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# Excavability of inter-bedded quartzites and phyllites of the Lower Carboniferous Sungai Perlis Beds at Bukit Teluk Batu, Terengganu Darul Iman

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**Abstract:** North-south striking quartzites and phyllites of the Carboniferous Sungai Perlis Beds with steep eastward and westward dips give rise to the ridge at Bukit Teluk Batu. The strata with individual bed thicknesses of 0.5 to 2.0 m, are strongly jointed and weathered to variable depths; slope cuts showing three broad weathering zones i.e., an upper pedological soil, an intermediate saprock, and the bottom bedrock. The pedological soil is 2 to 4 m thick and consists of yellow to red, firm to stiff, silty clays with quartz clasts and lateritic concretions. The saprock is some 15 to 20 m thick and consists of alternating bands of yellow to brown and grey, loose to dense, sands (representing completely to highly and moderately weathered quartzites), and soft to hard, clayey silts and silts (representing completely to highly and moderately weathered phyllites). Original bedrock minerals, textures and structures are distinctly preserved in the saprock zone which can be separated into sub-zones IIA, IIB and IIC. Bedrock, at depths exceeding 20 m, consists of steeply dipping, pink to dark grey, slightly weathered quartzites and phyllites. Seismic refraction surveys show the pedological soil to have p-wave velocities <500 m/s, whilst the saprock has velocities between 700 and 1,200 m/s, and the bedrock, velocities >2,100 m/s. Borehole standard penetration tests show the pedological soil to have N values <15 and the saprock N values >20, whilst the bedrock requires coring. The pedological soil and saprock have been excavated by scraping and ripping, though the bedrock zone is non-rippable; its upper surface marked by the teeth marks of scrapers. It is concluded that seismic refraction surveys and borehole standard penetration tests in areas of inter-bedded quartzites and phyllites can allow for differentiation of weathering zones and prediction of their excavability.

**Keywords:** Sungai Perlis Beds, quartzites and phyllites, weathering zones, pedological soil, saprock, bedrock, rippable, non-rippable

## INTRODUCTION

Excavation refers to the process of removing earth materials to form a cavity at, or below, the earth's surface. Excavations at the surface are called open excavations and are carried out during the construction of slope cuts, foundations, borrow pits and quarries, whilst subsurface excavations are involved in the construction of tunnels and underground chambers (Bell *et al.*, 1995). Geological conditions are a most important consideration in the formation of excavations for they affect the method of excavation as well as the stability of the opening, and surrounding, or overlying, ground. The term 'excavatability' is a measure of how easy it is to remove earth materials and as a means of determining appropriate excavation methods (BGS, 2015). 'Excavatability' is considered to be a function of the geotechnical properties of earth materials (strength or density), as well as mass characteristics, in particular, the mechanical discontinuities present (BGS, 2015).

Bell *et al.* (1995) differentiate between excavation in soft ground where the process may proceed without the need to loosen the ground before excavation, and that in hard ground where drilling and blasting or mechanized excavation would probably be chosen. In ground that is too hard for direct immediate excavation, ripping is an inexpensive method of breaking discontinuous ground or soft rock masses, before removal by earth moving machinery. The process is carried out by driving a pick into the rock mass and dragging it across the area to be excavated. Geological factors which influence rippability in rock masses include the rock type and fabric, intact strength and degree of weathering, rock hardness and



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abrasiveness, and the nature, incidence and geometry of discontinuities (Bell *et al.*, 1995).

In Malaysia, the Public Works Department (Jabatan Kerja Raya) distinguishes between 'hard material/rock', and 'common', excavation; hard material/rock excavation being "excavation in any material that cannot be loosened by an excavator with a minimum operating weight of 44 tons (US or short tons) and minimum engine rating of 321 BHP" (JKR, 2005). Broad guidelines on the expected method of excavation in different earth materials in Malaysia have been published by the Public Works Department (JKR, 2005).

Published work on the excavatability of earth materials in Malaysia is limited to the paper discussing a proposed rippability classification of quartzites from the Kenny Hill Formation at Dengkil in Selangor Darul Aman (Mohd For Mohd Amin *et al.,* 2009). The proposed classification involved comparison of field production rates ($Q_r$) with a laboratory calculated specific energy (SE) parameter. The field production rate ($Q_r$) in $m^3$/hour was calculated using a single shank Caterpillar D6 ripper dozer (165 horse power) and measuring the volume of cut per ripping cycle, whilst the specific energy (SE) (in MJ/$m^3$) was calculated using the mean power (in Joules) required to rip a block sample in the laboratory with a cutting shank divided by the volume of the cut. Several laboratory determined material properties of the quartzites were found to have good correlations with the specific energy (SE) as tensile strength ($R^2$=0.903), laboratory seismic velocity ($R^2$=0.861) and rebound value ($R^2$=0.866) (Mohd For Mohd Amin *et al.*, 2009).

