of white to yellow and red, friable, gravelly silty sands with distinct relict granite textures and quartz veins, but indistinct to distinct, relict joint and fault planes. The top IIA sub-zone with indistinct relict joint planes is 5.7 m thick and devoid of litho-relicts, whilst the lower IIB sub-zone with distinct relict joint planes, is 8.4 m thick and contains a few weathered core-stones. In the lower sub-zones IIC and IID, small to large core-boulders (litho-relicts) are prominent and separated by thin to broad, bands of white to yellow, friable, gravelly silty sands with distinct relict textures, quartz veins, fracture and fault planes. Core-boulders form less than 30% by area of sub-zone IIC (6.9 m thick), but more than 50% of the lower IID sub-zone (10.9 m thick).

Several schemes have been proposed for assigning rock mass weathering grades (or classes) to weathering zones; the more widely known ones being those by IAEG (1981), ISRM (1981), GCO (1988) and ISRM (2015). In terms of these published schemes, the pedological soil (zone I) would constitute rock mass weathering grade VI, whilst the bottom sub-zone IID with its' many core-boulders would be classified as grade III. Sub-zone IIC would then constitute rock mass weathering grade IV, and sub-zones IIA and IIB, constitute rock mass weathering grade V (Figure 4).

It is to be noted that the earth materials constituting the weathering profile can be classified as "residual soil" in terms of the Earth Manual (USBR, 1974) for their excavation only involved scraping and ripping or "common excavation" according to the Public Works Department of Malaysia (JKR, 2007).

RESULTS

Variations in physical properties

Variations with depth in physical properties are seen, though no distinct pattern can be differentiated for most of them. The dry density of zone I earth materials ranges from 1,222 to 1,801 kg/m^3 and those of zone II from 1,450 to 1,742 kg/m^3 (Table 3). No distinct variation of density with depth can be identified; sub-zone IA being the least dense, and sub-zone IC_1 the densest.

Dry unit weights mirror those of dry density; the zone I earth materials with values of 11.98 to 17.66 kN/m^3 and those from zone II with values of 14.22 to 17.09 kN/m^3 (Table 3). No distinct variation of unit weight with depth can be differentiated; sub-zone IA having the minimum value, and sub-zone IC_1 the largest value.

The specific gravity of soil particles is of limited variation; zone I earth materials with values of 2.62 to 2.70, and those from zone II of 2.63 to 2.65 (Table 3). This limited variation is not unexpected for the main primary and secondary minerals present have closely similar values of specific gravity. Quartz has a specific gravity of 2.65, kaolinite, a specific gravity between 2.61 and 2.68, and sericite a specific gravity between 2.77 and 2.88 (Deer *et al*., 1977).

Porosity is variable with depth; sub-zone IA being the most porous (55%) and sub-zone IC_1 the least porous (33%) (Table 3). The zone II earth materials have a more restricted range in porosity; sub-zone IID with values of 37% to 44%, and the other sub-zones with values of 36% to 41% (Table 3). Values of void ratio mirror those of porosity; sub-zone IA with the largest value (1.21), and sub-zone IC_1 the minimum value (0.50). The earth materials of zone II show a more restricted range in void ratio from 0.56 to 0.73 (Table 3).

Moisture contents are variable with depth; the zone I earth materials with 13.1% to 24.2%, and those from zone II with 10.0% to 20.4% (Table 3). Variations in moisture content give rise to differences in the degree of saturation; the zone I earth materials with values of 54% to 71% and those of zone II with values of 50% to 68% (Table 3). Distinct differences in the degree of saturation with depth are seen; the largest values shown by samples from the clayey sub-zones IC_1 and IC_2 (62% to 71%) and those from the bottom sub-zone IID (66% to 68%).

Variations in soil index properties

Distinct variations with depth in particle size distributions are present; the zone I earth materials with large clay fractions (>19%) and those of zone II with large silt fractions (>22%) (Table 4). Sand contents are more variable; the zone I earth materials with 28% to 37%, and those of zone II with 23% to 44% (Table 4). Total sand and gravel contents range from 37% to 68% (Table 4) and reflect the inherent, coarse texture of the granitic bedrock material.

