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Soil moisture retention characteristics of saprock from the weathering profile over a biotite-muscovite granite in Peninsular Malaysia

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Abstract: The weathering profile at the slope cut near Km 16 of the Kuala Lumpur - Ipoh trunk road can be differentiated into an upper, 11.8 m thick pedological soil (zone I) and a lower, 31.9 m thick saprock (zone II) comprising silty sandy gravels that distinctly preserve the minerals, textures and structures of the original granite. In order to investigate the influence of particle size distributions on soil moisture retention characteristics, saprock samples were collected at depths of 26.53 m (Sample A), 31.29 m (Sample B) and 41.93 m (Sample C). Samples A and B, with porosities of 37%, comprise 33% gravel, 27% sand, 22% silt and 18% clay, and 31% gravel, 24% sand, 25% silt and 22% clay, respectively. Sample C with a porosity of 44% consists of 24% gravel, 28% sand, 38% silt and 10% clay. Tests with the pressure plate method show increasing suctions from 0 kPa through 0.98 kPa and 9.8 kPa to 33 kPa and 1,500 kPa to result in gravimetric soil moisture retentions of 31.9% through 28.6% and 23.3% to 16.9% and 6.8% in sample A, of 32.1% through 24.9% and 21.5% to 17.8% and 7.4% in sample B, and of 31.5% through 30.3% and 27.30% to 23.5% and 9.5% in sample C. Regression analyses of gravel, sand and clay contents plotted against moisture contents retained at high suctions (33 kPa and 1,500 kPa) yield negative trends with variable correlation coefficients (R^2), though plots involving silt contents yield positive trends with large correlation coefficients (R^2 >0.9966). It is concluded that adsorption of water on surfaces of silt sized particles (of mainly sericite derived from weathering of feldspars) that gives rise to the retention of soil moisture in saprock.

Keywords: Biotite-muscovite granite, saprock, soil moisture retention, silt content

INTRODUCTION

Deep weathering profiles (several tens of meters thick) are found in Peninsular Malaysia as a result of favorable tectonic and environmental factors that have facilitated pervasive chemical weathering during a larger part of the Cenozoic era (Raj, 2009). The profiles are found over a variety of bedrock and characterized by the indistinct to distinct preservation of the minerals, textures and structures of the original bedrock material and mass. As the earth materials of the profiles are "able to be removed by commonly accepted excavating methods", they are known as residual soils in geotechnical literature in the Peninsula (USBR, 1974; JKR, 2007). These residual soils are considered to be unsaturated soils as they are located above unconfined groundwater tables that are only found at the base of weathering profiles in the hilly to mountainous terrain of the Peninsula (Faisal *et al*., 2005; Bujang *et al*., 2005a; Raj, 2009).

Unsaturated soils are characterized by the presence of negative pore water pressures; the relationship between negative pore pressures and moisture content expressed by the soil water characteristic curve (Agus *et al*., 2001). The soil water characteristic curve or soil moisture retention curve is considered to be a fundamental relationship that should be determined in investigations of unsaturated soils (Vanapalli *et al*., 1996). The soil moisture retention curve is also of importance in agriculture where it is essential to the development of effective irrigation and plant stress management techniques as suction/water relationships directly affect the yield and quality of crops (Scherer *et al*., 1996).

In Peninsular Malaysia, there is limited published data on the soil moisture retention characteristics of its unsaturated residual soils, especially those over granitic bedrock. In a study to evaluate the hydraulic conductivity of saprolite (IC soil horizon), samples were collected from 16 locations in the Peninsula and their soil moisture retention curves determined with the pressure plate method (Hamdan *et al*., 2006). Increasing suctions from 0 kPa to 1,500 kPa resulted in decreasing volumetric soil moisture retentions from 60% to 11% in the case of a granite saprolite, from 47% to 19% in the case of a schist saprolite, from 82% to 30% in the case of a shale saprolite, and from 94% to 35% in the case of a basalt saprolite (Hamdan *et al*., 2006).

