Weathering profiles of Bunya Phyllite in southwest Brisbane - A geotechnical approach

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ABSTRACT

This paper presents the results of a study of the morphology of weathering profiles of Bunya Phyllite, located in Western Brisbane, Australia. Several cut slopes located in the suburbs of St. Lucia, Taringa and Indooroopilly were analysed in order to provide accurate knowledge of their morphological characteristics. From these, six outcrops were selected for a more detailed description of their physical, geological, structural and geotechnical parameters, focusing on weathered rock materials, including several characteristics of the rock matrix (fabric, mineralogy, degree of weathering, etc.) and rock mass (rock:soil ratio, discontinuity characteristics, JRC, JCS etc.). Samples from the upper portion of the profiles, into the transition zone between rock and soil, were collected in order to determine physical indices, preparation and description of thin sections, and point load tests (the last two are not included in the present paper). The results show that phyllite weathering profiles are relatively thin and the contacts between different material layers are sharp. A strong structural conditioning of weathering can be noted in all outcrops. Soil-like material is present only in portions of the rock mass close to the ground surface or along structural discontinuities (foliation and fractures). A remarkable and specific characteristic of the studied weathering profiles is the presence of stress relief joints parallel to the foliation, which plays an important role in the differentiation of the rock mass layers and weathering.

Keywords: mineralogy, morphology, phyllites, physical characteristics, weathering profiles.

1 INTRODUCTION

The significance of the study of weathering profiles is closely related to the presence of several transitional materials between rock and soil, that present different geotechnical parameters and, as a consequence, different geotechnical behaviour. The presence of these weathering profiles on a geotechnical work site such as cut slopes, foundations and open and underground excavations dictates stability, as weathering produces material with extremely different mechanical parameters (Anonymous 1995; Beavis 1985; Beavis et al. 1982; Gupta & Rao 2001; and Marques et al. 2010). Add to this scenario the presence of structural discontinuities that, besides influencing underground water circulation and hence weathering, introduces great variations in mechanical behaviour. This context presents an important and complex instability mechanism of rock masses that has been responsible by many geotechnical problems in different weathering (climatic) conditions.

The main purpose of the present paper is to present the results of a detailed morphological, structural, physical and mineralogical characterisation of the transitional zone between rock and soil in Bunya phyllite weathering profiles commonly found at South-East Queensland, Australia. These profiles were developed under sub-tropical climatic conditions and the study is part of more general research that involves two other rock types (basalts and sandstones) developed under two different climatic conditions, sub-tropical (South-East Queensland) and tropical (South-East Brazil).

The Bunya Phyllite forms a 10 km wide, north-northwest trending belt in the core of the South D'Aguilar Sub-province (Bryan & Jones 1951). These rocks originated from fine-grained to muddy sediments, with more recrystallised and medium-grained portions also occurring (GSA 2012). Some inter-bedded quartzite and greenstone layers can be seen on Indooroopilly area. Bunya phyllite is commonly found in the western Brisbane suburbs, mainly in Indooroopilly, Taringa and St. Lucia. According to GSA (op. cit.), the Bunya phillite is an intensely crumpled and deformed metamorphic rock, light to medium grey in colour, and banded with layers of mica and quartz. Platy mica recrystallization has generated a thin foliation. Quartz veins are present and vary from parallel to foliation to strongly folded and contorted. The main geological structures are a well-developed slaty cleavage and some families of tectonic fractures.

According to Marques et al. (2010), foliation, in particular, plays an important role in the development of weathering profiles in high grade metamorphic rocks (gneisses) and when this structure is parallel to the surface, contacts between different weathering materials are abrupt. This seems to occur in Bunya phyllite as well, as is latter discussed.

2 PROFILES STUDIED

Sixteen phyllite weathering profiles were visited in order to describe the morphology of the weathering profile and its variations. From these, six points (labelled PHY01 to PHY06 in Figure 1 and Table 1), were described in detail and were used for field tests and sample collection for laboratory tests. All selected profiles are located in western Brisbane, specifically in the suburbs of Indooroopilly, Taringa and St. Lucia.