Silt contents are variable with depth; the zone I earth materials with 7% to 27%, and those of zone II with 22% to 38% (Table 4). Although variable in detail, there is a

Table 3: Physical properties of earth materials in the weathering profile.

Sub-zone	Sample No.	Vertical Depth (m)	Dry Density (kg/m³)	Dry Unit Weight (kN/m³)	Specific Gravity Particles	Porosity (%)	Void Ratio	Water Content (%)	Degree Saturate (%)
IA	1	0.53	1,222	11.98	2.70	55	1.21	24.2	54
IB	2	1.06	1,609	15.78	2.65	39	0.65	15.5	64
IC_1	3	2.11	1,635	16.04	2.66	39	0.63	17.4	74
IC_1	4	3.17	1,654	16.23	2.70	39	0.63	14.9	63
IC_1	5	4.22	1,667	16.35	2.63	37	0.58	13.8	63
IC_1	6	5.81	1,801	17.66	2.70	33	0.50	13.2	71
IC_2	7	7.39	1,700	16.68	2.65	36	0.56	13.1	62
IC_2	8	9.31	1,553	15.24	2.62	41	0.69	17.5	67
IC_2	9	10.60	1,648	16.17	2.70	39	0.64	16.3	69
IIA	10	12.33	1,677	16.45	2.65	37	0.58	12.4	56
IIA	11	14.05	1,617	15.86	2.66	39	0.65	12.1	50
IIA	12	16.50	1,640	16.09	2.65	38	0.62	11.6	50
IIB	13	18.08	1,742	17.09	2.65	34	0.52	10.0	51
IIB	14	20.20	1,660	16.29	2.63	37	0.58	14.8	67
IIB	15	22.84	1,609	15.78	2.64	39	0.64	12.0	49
IIB	16	24.42	1,553	15.23	2.64	41	0.70	16.4	62
IIC	17	26.53	1,677	16.45	2.65	37	0.58	14.7	67
IIC	18	29.17	1,704	16.72	2.65	36	0.56	13.6	65
IIC	19	31.29	1,626	15.96	2.60	37	0.60	14.5	63
IID	20	33.40	1,500	14.71	2.60	42	0.73	15.4	55
IID	21	35.86	1,491	14.63	2.65	44	0.78	20.0	68
IID	22	37.26	1,553	15.23	2.60	40	0.67	17.1	66
IID	23	38.89	1,607	15.76	2.65	39	0.65	16.7	68
IID	24	40.76	1,504	14.76	2.60	42	0.73	18.7	67
IID	25	41.93	1,450	14.22	2.60	44	0.79	20.4	67
IID	26	42.86	1,660	16.28	2.65	37	0.60	13.8	61

general increase of silt contents with depth; this increase reflecting an increase in content of primary and secondary sericites (Table 5).

Clay contents are also variable with depth; the zone I earth materials with 19% to 55%, and those of zone II with 9% to 20% (Table 4). There is a distinct increase in clay contents up the profile; an increase that coincides with a corresponding decrease in silt contents. Increasing effects of weathering up the profile are thus reflected by increasing clay contents due to increasing disaggregation of silt sized particles.

Consistency limits are of limited variation with the plastic limits of zone I earth materials ranging from 23.6% to 31.5%, and those of zone II from 20.5% to 34.9% (Table 4). Liquid limits furthermore, could only be determined for samples from zone I and sub-zone IIA; the large silt contents (>21%) of the other samples preventing the proper excavation of grooves when employing the Atterberg device.

Table 4: Soil index properties of earth materials in the weathering profile.