Another study, also involving the pressure plate method, showed saprolite (IC soil horizon) of a weathering profile over porphyritic biotite granite to experience decreasing gravimetric moisture contents from 34.5% to 18.0% with increasing suctions from 0 kPa to 1,500 kPa (Raj, 2010). Saprock samples from sub-zones IIB and IID at this weathering profile also experienced decreasing moisture contents from 34% to 6.4%, and from 26.8% to 3.9%, respectively, with increasing suctions from 0 kPa to 1,500 kPa (Raj, 2010). In the study, it was noted that the earth materials present varied with depth in not only texture and mineral compositions, but also in the extent of preservation of the original bedrock minerals, textures and structures. It was thus emphasized that discussions on the physical and soil index properties of earth materials in weathering profiles (and residual soils), as well as their soil moisture retention characteristics, be carried out with reference to the locations of samples (Raj, 2010).

There is also limited published data on the soil moisture retention characteristics of earth materials in neighboring, humid tropical areas. A study involving residual soils over the sedimentary Jurong Formation and the Bukit Timah Granite in Singapore Island concluded that the depth of weathering did not have a consistent effect on their soil water characteristic curves, though soils over the granite had a wider range of pore sizes (Agus *et al.*, 2001). Several multi-variate empirical equations using a number of basic soil properties were also proposed in this study to estimate the soil water characteristic curves of Singapore residual soils (Agus *et al.*, 2001).

Published literature on topics related to soil moisture retention characteristics in Malaysia include a paper that discusses modifications to the standard shear box that allowed testing of samples under unsaturated conditions (Bujang *et al.*, 2005a). Results of a series of direct shear tests with fixed suction on samples of saprolite (soil horizon IC) from a weathering profile over porphyritic biotite granite led to the conclusion that suction played a role in increasing the shear strength of unsaturated soil, though there was a non-linear failure envelope due to the non-linear soil water characteristic curve (Bujang *et al.*, 2005b; Thamer *et al.*, 2006).

As a part of a study to characterize weathering profiles in Peninsular Malaysia was investigated the profile developed over biotite-muscovite granite that outcrops in the north-west of Kuala Lumpur (Raj, 1983). In this paper are presented the results of laboratory tests carried out to investigate the influence of particle size distributions on soil moisture retention characteristics of saprock at the profile.

GEOLOGICAL SETTING OF INVESTIGATED WEATHERING PROFILE

The investigated profile is located at the slope cut close to milestone 10 (Km 16) of the Kuala Lumpur - Ipoh trunk road (Federal Route 1) and was exposed during earthworks for widening of the road. The cut, at an elevation of 120 m above sea-level, is found 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).

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. This Fault Zone is about 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 lenticular bodies (Yusari, 1993).

In thin-sections, the granite is holocrystalline with hypidiomorphic to allotriomorphic grains; the primary

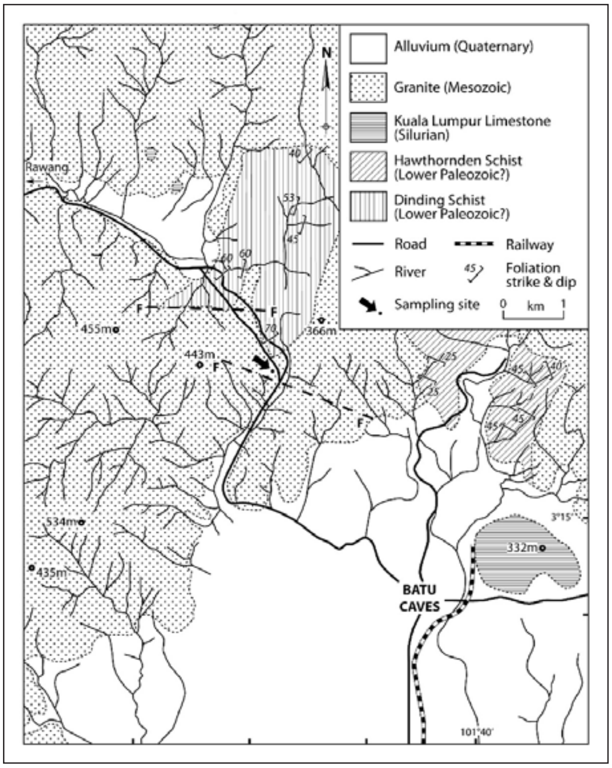

Figure 1: Geological sketch map of the Batu Caves area, Kuala Lumpur (after Gobbett, 1965; Yusari, 1993).