The standard weathering classifications of rock mass by IAEG (1981) and ISRM (1981) furthermore, require considerable modification when applied to meta-sedimentary bedrock in humid tropical areas in view of their continuous weathering to form residual soils (Komoo & Morgana, 1988). The absence of fresh or unaltered meta-sedimentary bedrock at surface outcrops, and in boreholes, in Malaysia furthermore, makes it difficult to define the boundary between rock and soil and thus disallows use of rock/soil ratios for classification of rock mass weathering (Komoo & Mogana, 1988).

The rock mass weathering grades of IAEG (1981) were thus generalized in classifying outcrops of weathered slates, quartzites, phyllites and schists of the Sungai Perlis Beds at Chendering in Terengganu Darul Iman (Hamzah Hussin *et al.*, 2015). Weathering grade VI formed the topmost 1.5 to 2.0 m thick soil cover, whilst grades IV and V varied in colour from yellowish to reddish brown and red. Grade IV was said to be very weak to extremely weak rock, whilst grade V behaved totally as a soft soil. The original rock fabric and structures (as bedding, foliation and joints) were recognizable in both grades IV and V; the relict structures largely controlling their geo-mechanical behaviour. Grade III (moderately weathered) was said to be generally light to pale grey in colour and normally behaved as medium strong to weak rock (Hamzah Hussin *et al.*, 2015).

As part of a study to define the excavatability of earth materials in Malaysia, several excavations in inter-bedded quartzites and phyllites of the Lower Carboniferous Sungai Perlis Beds at Bukit Teluk Batu in south Terengganu Darul Iman were investigated. The excavations had been created by scrapers and rippers attached to earth moving machinery and showed the bedrock to be weathered to variable depths. In this geological short-note, an idealized weathering profile over the inter-bedded quartzites and phyllites is first described before its' constituent zones and sub-zones are correlated with borehole standard penetration tests and p-wave velocities from seismic refraction surveys. The assignment of rock mass classes (ISRM, 2007) and rock mass weathering grades (IAEG, 1981; ISRM, 1981) to the weathering zones and sub-zones is also discussed as is their excavability based on the past field performances of earth moving machinery.

## GEOLOGICAL SETTING

The study area covers the western side of the ridge at Bukit Teluk Batu which is located to the south of the small town of Kemasik in south Terengganu Darul Iman (Figure 1). The ridge is developed over approximately north-south striking meta-sedimentary strata that dip

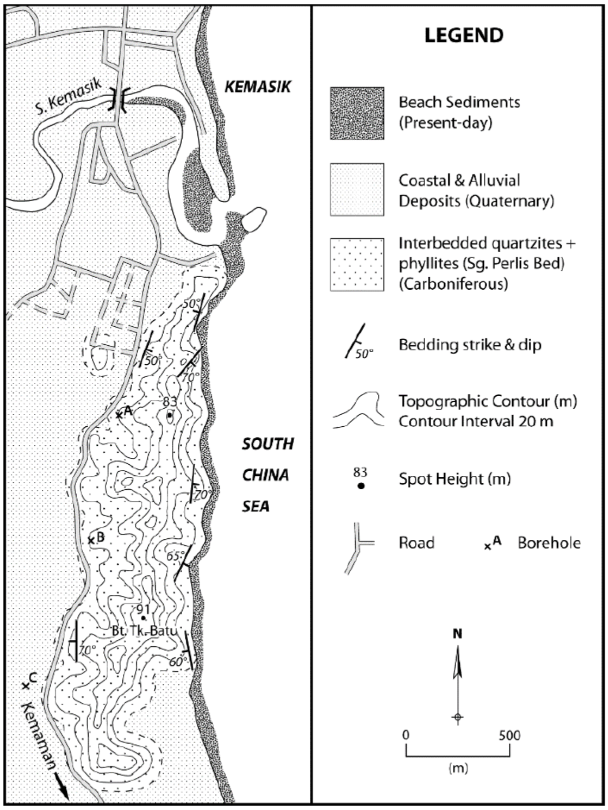


**Figure 1:** Geology map of Bukit Teluk Batu.

moderately to steeply towards the east and west. The strata, with very variable individual bed thicknesses are strongly jointed and have been separated into two broad lithological sequences by Ahmad Zainuddin (1984). On the western side are found sequences of inter-bedded quartzites and phyllites; the strata having individual bed thicknesses of 0.5 to 2.0 m. On the eastern side, and forming prominent headlands along the coast, are found massive meta-quartzites with thin beds of meta-argillites (phyllites and slates). Quartz veins of different generations are seen in the meta-quartzites which have a blocky appearance due to the presence of several sets of joints.