Sub-zone	Sample Number	Vertical Depth (m)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Plastic Limit	Liquid Limit	Textural Weathering Index (I_w)
IA	1	0.53	2	35	8	55	31.5	74.0	0.87
IB	2	1.06	23	37	7	33	30.9	79.7	0.83
IC$_1$	3	2.11	22	28	18	32	29.7	74.0	0.64
IC$_1$	4	3.17	19	34	21	26	28.3	67.3	0.55
IC$_1$	5	4.22	27	36	14	23	26.9	59.5	0.62
IC$_2$	6	5.81	31	29	20	20	25.0	57.2	0.50
IC$_2$	7	7.39	20	43	18	19	23.6	51.8	0.51
IC$_2$	8	9.31	19	39	23	19	25.1	51.7	0.45
IC$_2$	9	10.60	27	36	18	19	23.8	45.7	0.51
IIA	10	12.33	26	31	30	13	21.9	44.0	0.30
IIA	11	14.05	26	42	22	10	21.6	36.5	0.31
IIA	12	16.50	21	38	28	13	27.3	ind	0.32
IIB	13	18.08	30	35	23	12	25.3	ind	0.34
IIB	14	20.20	15	40	29	16	24.5	ind	0.36
IIB	15	22.84	24	39	28	9	23.8	ind	0.24
IIB	16	24.42	25	44	21	10	20.5	ind	0.32
IIC	17	26.53	33	27	22	18	21.8	ind	0.45
IIC	18	29.17	34	23	32	11	22.1	ind	0.26
IIC	19	31.29	31	24	25	20	21.6	ind	0.44
IID	20	33.40	28	25	37	11	22.6	ind	0.23
IID	21	35.86	21	37	30	12	28.1	ind	0.29
IID	22	37.26	28	27	36	9	30.0	ind	0.20
IID	23	38.89	33	25	23	19	30.9	ind	0.45
IID	24	40.76	23	35	32	10	32.0	ind	0.24
IID	25	41.93	24	28	38	10	34.9	ind	0.21
IID	26	42.86	31	26	34	9	30.7	ind	0.21

Note: Textural Weathering Index (Iw) = (% clay)/(% clay + % silt)

Variations in mineralogy

Binocular microscope examination of the silt, sand and gravel fractions show differences in mineral compositions that point to the increasing effects of weathering processes up the profile (Table 5). The silt sized fractions all consist of sericite flakes with samples from zone II also containing some larger muscovite flakes (Table 5). The absence of larger muscovite flakes in the zone I samples, and the decrease in silt contents up the profile, indicates their continued disaggregation due to increasing effects of weathering processes.

The sand fractions of zone I mainly comprise pink to red stained quartz grains, whilst those of the lower sub-zones IIC and IID consist of vitreous quartz grains and some white (kaolinized) to cloudy (fresh) feldspar grains (Table 5). The sand fractions of sub-zones IIA and IIB, however, consist of both stained and vitreous quartz grains as well as some, white (kaolinized) feldspar grains. The absence of fresh feldspar grains in sub-zones IIA and IIB indicates their decomposition to sericite and kaolinite; a feature marked by the increase in silt and clay contents. The stained quartz grains of zone

Table 5: Minerals in different size fractions in the weathering profile.

Sub-zone	Gravel (2.00-6.00 mm)	Sand (0.0625-2.00 mm)	Silt (0.0039-0.0625 mm)	Clay (<0.0039 mm)
IA	None	Angular, vitreous quartz grains; some stained red	Sericite flakes	Kaolinite & Illite
IB	Angular, quartz grains.	Angular, vitreous quartz grains; many stained red	Sericite flakes	Kaolinite & Illite
IC_1	Angular, quartz grains.	Angular, vitreous quartz grains; mostly stained pink to red	Sericite flakes	Kaolinite & Illite
IC_2	Angular, quartz grains.	Angular, vitreous quartz grains; mostly stained pink to red	Sericite flakes	Kaolinite & Illite
IIA	Angular, quartz grains	Angular, vitreous quartz grains (some stained red) with a few white (kaolinized) feldspar grains	Sericite & muscovite flakes	Kaolinite & illite
IIB	Angular, quartz grains	Angular, vitreous quartz grains with some white (kaolinized) feldspar grains	Sericite & muscovite flakes	Kaolinite & Illite
IIC	Angular, quartz grains	Angular, vitreous quartz grains with many, white (kaolinized) & a few cloudy (fresh) feldspar grains.	Sericite & muscovite flakes	Kaolinite & Illite
IID	Angular, quartz grains	Angular, vitreous quartz grains with many, cloudy (fresh) & rare white (kaolinized) feldspar grains	Sericite & muscovite flakes	Kaolinite & Illite

I and upper zone II furthermore, indicate the downward movement of secondary iron hydroxides by pedological processes. The sand and gravel sized quartz grains do not appear to show any alteration (or decomposition), though they have experienced physical disaggregation as indicated by variable sand and gravel contents.