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 at the bottom of the exposed weathering profile.

METHODOLOGY

Tape and compass traverses were first carried out along all berms of the slope cut to describe the exposed earth materials in terms of the Soil Survey Manual for Malayan Conditions (Leamy & Panton, 1966) and the Guidelines for Soil Description of the Food and Agriculture Organization (FAO, 2006). Pedological features that were described included the colour, consistency and soil structure of the earth materials as well as their content of concretions, stains and organic matter. Geological features were also mapped and described, in particular the minerals, textures and structures of the original bedrock material and mass now indistinctly to distinctly preserved (as relict minerals, textures and structures) in the earth materials. Lateral similarity in pedological and geological features was then used to distinguish 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) (Table 1 and Figure 2).

Table 1: 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 textures & 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 colours with some red mottles. Distinct relict bedrock textures, 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 colours. Distinct relict bedrock textures, quartz veins, joint & fault planes. Many partly weathered to fresh core-boulders (<30% by area). Boundary irregular, diffuse.
IID	32.8-43.7	Friable, gravelly silty sands of mainly white & yellow colours. Distinct relict bedrock textures, quartz veins, joint & fault planes. Many, partly weathered to fresh core-boulders (>50% by area).

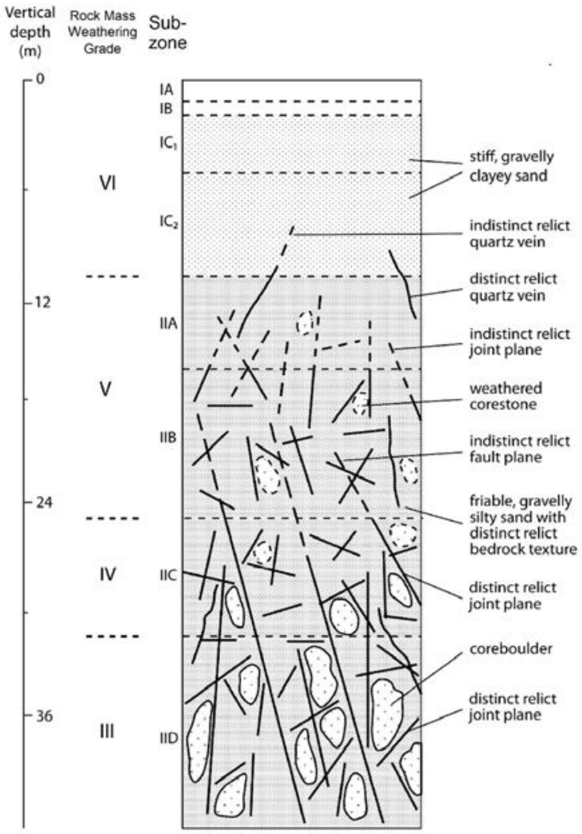

Figure 2: Schematic sketch of morphological features at the weathering profile.

Brass rings of 4 cm length and 7.6 cm internal diameter were then used to collect constant volume samples from *in situ* weathered granite (saprock) at depths of 26.53 m, 31.29 m and 41.93 m (Figure 3). The rings had 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. A brass ring was first driven into the soil by hammering gently on its top until the top was flush with the ground surface. A second brass ring, with its cutting edge facing upwards, was then placed on the top of the first ring which was then driven deeper into the soil by gently hammering on the top of the second ring; a piece of wood placed over the second ring to minimize damage and disturbance of the sample. Both rings were then dug out from the ground by excavating the surrounding and underlying soil. The sample in the upper ring was discarded whilst the sample in the lower ring was trimmed and sealed with rubber discs that were held in place by screwed-on metal plates. Prior to sampling, the rings were externally greased to facilitate entry into the soil, whilst materials on the slope were excavated to a depth of some 0.5 m to minimize surface disturbance. Prior to sampling, the soil was also trimmed into an approximately cylindrical shape, slightly larger than the ring diameter, to reduce