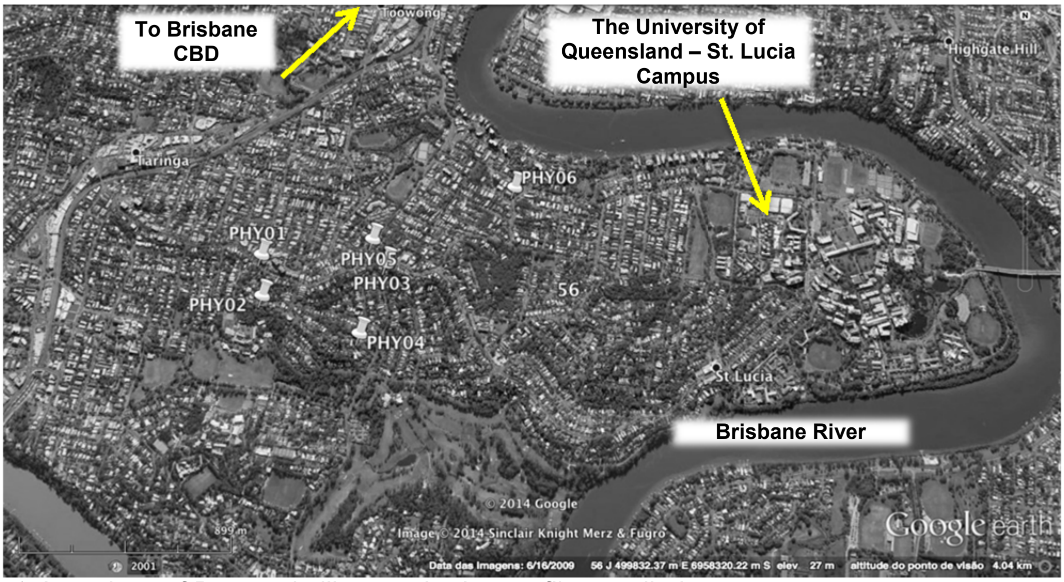


Figure 1. Locations of Bunya phyllite weathering profiles studied.

Table 1: Address and geographic coordinates of the weathering profiles described and sampled.

Profile Id	Address	UTM Coordinates (56J - WGS84)	
		N	E
PHY01	Swann Road in front of number 180 – 190, Indooroopilly	6.958.419	498.597
PHY02	McCaul St in front of Indooroopilly Secondary State High School, between Kobada St & Darvall St, Indooroopilly	6.958.230	498.610
PHY03	Indooroopilly Road in front of 159, Indooroopilly	6.958.064	499.052
PHY04[a]	McCaul St, in front of #18, Indooroopilly	6.958.380	499. 157
PHY05	Gailey Road, in front of #157, Taringa	6.958.499	499.076
PHY06	Corner of Ryan Road and Bellevue Terrace, St. Lucia	6.958.765	499.728

[a] PHY04 was located on a construction site and because of that, only the description of the morphology and sampling for physical tests and thin section preparation and analysis could be carried out as the cut was latter hidden by a rock block wall.

Several weathering classification schemes have been proposed, such as Anonymous (1995), IAEG (1981), Beavis (1985) and ISRM (2007); this last one being one of the most widely used (Table 2), and which was adopted in the present study. Additionally, some practical tests such as strength under a geological hammer/pocket knife/hand pressure, and discolouration were used. Physical parameters (dry/wet density, porosity and water absorption capacity) and Schmidt hammer tests were performed in accordance with ISRM (2007) suggested methods. Mineralogy was identified based on visualisation through a pocket magnifier by an experienced geologist. Table 3 lists all characteristics, descriptions and parameters evaluated for each weathering profile, for the rock mass and rock matrix, separately. The results of physical parameter testing were based on samples from all six weathering profiles, while detailed field characterisation was based on five weathering profiles, as PHY04 could not be accessed.