X-ray diffractograms show kaolinite and illite to be the only clay minerals present (Table 5). Kaolinite is the predominant clay mineral and identified by the 7.20 Å and 3.59 Å peaks on the untreated diffractograms; the 7.20 Å peak still present on the glycolated diffractograms, but absent in the 500°C heated diffractograms (Figure 5). Illite is present in limited amounts and identified by the 10.05 Å, 4.90 Å and 3.35 Å peaks on the untreated diffractograms; the 10.05 Å peak still present in the glycolated, and 500°C heated, diffractograms (Figure 5). Increasing heights of the 7.20 Å and 3.59 Å peaks up the profile furthermore, indicate increasing kaolinite contents due to increasing effects of weathering (Figure 5).

Variations in preservation of joint and fault planes

Field observations show variations with depth in preservation of the joint and fault planes inherent in the original granitic bedrock mass. Joint planes are seen indistinctly preserved in sub-zone IIA, but distinctly preserved in sub-zones IIB, IIC and IID, whilst fault planes are indistinctly preserved in sub-zone IIB and distinctly preserved in sub-zones IIC and IID (Figure 4 and Table 2). Relict joint and fault planes, however, are not observed within the earth materials of the pedological soil (Table 2).

The indistinctly preserved joint planes are seen as vague planar surfaces of limited extents that demarcate blocks of *in situ* ‘highly’ to ‘very highly’ weathered granite, whilst the indistinctly preserved fault planes are similar in appearance but of longer extent and bordered by blocks of *in situ* ‘moderately’ to ‘highly’ weathered granite. The distinctly preserved joint and fault planes, however, are definite planes of separation demarcating blocks of *in situ* ‘slightly’ to ‘moderately’ weathered granite. Preservation of the discontinuity planes is thus dependent on the extent of *in situ* alteration of the bounding granite blocks; the less weathered granite allowing distinct preservation and the more weathered granite allowing indistinct preservation.

Variations in degree of weathering of rock material

Application of physical criteria to define the degree of weathering of ‘rock’ material at the present weathering profile is not practical as they predominantly comprise friable, gravelly silty sands (Table 2). Application of chemical weathering indices to define the degree of