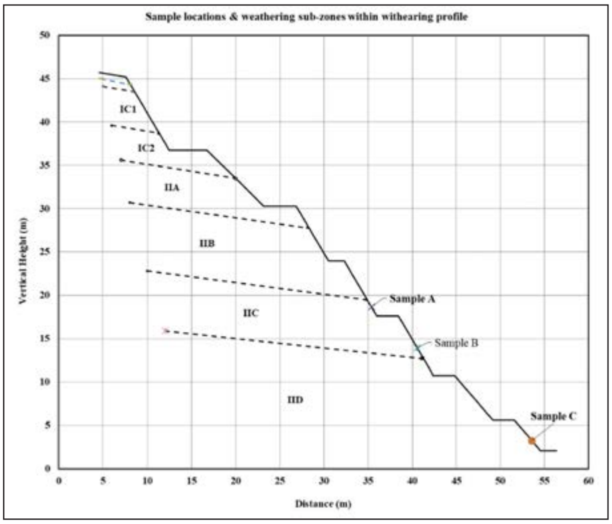

Figure 3: Sample locations and weathering sub-zones.

lateral compaction. Two constant volume samples were collected at each sampling point; one for determination of its physical and soil index properties, and the other for determination of its soil moisture retention characteristics.

The sample rings were transported to the laboratory where the moisture contents, unit weights and densities of one set of samples were determined before the specific gravity of constituent mineral grains was measured using a pycnometer (ASTM, 1970). Porosities, void ratios and degrees of saturation of the samples were then calculated before the plastic 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 (<0.0625 mm), 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 the size limits for soil particles is based on 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.

Samples from the second set of brass rings were extracted in the laboratory and cut into five pieces of about similar volumes which were then saturated by allowing them to stand in water overnight. The moisture content of one of the five saturated samples was determined, whilst the remaining samples were placed on water saturated ceramic porous plates in four separate chambers. The air pressures in the pressure chambers were then adjusted to subject the samples to different pressures; the lower side of the porous plates being exposed to atmospheric pressure. The pressures were kept constant for one week until the overflow of excess water had stopped. After release of the pressures, the samples were removed and their moisture contents determined. The pressure plate tests were carried out at the Soils Laboratory of Universiti Pertanian Malaysia (now Universiti Putra Malaysia) where such tests were being routinely carried out for agricultural soil surveys.

WEATHERING ZONES AND ROCK MASS WEATHERING GRADES

Variations in preservation of the minerals, textures and structures of the original granitic bedrock material and mass allowed differentiation of the pedological soil (zone I), and saprock (zone II), zones of the pedo-weathering profile concept (Tandarich *et al.*, 2002) (Table 1 and Figure 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 1). 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 m 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 1).

The saprock (zone II) is some 31.9 m thick and consists of silty sandy gravels to gravelly silty sands that indistinctly to distinctly preserve the minerals, textures and structures of the original granite; the degree of preservation increasing with depth. Zone II can be sub-divided 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 to weathering zones; the more widely known ones being those by IAEG (1981), GCO (1988) and GSL (1990). 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 2).

The earth materials of the weathering profile are classified as residual soils over granite in geotechnical work for their excavation has only involved scraping and ripping or "common excavation" (JKR, 2007). The residual soils would also be considered as being unsaturated soils as they located above the unconfined groundwater table (that is seen at the bottom of the weathering profile).

RESULTS

Descriptions of saprock samples

Binocular microscope examinations show the gravel and sand sized fractions to consist predominantly of vitreous quartz grains with some altered (whitish) and fresh (cloudy) feldspar grains. The silt sized particles, however, are seen to consist almost entirely of sericite flakes with a few, larger muscovite flakes. These sericites originate from not only sericitization of feldspars in the original granite (Yusari, 1993), but also from *in situ* alteration of feldspars within the weathering profile. The *in situ* alteration of feldspars is considered to result from leaching of its cations as there has been downward migration of the unconfined groundwater table at the profile (Raj, 1983). X-ray diffractograms of the clay fractions furthermore, show kaolinite and illite to be the only clay minerals present (Table 2).

Physical properties of saprock samples

As the samples were collected at different depths, there are some variations in physical properties. Samples A and B have closely similar values of dry unit weight of 16.45, and 15.96, kN/m^3, and dry density of 1,677, and 1,626, kg/m^3, whilst sample C has corresponding values of 14.22 kN/m^3, and 1,450 kg/m^3 (Table 3). In view of similar primary and secondary minerals, the specific gravity of soil particles in all samples shows little variation (Table 3).