Table 2: ISRM (2007) suggestion for classification and description of rock masses.

Term	Description	Class
Sound Rock (SR)	No visible sign of matrix weathering; some rock discoloration may be present along main discontinuities.	I
Slightly Weathered Rock (SW)	Discoloration of rock indicates beginning of rock matrix weathering and along discontinuities surfaces. All rock matrix can be discoloured by weathering and can be slightly softer externally than in sound condition.	II
Moderately Weathered Rock (MW)	Lower than half of rock matrix is decomposed or disintegrated to soil condition. Sound or discoloured rock is present forming discontinue zones or as corestones.	III
Highly Weathered Rock (HW)	More than half of rock matrix is decomposed or disintegrated to soil condition. Sound or discoloured rock is present forming discontinue zones or as corestones.	IV
Completely Weathered Rock (CW)	All rock matrix is decomposed or disintegrated to soil condition. Original structure of rock mass is commonly preserved.	V
Residual Soil (RS)	All rock is transformed into soil. Geological structure of rock mass is destroyed. There is a great volume variation, but no soil significant soil transport is present.	VI

Table 3: Parameters evaluated for each layer identified in the weathering profiles.

Rock Mass Characteristics	Rock Matrix Characteristics
- Soil or rock behaviour - Rock: Soil ratio - Type and attitude of geological structures - Volumetric joint counting Jv, as defined by (Palmstrom, 2005) - RQD (based on Jv) - Characteristics of discontinuities (spacing, persistence, aperture, presence and type of filling material, JRC) - JCS	- Name and genetic type of rock - Texture (grain size, colour, signs of weathering, fabric, presence of orientation, etc.) - Weathering grades (based on ISRM, 2007) - Physical properties (dry and saturated density, porosity, water absorption capacity) - Microscopic indexes (microfracturing and micropetrographic) [a] - Point load[a]

[a] Results from microscopic indexes and point load tests are not presented in this paper.