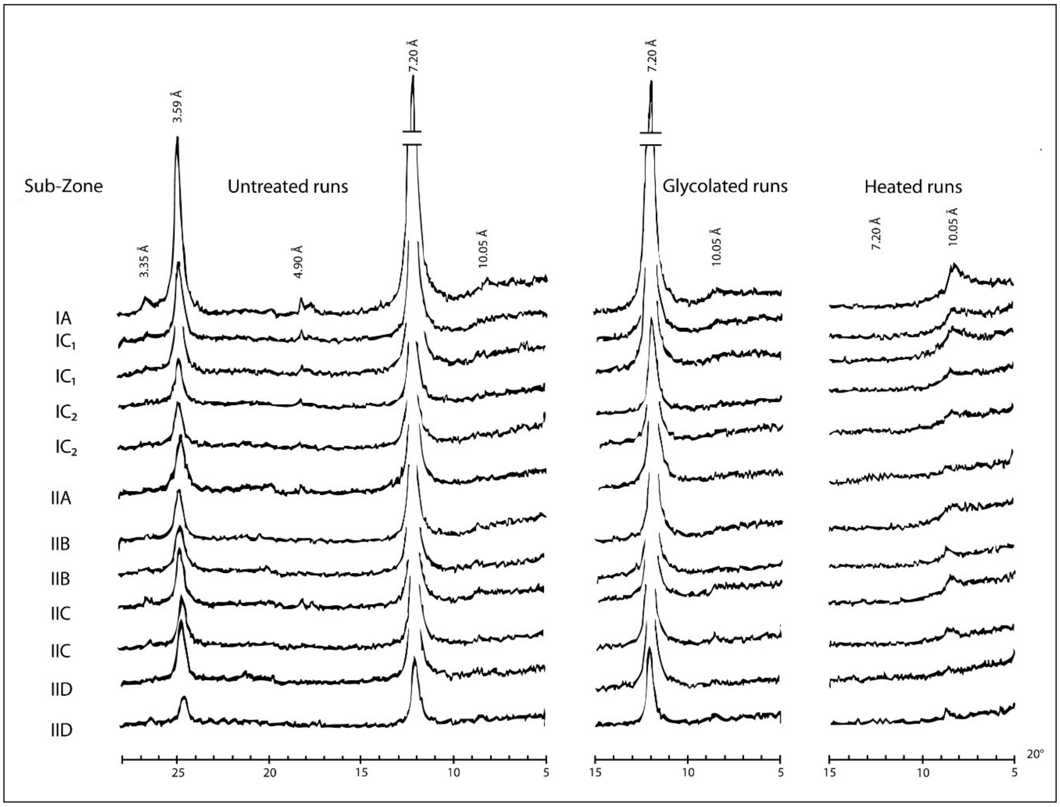

Figure 5: X-ray diffractograms of clay fractions in the weathering profile.

weathering is also not practical as they have been leached by the downward migration of an unconfined groundwater table (that is now present at the bottom of the slope cut). A study of three deep weathering profiles over basalt, granite and schist in Peninsular Malaysia has furthermore, concluded that they had remarkably similar physico-chemical properties despite differences in parent material (Hamdan & Burnham, 1996).

In view of these limitations, a textural weathering index (I_w) was proposed to describe the degree of weathering of rock material in earth materials at a weathering profile over rhyolite in Peninsular Malaysia (Raj, 2018). This Index, based on the ratio of the clay to total silt and clay contents, was proposed as there was an increase in clay contents (of illite and kaolinite) up the profile, but a corresponding decrease in silt contents (of mainly sericite).

A similar pattern of increasing clay contents upwards, and a corresponding decrease in silt contents is also seen at the present profile; the textural weathering index clearly differentiating the earth materials of the pedological soil (I_w >0.50) from saprock (I_w <0.40) (Table 4). A general increase in the textural weathering index up the profile furthermore, quantitatively describes an increasing degree of weathering (or alteration) of the granitic rock material. Abrupt variations in the index, however, are present and reflect inherent textural differences within the original granitic rock material and mass.

DISCUSSION

Comparison with published literature

Variations with depth in physical properties of earth materials at the present profile are very similar to those in the weathering profiles over porphyritic biotite granite (Raj, 1985) and rhyolite (Raj, 2018). Ranges in values of dry density as well as dry unit weights are similar for all three profiles, though the present profile does not show the distinct upward decrease in density and unit weight seen in the other two profiles. This difference is due to the biotite-muscovite granite having more variable textures due to its location within the Kuala Lumpur Fault Zone. The specific gravity of soil particles in all three profile is closely similar in view of the similarity of primary and secondary minerals. The zone II earth materials of all three profiles also show a general increase in porosity and void ratio upwards; a feature indicating the increasing effects of weathering processes.

Variations with depth in particle size distributions of earth materials at the present profile are generally similar to those in the weathering profiles over porphyritic biotite granite (Raj, 1985) and rhyolite (Raj, 2018). Gravel contents (15% to 34%), however, are greater than those at the other two profiles (<17%), whilst the sand contents (23% to 44%) are relatively lower (33% to 66%). These differences are considered to reflect inherent textural variations between the present, coarse grained, biotite-muscovite granite, the medium grained, porphyritic biotite granite and the fine grained, rhyolite. Silt contents (7% to 38%) and their zonal variations are similar in all three profiles; there also being the same upward decrease in silt contents due to their continued disaggregation. Clay contents (9% to 32%) and their zonal variations are also quite similar in all three profiles; the same upward increase in clay contents reflecting increasing disaggregation of silt sized particles.