Fossils have not been found at Bukit Teluk Batu, though plant fossils in similar meta-sediments to the south at Tanjung Sulong in Kemaman (Goh, 1973), and at Tanjung Gelang in Pahang Darul Makmur (Yap, 1976), indicate a Lower Carboniferous age. To the northwest, in the Ulu Paka area, similar Lower Carboniferous meta-sediments have been informally named the “Sungai Perlis Beds” and consist of mainly carbonaceous slate, argillite, phyllite and schist, together with minor bands and lenses of quartzite, meta-conglomerate, and calc-silicate hornfels (Chand, 1978; Lee, 2009).

## METHODOLOGY

Excavations in inter-bedded quartzites and phyllites on the west side of Bukit Teluk Batu (Figure 2) were first visited and the exposed weathering profiles described in terms of several pedological and geological features. Pedological features that were described are based on the Soil Survey Manual for Malayan Conditions (Leamy & Patton, 1966) and the Guidelines for Soil Description (FAO, 2006), and include descriptions of the color, consistency, soil structure and texture of the earth materials as well as their content of concretions and organic matter. Geological features that were described primarily involve the extent of preservation of the original bedrock minerals, textures and structures now seen as relict features in the *in situ* weathered strata. From the field descriptions of the pedological and geological features, an idealized weathering profile over the inter-bedded quartzites and phyllites was then formulated. In view of the steep dips, variations in weathering (or alteration) of individual quartzite and phyllite beds could be traced up-dip from slightly to moderately weathered strata at the foots of cuts through highly and completely weathered strata to pedological soil at the tops.

**Figure 2:** Excavation in Sungai Perlis Beds on west side of Bukit Teluk Batu.

In order to better describe the subsurface earth materials present, boreholes were sunk at three sites in the area; two on the crests of low ridges, and one in a broad plain (Figure 1). The boreholes were advanced by wash boring with split spoon samples at 1.5 m intervals. The SPT (Standard Penetration Test or N) values for advancement of the split spoon sampler of 0.45 m length were recorded with samples described in the field before being sent to the laboratory for standard soil classification tests.

Seismic refraction surveys were also carried out along two lines to determine the thicknesses and seismic velocities of subsurface layers; the survey lines passing through boreholes A and B (Figure 1). P (primary) waves were generated at the ground surface with the use of a hammer and a metal plate, whilst the refracted seismic waves were detected with a series of vertical component geophones and recorded with a 24-channel ABEM Mark VI seismograph.

## IDEALIZED WEATHERING PROFILE

The idealized weathering profile comprises the three broad zones of the pedo-weathering profile concept (Tandarich *et al*., 2002), i.e., the top pedological soil (zone I), the intermediate saprock (zone II), and the lower bedrock (zone III) (Table 1 and Figure 3). The pedological soil is some 2 to 4 m thick and consists of IA, IB and IC soil horizons (Table 1). The IA and IB horizons (solum) are relatively thin and comprise yellowish brown, firm clay with some lateritic concretions, whilst the IC horizon (saprolite) consists of mottled red and reddish yellow, stiff, gravelly silty clay with many vein quartz clasts and a few lateritized core-stones.

The saprock (zone II) is some 15 to 20 m thick and consists of steeply dipping, alternating bands of completely to highly and moderately weathered quartzites and phyllites that indistinctly to distinctly preserve the minerals, textures and structures of the original bedrock material and mass. Variations in relative contents of the completely to highly and moderately weathered strata allow the saprock to be separated into an upper IIA sub-zone, an intermediate IIB sub-zone, and a lower IIC sub-zone (Table 1 and Figure 3).