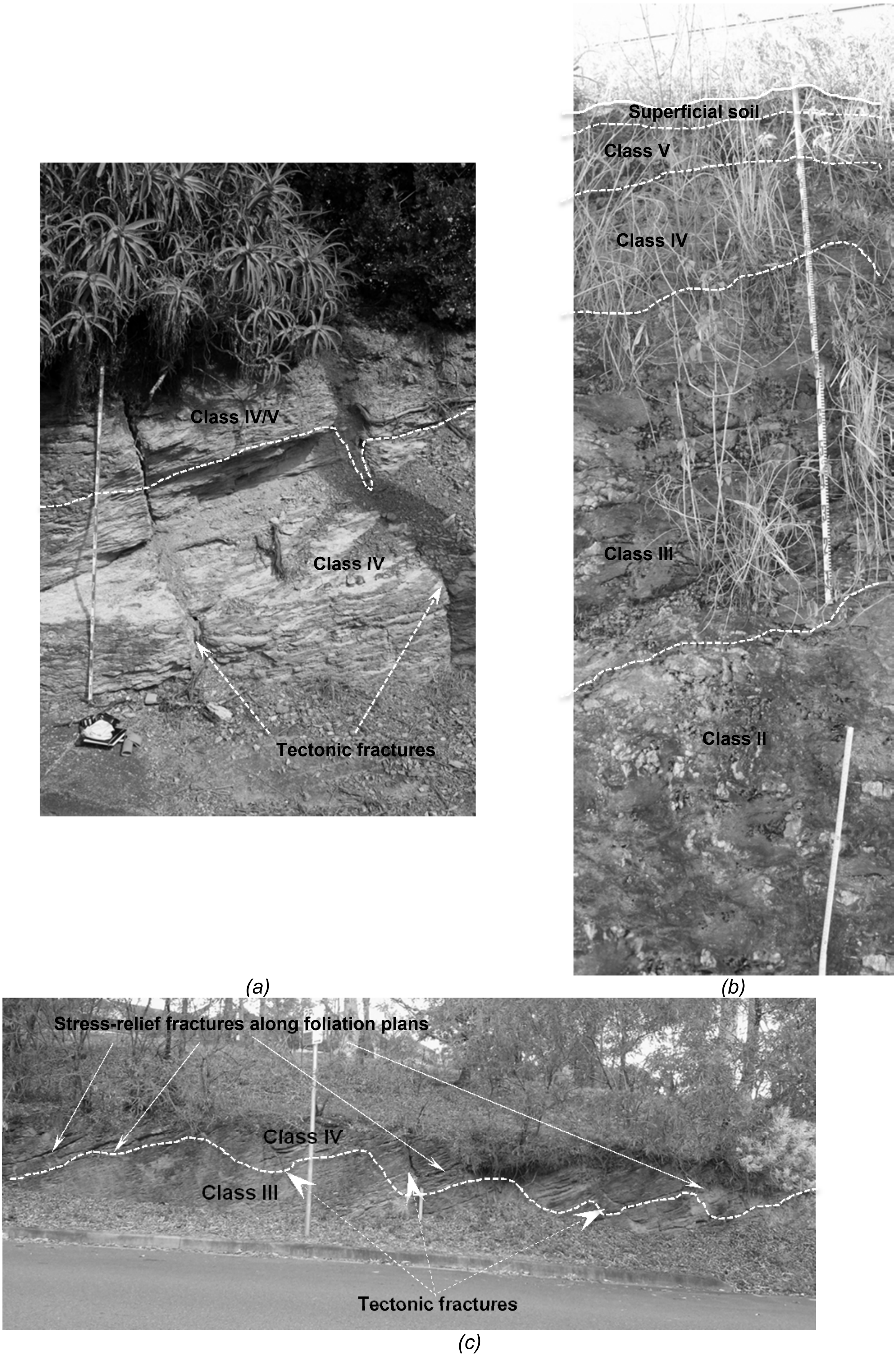
3 RESULTS

Some of the general results obtained for all studied weathering profiles of Bunya phyllite are detailed in this section. Specific characteristics are highlighted.

3.1 Typical Morphology of Bunya Phyllite Weathering Profiles

A thorough inspection of the weathering profiles of Bunya phyllite has allowed a consistent knowledge of its mains characteristics and controls. Figures 2 and 3 present some examples of important aspects of Bunya phyllite weathering profiles.

Two key remarkable aspects were the abrupt contact between soil and rock material and the small thickness of the soil material layers, which were frequently thinner than 0.7 m. Thicker superficial soil layers can also be found, but this is not the predominant occurrence and is related to some specific conditions such as the presence of faults, intense fracturing, groundwater, etc.



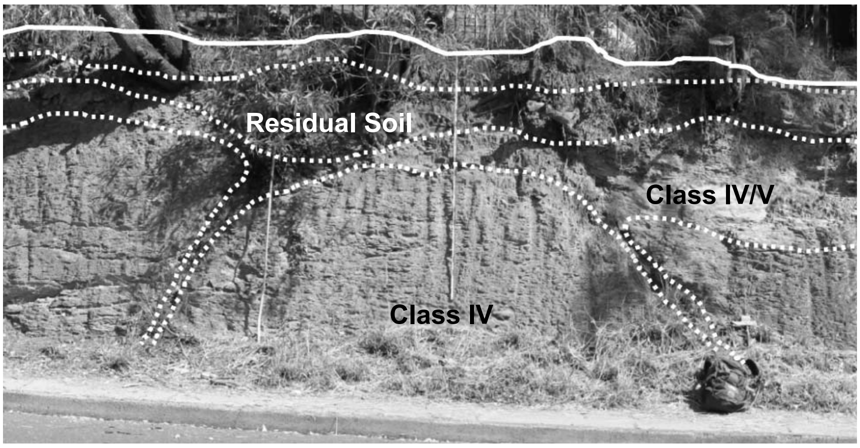
(c)

Figure 2. Weathering patterns observed in Bunya phyllite. Fracturing along foliation increases in more weathered materials. (a) PHY06, (b) PHY05 and (c) one of the sixteen outcrops initially visited.