The main minerals (quartz and sericite) in the gravel, sand and silt sized fractions of earth materials at the present profile are exactly similar to those in the weathering profiles over porphyritic biotite granite (Raj, 1985) and rhyolite (Raj, 2018). This similarity is expected in view of the same primary minerals present in all three acidic igneous bedrock varieties. Variations with depth in the textural weathering index (I_w) at the present profile are similar to those in the profile over rhyolite (Raj, 2018) with similar distinct differences between the pedological soil (I_w >0.50) and saprock (I_w <0.40). Within saprock, however, the weathering index shows some abrupt changes due to textural variations in the biotite-muscovite granite which is located within the Kuala Lumpur Fault Zone. Location within the fault zone has led to much shearing and fracturing of the granite; a feature that results in its' limited content of litho-relicts (core-boulders) as compared with the profiles over porphyritic biotite granite (Raj, 1985) and rhyolite (Raj, 2018).

In situ weathering of bedrock material and mass

The presence of the pedological soil, and saprock, zones of the pedo-weathering profile concept of Tandarich *et al.* (2002) substantiates the view of Carroll (1970) that chemical weathering at the outer part of the lithosphere takes place in two stages; the first stage being the production of decomposed rocks, on which the second stage, soil formation, takes place. The pedological soil thus results from alteration of bedrock by both geochemical and pedological processes, whilst the saprock results from alteration of bedrock by geochemical processes.

Indistinct preservation of granitic texture in the gravelly clayey sands of saprolite (sub-zone IC_2), and its distinct preservation in the gravelly silty sands of saprock (zone II) clearly point to *in situ* development of the earth materials at the present weathering profile (Table 2 and Figure 4). *In situ* weathering is furthermore, amplified by the indistinct to distinct preservation of joint and fault planes of the original bedrock mass in the gravelly silty sands of saprock (Figure 4). Increasing *in situ* alteration of granitic rock material up the profile is also marked by an increase in clay contents (of secondary kaolinite and illite) and a corresponding decrease in silt contents (of mainly primary and secondary sericite). Remnants or litho-relicts of the original bedrock mass finally are seen as core-stones and core-boulders surrounded by gravelly silty sands in sub-zones IIC and IID of the weathering profile (Figure 4).

The presently exposed weathering profile is thus considered to result from *in situ* weathering of a coarse grained, biotite-muscovite granitic rock mass; the earth materials of saprock (zone II) reflecting alteration of granitic rock material by geochemical processes, and those of the pedological soil (zone I) by both geochemical and pedological processes. *In situ* weathering of the granitic bedrock material and mass has occurred due to a long continued, downward migration of an unconfined groundwater table (now seen at the bottom of the profile).

CONCLUSIONS

The weathering profile can be separated into an upper, 11.8 m thick pedological soil (zone I) comprising gravelly clayey sands and a lower, 31.9 m thick saprock (zone II) consisting of gravelly silty sands that indistinctly to distinctly preserve the minerals, textures and structures of the original granitic (rock) material and mass. Zone I can be separated into A, B and C soil horizons, whilst zone II can be differentiated into sub-zones IIA, IIB, IIC and IID, based on differences in preservation of relict structures and content of core-boulders. The earth materials of zone I represent rock mass weathering grade VI, whilst those of sub-zones IIA and IIB represent grade V, and those of sub-zones IIC and IID represent grades IV and III respectively.

Constant volume samples show the earth materials of zones I and II to have variable dry densities as well as variable dry unit weights. Soil particles have a limited range in specific gravity (2.62 to 2.70) due to common primary and secondary minerals. The zone I earth materials are also more porous (33% to 55%) than those of zone II (36% to 44%) and have large clay contents (>19%) whilst those of zone II have large silt contents (>23%). Sand contents are more variable (23% to 44%); the relatively large total sand and gravel contents (37% to 68%) reflecting the inherent, coarse grained granitic rock material. Increasing clay contents (of kaolinite and illite) up the profile, and a corresponding decrease in silt contents (of mainly sericite), reflect increasing alteration of granitic rock material; a feature also shown by increasing values of the textural weathering index (I_w).