The upper IIA sub-zone is characterized by alternating bands of red to pink, loose to medium dense, sand (representing completely weathered quartzite) and reddish to yellow, soft to stiff, clayey silt and silt (representing

**Table 1:** Pedological and geological features of idealized weathering profile.

| Zone | Sub-zone | Thickness | Pedological and Geological Features |
|---|---|---|---|
| Pedological Soil (I) | IA | ≈0.5 m | Yellowish brown, firm clay with some roots. |
| | IB | ≈1.0 m | Brownish yellow, firm clay with reddish yellow & red mottles. Some lateritic concretions. Boundary sharp. |
| | IC | ≈1.5 m | Mottled red & reddish yellow, stiff, gravelly silty clay. Many vein quartz clasts & a few lateritized core-stones. Boundary gradual. |
| Saprock (II) | IIA | ≈3.0 m | Indistinct to distinct, bands of red to pink, loose to medium dense, sand (completely weathered quartzite) and reddish to yellow, soft to stiff, clayey silt & silt (completely weathered phyllite). Indistinct preservation of minerals, textures & structures of original bedrock material & mass. Boundary irregular & gradual. |
| | IIB | ≈6.0 m | Steeply dipping, thin to thick, distinct bands of pink to yellow, medium dense to dense, sand (highly weathered quartzite) and yellow to red, stiff to hard, clayey silt & silt (highly weathered phyllite). Distinct preservation of minerals, textures & structures of original bedrock material & mass. Boundary irregular & gradual. |
| | IIC | ≈8.0 m | Steeply dipping, thin to thick, distinct bands of yellow to grey, dense to very dense, sand (moderately weathered quartzite) and pink to yellow, hard, clayey silt & silt (moderately weathered phyllite). Distinct preservation of minerals, textures & structures of original bedrock material & mass. Boundary very irregular & distinct. |
| Bedrock (III) | IIIA | >20.0 m | Steeply dipping, thin to thick, alternating strata of dark grey, slightly weathered quartzite and pink to grey, slightly weathered phyllite. Many quartz veins & pods. |

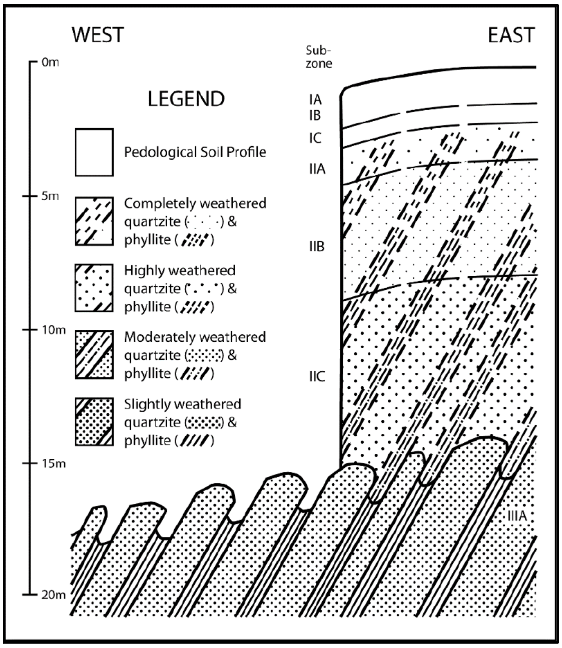


**Figure 3:** Idealized geological cross-section through the western side of Bukit Teluk Batu.

completely weathered phyllite) with indistinct to distinct preservation of the original bedrock minerals, textures and structures. The bottom IIC sub-zone, however, is characterized by alternating bands of yellow to grey, dense sand (representing moderately weathered quartzite) and pink to yellow, hard, clayey silt and silt (representing moderately weathered phyllite) with distinct preservation of the minerals, textures and structures of the original bedrock material and mass. The intermediate IIB sub-zone, furthermore, is characterized by alternating bands of pink to yellow, medium dense to dense, sand (representing highly weathered quartzite) and yellow to red, stiff to hard, clayey silt and silt (marking highly weathered phyllite) with distinct preservation of the minerals, textures and structures of the original bedrock material and mass.

The bedrock zone (zone III) is characterized by steeply dipping, alternating strata of dark grey, slightly weathered quartzite, and pink to grey, slightly weathered phyllite with total preservation of the minerals, textures and structures of the original bedrock material and mass. The use of a geological hammer for field determination of unconfined compressive strengths (as per BS EN ISO

14689-1:2003) shows the slightly weathered quartzites and phyllites to be classified as extremely weak to very weak rock. Field point load tests on block samples of the slightly weathered quartzites and phyllites support this interpretation for they yield point load strength indices [$Is_{(50)}$] between 0.5 and 3.3 MPa (Table 2).

Outcrops of bedrock are marked by a very irregular ground surface with protruding, narrow to broad, linear stumps of slightly weathered quartzite separated by linear, shallow depressions along slightly weathered (and less resistant) phyllite. These irregular ground surfaces mark the limits of "common excavation" (JKR, 2005) for the surfaces of the protruding quartzite stumps are marked by the teeth marks of scrapers attached to dozers (Figure 4).