The transition zone between slightly, moderately and highly weathered rock and residual soil is usually very thin and commonly not all degrees of weathering (Table 2) are present. Contacts between weathering classes are usually abrupt and, in the case of Bunya phyllite, this behaviour was found to be mainly due to structural controls, as is discussed latter.

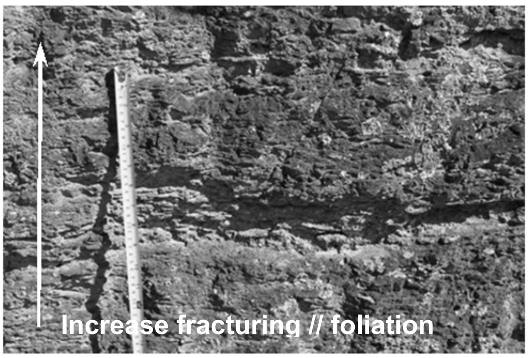
Foliation is the most prevalent structure and its dip is usually low (varying from 0 to 15^0); the exceptions being some portions of PHY05 (values of 40^0 can be found, mainly related to folds, but the average dip is around 3^0 to 10^0) and PHY06 (foliation is more steep then other and varies from 17^0 to 29^0). Because of these low dip angles, stress relief caused by erosion and tectonic uplift on the Bunya phyllite layers result in an increase of fracturing along foliation, and also larger foliation opening with increasing weathering. Figures 2b and 2c show the effect of stress relief on weathering, as the most noticeable difference between Class III and Class II (Figure 2b) and between Class III and Class IV (Figure 2c) materials is the increase in rock fracturing parallel to foliation. The stress relief processes play an important role in the development of weathering profiles of Bunya phyllite and also in the boundaries between weathering classes.

Figures 2a and 2b show the importance of tectonic fractures (vertical and inclined) to the erratic contacts between weathering classes, as these structures allow greater weathering along their planes, resulting in an irregular surface between weathering classes. Figure 3a shows the outcrop at PHY01 and the effect of weathering along these fractures, which is responsible for the undulation of contacts between the different weathering classes. Figure 3b shows opening on fractures parallel to the foliation in the more weathered classes, while Figure 3c shows an increase in rock fracturing parallel to foliation. Both processes were interpreted as a response to stress relief, and they control weathering. The assumption of increasing fracturing due to stress relief and not in response to weathering is based on the increase in rock fracturing parallel to foliation in the vicinity of the ground surface and on the fact that fractures in the more sound classes do not present weathering material along these fractures.



(a)

(b)



(c)

Figure 3. Aspects of weathering profile observed at PHY01, showing the undulation of weathering class contacts (3a) fracture parallel to foliation opening (3b) and presence of high frequency fracturing parallel to foliation on highly weathered material (3c).

3.2 Macroscopic Mineralogy and Fabric

Bunya phyllite occurs as a very well foliated rock with quartz veins and layers parallel to foliation. The rock matrix has alternating layers of micaceous bands and very small quartz-rich layers and quartz veins. Mineralogy was determined by using a pocket magnifier, and is mainly composed of quartz and a weathered micaceous mineral (biotite/chlorite). Some feldspar grains can also be seen as minor minerals. Clay minerals and iron oxides are present and characterise the main result of chemical weathering of the primary minerals. Table 4 presents the average macroscopic characteristics (mineralogical, structural and fabric) of all weathering classes observed in the Bunya phyllite.

Table 4: Average macroscopic characteristics of rock matrix and rock mass for different weathering classes of Bunya Phyllite.