The presently exposed weathering profile results from in situ weathering of a sheared, coarse grained, biotite-muscovite granite (rock) mass; the earth materials of saprock (zone II) reflecting alteration of granitic rock material by geochemical processes, and those of the pedological soil (zone I) by both geochemical and pedological processes.

ACKNOWLEDGEMENTS

Grateful thanks are extended to the University of Malaya for an F-Vote Research Grant that supported this study. Grateful thanks are also extended to the two anonymous reviewers for their valuable comments on the initial submission.

CONFLICT OF INTEREST

The author has no conflicts of interest to declare that are relevant to the contents of this article.

REFERENCES

ASTM, American Society for Testing and Materials, 1970. Special Procedures for Testing Soil and Rock for Engineering Purposes. Special Publication 479, American Society for Testing and Materials, Philadelphia, 630 p.

Aydin, A., 2006. Stability of saprolitic slopes: nature and role of field scale heterogeneities. Natural Hazards Earth System Sciences, 6, 89-96.

Baynes, F.J., Dearman, W.R. & Irfan, T.Y., 1978. Practical assessment of grade in a weathered granite. Bulletin International Association Engineering Geology, 18, 101-109.

Carroll, D., 1970. Rock Weathering. Plenum Press, New York, 203 p.

CEB, Central Electricity Board of the Federation of Malaya, 1962. Report on Batang Padang Hydro-electric Scheme. Volume 3, Geological Investigations. Preece, Cardew & Rider, Consulting Engineers, London S.W.1., 50 p.

Cobbing, E.J., Pitfield, P.E.J., Darbyshire, D.P.F. & Mallick, D.I.J., 1992. The granites of the southeast Asian Tin Belt. British Geological Survey Overseas Memoir 10, 369 p.

Dearman, W.R., 1974. Weathering classification in the characterization of rock for engineering purposes in British practice. Bulletin International Association Engineering Geology, 9, 33-42.

Dearman, W.R., 1976. Weathering classification in the characterization of rock - A review. Bulletin International Association Engineering Geology, 13, 123-127.

Deer, W.A., Howie, R.A. & Zussman, J., 1977. An Introduction to the Rock Forming Minerals. Longman Group Limited, London, 528 p.

Deere, D.V. & Patton, F.D., 1971. Slope stability in residual soils. Proceedings 6th Pan-American Conference Soil Mechanics & Foundation Engineering Puerto Rico, 1, 87-170.

GCO, Geotechnical Control Office, 1988. Guide to Rock and Soil Descriptions, Geoguide 3. Geotechnical Control Office, Hong Kong, 186 p.

Gobbett, D.J., 1965. The Lower Palaeozoic rocks of Kuala Lumpur, Malaysia. Federation Museums Journal, 9, 67-79.

Hamdan, J. & Burnham, C.P., 1996. The contribution of nutrients from parent materials in three deeply weathered soils of Peninsular Malaysia. Geoderma, 74, 219-233.

Hamdan, J. & Burnham, C.P., 1997. Physico-chemical characteristics of three saprolites in Peninsular Malaysia. Communications Soil Science & Plant Analysis, 28, 1817-1834.

IAEG, International Association Engineering Geology, 1981. Rock and soil description for engineering geological mapping. Bulletin International Association Engineering Geology, 24, 235-274.

ISRM, International Society for Rock Mechanics, 1981. Rock Characterization, Testing and Monitoring: ISRM Suggested Methods, T. Brown (Ed.), 211 p.

ISRM, International Society for Rock Mechanics, 2015. The ISRM Suggested Methods for Rock Characterization, Testing and Monitoring: 2007-2014, 2015 Edition, R. Ulusay (Ed.), 211 p.

Irfan, T.Y. & Dearman, W.R., 1978. The engineering petrography of a weathered granite in Cornwall, England. Quarterly Journal Engineering Geology, 11, 233-244.