Porosity is somewhat variable; samples A and B with a similar value of 37%, whilst sample C is more porous with 44% (Table 3). Void ratio is also variable; samples A, B and C having values of 0.58, 0.60 and 0.79, respectively (Table 3).

Soil index properties of saprock samples

Differences in depth of samples give rise to some variation in soil index properties (Table 4). Gravel contents are quite variable; samples A and B with 33%, and 31%, and sample C with 24%. Sand contents, however, are less

Table 2: Descriptions of saprock samples.

Sample	Vertical Depth (m)	Sub-zone	Description
A	26.53	IIC	Yellow to white, friable, silty sandy gravel with distinct relict bedrock texture. Highly weathered granite. Coarse fraction of quartz grains, sericite & muscovite flakes & some (kaolinized) feldspar grains. A few fresh (cloudy) feldspar grains. Clay fraction of kaolinite & illite.
B	31.29	IIC	Yellow to white, friable, silty sandy gravel with distinct relict bedrock texture. Highly weathered granite. Coarse fraction of quartz grains, sericite & muscovite flakes & some (kaolinized) feldspar grains. A few fresh (cloudy) feldspar grains. Clay fraction of kaolinite and illite.
C	41.93	IID	White to yellow, friable, gravelly sandy silt with distinct relict bedrock texture. Moderately weathered granite. Coarse fraction of quartz grains, sericite & muscovite flakes & several fresh (cloudy) feldspar grains. Also some (kaolinized) feldspar grains. Clay fraction of kaolinite & illite.

Table 3: Physical properties of saprock samples.

Sample	Vertical Depth (m)	Dry Unit Weight (kN/m^3)	Dry Density (kg/m^3)	Particle Specific Gravity	Porosity (%)	Void Ratio
A	26.53	16.45	1,677	2.65	37	0.58
B	31.29	15.96	1,626	2.60	37	0.60
C	41.93	14.22	1,450	2.62	44	0.79
Average		15.54	1,584	2.62	39.33	0.66

Table 4: Soil index properties of saprock samples.

Sample	Vertical Depth (m)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Plastic Limit (%)
A	26.53	33	27	22	18	21.8
B	31.29	31	24	25	20	21.6
C	41.93	24	28	38	10	34.9

variable; samples A, B and C having contents of 27%, 24% and 28%, respectively. Total sand and gravel contents are also variable with samples A, B and C having 60%, 55%, and 52%, respectively (Table 4).

Silt contents are quite variable; samples A and B with 22%, and 25%, and sample C with 38% (Table 4). Clay contents are also variable; samples A and B with 18%, and 22%, and sample C with 10% (Table 4). Differences in the silt and clay contents furthermore, give rise to some variation in plastic limits; samples A and B with closely similar values of 21.8%, and 21.6%, and sample C with a value of 34.9% (Table 4).

Soil moisture retention curves of saprock samples

The pressure plate tests show gravimetric moisture contents of the samples to decrease with increasing suctions (Table 5 and Figure 4). In sample A, the gravimetric moisture contents decrease from 31.9% through 28.6% and 23.3% to 16.9% and 6.8% under increasing suctions from 0 kPa through 0.98 kPa and 9.8 kPa to 33 kPa and 1,500 kPa. Under similarly increasing suctions, gravimetric moisture contents in sample B decrease from 32.1% through 24.9% and 21.5% to 17.8% and 7.4%, whilst in sample C, they decrease more abruptly from 31.6% through 30.3% and 27.3% to 23.5% and 9.5% (Table 5).

Storage and drainage pores in saprock samples

In agriculture, soil suction or soil moisture tension is considered to be the most important soil moisture characteristic for a growing plant and is usually defined in units of bars (where 1 bar = 100 kPa). A saturated

Table 5: Gravimetric moisture contents retained under different suction pressures.

Sample	Sub-zone	Vertical Depth	Gravimetric moisture content (%)				
			0 kPa	0.98 kPa	9.8 kPa	33 kPa	1,500 kPa
A	IIC	26.53 m	31.9	28.6	23.3	16.9	6.8
B	IIC	31.29 m	32.1	24.9	21.5	17.8	7.4
C	IID	41.93 m	31.6	30.3	27.3	23.5	9.5
Average			31.9	27.9	24.0	19.4	7.9

Table 6: Drainage and storage pores in saprock samples.