Rock Weathering Class	Description
II	Rock matrix mainly composed of slightly weathered phyllite. Only few fractures are present, all sealed and showing slight weathering, with some iron oxide stains. Sound rock is present, easily identified by the "bell sound" when hit by a geological hammer. This layer was only observed in the PHY05 profile. Several quartz layers, lenses and veins are present and their presence must be related to a quartzite layer outcropping nearby.
III	Rock matrix predominately moderately weathered (III). Highly weathered (IV) and soil portions are present only along some fractures parallel to foliation (aperture = 3 mm). Rock mass is very fractured with aperture of up to 5 mm, some of them filled with residual soil. Rock matrix presents weathering signs such as stains, points and layers with mottled colour. Foliation is prevalent. Iron oxides are present. Mineralogy is mainly composed of feldspar, quartz, biotite and clay minerals (as a result of weathering). Contact with class II is very sharp and marked by an increase of rock fracturing parallel to foliation.
IV	Rock matrix mainly composed of moderately weathered material with highly to completely weathered material along fractures and foliation planes throughout outcrop. Rock mass is highly fractured. Some very fractured quartz layers exist parallel to foliation, with slightly to moderately weathered material also present. Some rock matrix can be broken by hand pressure, while other rock matrix requires a geology hammer. Soil and weathered material have a thickness varying from 2 cm up to 10 cm inside fractures. Foliation is prevalent and clearly observed. Oxidation and discoloration occurs along fractures and foliation. Clay mineral formation can be observed on much of the rock material. Mineralogy is mainly composed of quartz, feldspar, biotite, chlorite and clay minerals (newly formed). Feldspar, biotite and chlorite crystals can show weathering. Signs of iron oxide (stains and stain spots) are present throughout outcrop. Fractures are common and mainly parallel to foliation. Contacts with Class III and Class V or IV/V are usually sharp.
IV/V	Highly weathered rock material (IV) is predominant, with very small amounts of moderately weathered (III) and soil. Mottled colour. Foliation is prevalent and well preserved in rock.
V	Young residual soil, with several phyllite fragments of moderately (III) to highly weathered rock (IV). Some blocks present intact rock. Mottled (yellow, red and orange variations). Texture is silty-clayey-sandy.

3.3 Physical Characterisation

Porosity, dry and wet densities, and water absorption capacity were measured for all layers and all profiles. Table 5 shows the results obtained and it can be seen that physical parameters can only can be used as an index for weathering of the Bunya phyllite, as they show an erratic pattern from one class to another. Care must be especially taken when comparing samples from class III to class IV and from class IV to class IV/V materials as iron released from the weathering of micaceous minerals can precipitate on the rock matrix and fractures, reducing its porosity and increasing its density. This happens because the test procedures for transitional materials require the washing of samples. Washing leads to the elimination of the more weathered material present on rock samples and thus, to some unreliable results. It must be pointed that all ISRM (2007) suggested methods imply an initial brushing of samples. The suggested method for rock that can disintegrate on wetting involves the use of mercury displacement, is very laborious and implies the need for grinding. Table 6 presents the average results and standard deviations (SD) for each rock weathering class. Results for class II materials are in line with the results obtained by other researchers for similar rocks (Ramamurthy et al. 1993).

Table 5: Physical parameters of each weathering class of studied profiles.

Profile Id	Weathering Class	Density (kg/m^3)		Porosity (%)	Water Absorption Capacity (%)
		Dry	Wet		
PHY 01	IV/V	2411	2521	11.1	4.6
	IV	2330	2465	13.5	5.8
PHY 02	IV/V	2460	2568	10.7	4.4
	IV	2510	2593	8.2	3.3
PHY 03	IV	2491	2589	9.8	3.9
	III	2488	2581	9.2	3.7
PHY 04	IV/V	2486	2548	6.2	2.5
	IV	2421	2525	10.4	4.3
PHY05	IV	2482	2574	9.2	3.7
	III	2592	2646	5.4	2.1
	II	2643	2676	3.3	1.1
PHY 06	IV/V	2377	2513	13.6	5.7
	IV	2353	2490	13.7	5.8

Table 6: Average results of physical parameters of each weathering class.