JKR, Jabatan Kerja Raya Malaysia, Public Works Department Malaysia, 2007. Guidelines for hard material/rock excavation. Technical Note (Roads) 24/05, Road Division Jabatan Kerja Raya Malaysia, 15 p.

Lan, H.X., Hu, R.L., Yue, Z.Q., Fee, C.F. & Wang, S.J., 2003. Engineering and geological characteristics of granite weathering profiles in South China. Journal Asian Earth Sciences, 21, 353-364.

Lee, S.G. & de Freitas, M.H., 1989. A revision of the description and classification of weathered granite and its application to granites in Korea. Quarterly Journal Engineering Geology, 22, 31-48.

Little, A.L., 1969. The engineering classification of residual tropical soils. Proceedings 7th International Conference Soil Mechanics & Foundation Engineering, Mexico, 1, 1-10.

Martin, C.P. & Hencher, S.R., 1986. Principles for description and classification of weathered rock for engineering purposes. In: Hawkins, A.B. (Ed.), Site Investigation Practice, Assessing BS 5930, Engineering Geology Special Publication 2, Geological Society London, 299-308.

Moye, D.G., 1955. Engineering geology for the Snowy Mountains scheme. Journal Institution Engineers Australia, 27, 287-298.

Ng, T.F., 1992. Petrography, structure and geotechnical studies of the Kuala Lumpur Granite, eastern part of Kuala Lumpur, Peninsular Malaysia. M.Phil. Thesis, Institute for Advanced Studies, University of Malaya, 527 p.

Ng, T.F., Raj, J.K. & Azman A. Ghani, 2013. Potential Alkali-Reactivity of granite aggregates in the Bukit Lagong, area, Selangor, Peninsular Malaysia. Sains Malaysiana, 42, 773-781.

Poppe, L.J., Paskevich, V.F., Hathaway, J.C. & Blackwood, B.S., 2001. A Laboratory Manual for X-Ray Powder Diffraction. United States Geological Survey Open-File Report 01-041. 88 p.

Rahardjo, H., Aung, K.K., Leong, E.C. & Rezaur, R.B., 2004. Characteristics of residual soils in Singapore as formed by weathering. Engineering Geology, 73, 157-169.

Raj, J.K., 1985. Characterization of the weathering profile developed over a porphyritic biotite granite bedrock in Peninsular Malaysia. Bulletin International Association Engineering Geology, 32, 121-128.

Raj, J.K., 2009. Geomorphology. In: Hutchison, C.S. & Tan, D.N.K. (Eds.), Geology of Peninsular Malaysia. University of Malaya & Geological Society of Malaysia, Kuala Lumpur. 5-29.

Raj, J.K., 2018. Physical characterization of a deep weathering profile over rhyolite in humid tropical Peninsular Malaysia. Geotechnical & Geological Engineering, 36, 3793-3809.

Ruxton, B.P. & Berry, L., 1957. The weathering of granite and associated erosional features in Hong Kong. Bulletin Geological Society of America, 68, 1263-1292.

Tandarich, J.P., Darmody, R.G., Follmer, L.R. & Johnson, D.L.,

2002. Historical development of soil and weathering profile concepts from Europe to the United States of America. Journal Soil Science Society of America, 66, 335-346.

Thorez, J., 1975. Phyllosilicates and Clay Minerals – A Laboratory Handbook for Their X-Ray Diffraction Analysis. G. Lelotte, Belgium, 582 p.

Thomas, M.F., 1974. Tropical Geomorphology – A study of weathering and landform development in warm climates. MacMillan Press Limited, London, 332 p.

USBR, United States Bureau of Reclamation, 1974. Earth Manual. United States Government Printing Office, Washington, 810 p.

Wentworth, C.K., 1922. A scale for grade and class terms for clastic sediments. Journal Geology, 30, 377-392.

Yusari, H.B., 1993. Geology of Batu Dam-Kancing area with emphasis on geochemistry and petrology of granitic rocks. B.Sc. (Hons) Dissertation, Department of Geology, University of Malaya, 142 p.

Manuscript received 7 September 2022;
Received in revised form 13 April 2023;
Accepted 15 April 2023
Available online 26 May 2023