Sample	Sub-zone	Vertical depth (m)	Quick drainage pores (%)	Slow drainage pores (%)	Total drainage pores (%)	Storage pores (%)	Total porosity (%)
A	IIC	26.53	8.6	6.4	15.0	10.1	25.1
B	IIC	31.29	10.6	3.8	14.4	10.4	24.8
C	IID	41.93	4.3	3.8	8.1	14.1	22.2
Average			7.8	4.7	12.5	11.5	24.0

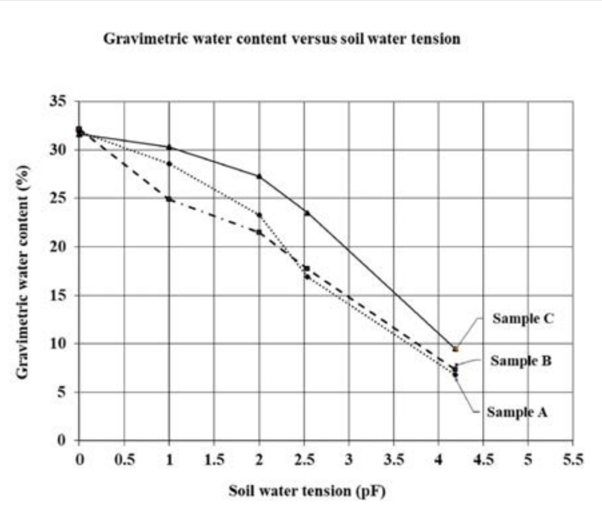

Figure 4: Soil moisture retention curves of saprock samples.

soil has a soil moisture tension of about 0.1 kPa or less, whilst at field capacity, most soils have a soil moisture tension between 5 kPa and 33 kPa; field capacity defined as the level of soil moisture left in the soil after drainage of gravitational water which frequently takes a few days to drain through the soil profile. The wilting point, which is defined as the soil moisture content where most plants cannot exert enough force to remove water from small pores in the soils, is at about 1,500 kPa soil moisture tension for most agronomic crops. Water, held between field capacity and the wilting point is available for plant use, whilst capillary water held in the soil beyond the wilting point can only be removed by evaporation (Scherer *et al.*, 1996). In view of these relationships, results of soil water retention curves are often expressed in terms of 'quick' and 'slow' drainage pores as well as 'storage' pores; these values being determined from the following equations:-

Quick drainage pores (%) = moisture content (0.0 kPa) - moisture content (0.98 kPa)
Slow drainage pores (%) = moisture content (9.8 kPa) - moisture content (33 kPa)
Storage pores (%) = moisture content (33 kPa) - moisture content (1,500 kPa)

Percentages of quick and slow drainage pores in the samples are quite variable, though the total drainage pores of samples A and B are closely similar with 15.0% and 14.4%, whilst sample C has 8.1% (Table 6). Total percentages of storage pores in samples A and B are also closely similar with 10.1% and 10.4%, whilst sample C has 14.1% (Table 6).

DISCUSSION

Comparison with published data

In earlier publications, it has been pointed out that the earth materials in a weathering profile over porphyritic biotite granite varied with depth in not only texture and composition but also in the extent of preservation of the original bedrock minerals, textures and structures (Raj, 1985; 2010). It was thus emphasized that discussions on the physical and soil index properties of earth materials in weathering profiles (and residual soils), as well as their soil moisture retention characteristics, be carried out with reference to the locations of samples. Results of the present study are thus only compared with the results of the study involving saprock samples from the weathering profile over porphyritic biotite granite (Raj, 2010).