Weathering Class	Density (kg/m^3)				Porosity (%)		Water Absorption Capacity (%)	
	Dry		Wet					
	Aver.	SD	Aver.	SD	Aver.	SD	Aver.	SD
PHY II	2643	----[b]	2676	----[b]	3.4	----[b]	1.2	----[b]
PHY III	2540	74	2614	46	7.3	2.7	2.9	1.2
PHY IV	2431	76	2539	54	10.8	2.3	4.5	1.1
PHY IV/V	2434	49	2538	25	10.4	3.1	4.3	1.3

[a] SD = Standard deviation; Aver. Average; [b] As only one test was performed, there is no SD.

3.4 Geotechnical Characterisation Based on Field Tests

As listed in Table 3, several field parameters were determined both for the rock matrix as for the rock mass. Table 7 presents these results. The fracture space index (I_f) was determined according to Beavis (1985), while the rock quality designation (RQD) was determined based on volumetric joint count (J_v) value, according to Palmstrom (2005).

Table 7: Results of field measurements for each weathering class.

Profile Id	Weathering Class	Rock:Soil Ratio (%)	I_f (m)	RQD (%)	JCS (MPa)	Fracture			
						JRC	Open[a] (mm)	Pers[b] (m)	Filling[c]
PHY01	IV/V	40 - 50	0.10	98	< 10	Fo - 10-12 Fr - 4-6	10 - 50	Fo[d] = 4-5 Fr[e] = 2	Soil or No filling
	IV	10	1.5 – 2.0	100	< 10		2		
PHY02	IV/V	10 - 20	0.05 – 0.10	98	< 10	Fo - 10-12 Fr - 4-12	Up to 20	Fo = 4-5 Fr = 0.5	Soil or Iron oxide
	IV	5 - 10	1.2 – 1.3	100	< 10		Up to 10		
PHY03	IV	10 - 20	≤ 0.10	97	< 10	Fo - 6-8 Fr - 10-12	Up to 50	Fo = 4-5 Fr = 2	Soil or Iron oxide
	III	0	> 1.2	100	11 - 13		4		
PHY05	IV	20 - 30	0.05 – 0.10	93	< 10	Fo - 10-14 Fr - 10-12	10	Fo = >10 Fr = 0.5-1	Soil or Some iron Oxide
	III	5	0.05 – 0.20	99	21 - 32		2		
	II	0	> 1.5	100	42 - 45		Sealed		
PHY06	IV/V	5 - 10	0.05 – 0.10	93	< 10	Fo - 14-16 Fr - 4-8	20	Fo = 5 Fr = 1	Soil or Iron oxide
	IV	1 - 2	> 1.2	99	< 10		2		

[a] Open = Average Opening, [b] Average Persistence, [c] Filling material, [d] Foliation, [e] Fracture.

4 CONCLUSION

From the results presented, the following conclusions can be drawn:

- the weathering profile of Bunya phyllite presents distinct morphological characteristics that allow the recognition of different weathering layers;
- contacts between soil and rock materials are sharp and soil thickness is small;
- tectonic (foliation and fractures) and stress relief structures play an important role in the morphology of weathering class contacts. Low dip foliation is particularly affected by stress relief and controls the engineering behaviour of weathering materials;
- physical parameters (porosity, density and water absorption capacity) can be related to weathering, but care should be taken as iron oxide liberation from micaceous minerals can precipitate, especially on the more weathered materials (class IV and IV/V). Nevertheless, if these parameters are properly analysed together with mineralogical analysis, a relationship with weathering can be established;
- Rock:Soil ratio, I_f value and fracture opening were the field parameters described showing the best relationship with weathering;
- The JCS could be used as a indication of rock matrix strength for profiles with more sound material, but it could not be used to differentiate class IV and class V materials as their strengths are too low to be measured by the hammer;
- RQD, JRC, persistence and filling material did not show significant changes with weathering. The problem with RQD was that the Palmstrom method does not take into account the presence of filling material and the opening of fractures in the determination of RQD values.

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