Pressure plate tests in the present study show gravimetric moisture contents to decrease on average from 31.9% through 27.9% and 24.0% to 19.4% and 7.9% with increasing suctions from 0 kPa through 0.98 kPa and 9.8 kPa to 33 kPa and 1,500 kPa (Table 5). These decreasing moisture contents are quite similar to those of saprock samples from sub-zone IID of the weathering profile over porphyritic biotite granite where moisture contents decreased on average from 24.3% through 21.2% and 14.7% to 10.6% and 3.3% with similar increasing suctions (Raj, 2010). The decreases in moisture contents, however, are not identical for there are significant textural differences between the samples. The saprock samples of the present study consist on average of 29% gravel, 26% sand, 28% silt and 16% clay, sized particles, whilst the saprock samples of the earlier study consist on average of 10% gravel, 68% sand, 17% silt and 6% clay, sized particles (Raj, 2010).

Quick and slow drainage pores in samples of the present study constitute on average some 7.8%, and 4.7%, respectively, whilst the total drainage porosity is 12.5%, and the total storage porosity some 11.5% (Table 6). In the earlier study involving saprock samples from sub-zone IID (Raj, 2010), the quick and slow drainage pores were found on average to constitute some 9.7%, and 4.1%, whilst the total drainage porosity was 13.8%, and the total storage porosity some 11.0%. The two sets of results are similar but not identical for there are significant textural differences between the samples.

Reasons for retention of soil-moisture under high suction pressures

The pressure plate tests show the soil moisture contents retained under different suction pressures to be variable with particle size distributions (Tables 4 and 5). Gravel contents appear to have little influence for regression analyses of their plots against moisture contents retained at high suctions (33 kPa and 1,500 kPa) yield negative trends with large (and unrealistic) intercept values. Sand contents similarly have little influence with regression analyses of their plots yielding positive trends with very low correlation coefficients (R^2 <0.4000). Clay contents also appear to have little influence with regression analyses of their plots yielding negative trends with large (and unrealistic) intercept values. Total clay and silt contents, however, appear to have some influence with regression analyses of their plots yielding positive trends with moderate correlation coefficients (R^2 <0.7957) but negative (and unrealistic) intercept values.

Regression analyses of silt contents plotted against moisture contents retained at high suctions (33 kPa and 1,500 kPa) furthermore, yield positive trends with large correlation coefficients (R^2 >0.9966) and low (reliable) intercept values (Figure 5). Silt sized particles are therefore, expected to influence the moisture contents

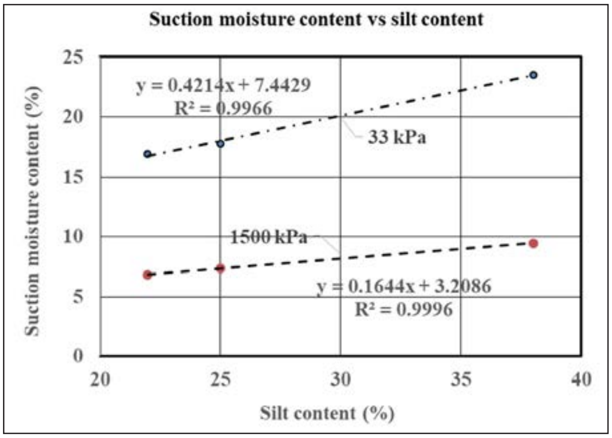

Figure 5: Silt contents plotted against moisture contents retained at high suctions (33 kPa and 1,500 kPa).

retained in the saprock samples at high suctions (33 kPa and 1,500 kPa). Retention of moisture by the silt sized particles results from the adsorption of water onto their surfaces; the silt sized particles having very large specific surface areas. Van der Waal forces furthermore, are considered to be primarily responsible for such particle surface hydration (Lu, 2016).

CONCLUSIONS

The weathering profile can be differentiated 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 silty sandy gravels to gravelly silty sands that indistinctly to distinctly preserve the minerals, textures and structures of the original bedrock material and mass. Regression analyses of gravel, sand, clay, and total clay and silt, contents plotted against moisture contents retained at high suctions (33 kPa and 1,500 kPa) yield variable trends with unreliable intercept values and low to moderate correlation coefficients (R^2 <0.7957). Regression analyses of silt contents plotted against moisture contents retained at high suctions (33 kPa and 1,500 kPa) yield positive trends with large correlation coefficients (R^2 >0.9966) and low intercept values. It is concluded that adsorption of water on the surfaces of silt sized particles (of mainly sericite derived from the weathering of feldspars) that gives rise to the retention of soil moisture in saprock.

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CONFLICT OF INTEREST

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

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