**Figure 4:** Teeth marks (10 cm width) of scrapers on slightly weathered quartzite.

## SEISMIC REFRACTION SURVEYS

Seismic refraction line 1 in the north, runs generally downslope and is oriented 190°-010°, i.e., about parallel to the strike of the quartzites and phyllites. Three subsurface layers could be differentiated; the topmost layer with a thickness of 1 to 3 m and p-wave velocity of 420 m/s and the second layer with a thickness of 10 to 22 m and velocity of 727 m/s. The bottom layer has a p-wave velocity of 2330 m/s; its upper surface located some 12 to 24 m below the ground surface (Table 3).

Seismic refraction line 2 in the south runs upslope and is about parallel to the strike of the meta-sedimentary bedrock as it is oriented 160°-340°. Three subsurface layers could also be differentiated; the topmost layer with a thickness of 1 to 3 m and p-wave velocity of 488 m/s and the intermediate layer with a thickness of 7 to 25 m and velocity of 1160 m/s. The bottom layer has a p-wave velocity of 3724 m/s; its upper surface located some 12 to 28 m below the ground surface (Table 4).

P-wave velocities of the bedrock zone of 2330 m/s and 3724 m/s can be correlated with the laboratory determined velocities of 1571 to 3063 m/s of quartzite samples from the Kenny Hill Formation at Dengkil in Selangor Darul Ehsan (Mohd For Mohd Amin *et al.,* 2009). P-wave velocities of the saprock zone of 727 m/s and 1160 m/s in the present study furthermore, can be correlated with the field determined seismic velocities ($V_f$) of 1000 to 2000 m/s of *in situ* rippable quartzites of the Kenny Hill Formation at Dengkil (Mohd For Mohd Amin *et al.,* 2009).

## BOREHOLE INVESTIGATIONS

Field logs of the three boreholes show variations in SPT (or N) values with depth, indicating differences in resistance to penetration by the subsurface earth materials (Tables 5 to 7). Three broad zones, however, can be differentiated; the zones coinciding with the pedological soil, saprock and bedrock zones of the idealized weathering profile.

**Table 2:** Point load strength indices of quartzite and phyllite from the Sungai Perlis Beds.

| Rock Type | Locality | $Is_{(50)}$ MPa | Orientation of samples | Reference |
|---|---|---|---|---|
| Quartzite | Bukit Teluk Batu | 2.303 | Perpendicular to bedding | Raj (2010) |
| Quartzite | Kuala Dungun | 3.236 | Perpendicular to bedding | Zulnaidi Bin Ismail (2012) |
| Quartzite | Kuala Dungun | 1.195 | Parallel to bedding | |
| Phyllite | Kuala Dungun | 0.863 | Not specified | |

**Table 3:** Seismic refraction survey along line 1 (through borehole BH A).

| Layer | Velocity | Thickness | Interpretation |
|---|---|---|---|
| 1st (Top) | 420 m/s | 1 - 3 m | Pedological soil zone |
| 2nd (Middle) | 727 m/s | 10 - 22 m | Saprock zone - Moderately to highly & completely weathered quartzites & phyllites |
| 3rd (Bottom) | 2330 m/s | 12 - 24 m depth | Bedrock zone - Slightly weathered to fresh quartzites & phyllites |

In borehole A, the top 2.5 m thick, yellow brown, stiff, sandy silt (N=13) represents the pedological soil and overlies a 4.5 m thick, yellow brown and grey, hard sandy silt (N=50/90 mm) interpreted to be highly weathered phyllite and quartzite (Table 5). Below the highly weathered strata is a 5.5 m thick, reddish brown to grey, hard, sandy silt (N=50/15 mm and N=50/90 mm) that is interpreted to represent moderately weathered phyllite and quartzite (Table 5).

In borehole B, the top 2 m thick, yellow brown to grey, stiff, sandy silt (N=13) represents the pedological soil and overlies a 2 m thick, yellow to dark grey, stiff sandy silt (N=22) interpreted to be completely weathered phyllite and quartzite (Table 6). Below the completely weathered strata is a 4.5 m thick, yellow to grey, hard, sandy silt (N=50/225 mm, and N=50/180 mm) considered to represent highly weathered phyllite and quartzite. Below the highly weathered strata is a 5 m thick, reddish to yellow and grey, hard, sandy silt (N=50/90 mm and N=50/95 mm), interpreted to be moderately weathered phyllite and quartzite. At depths of 13.5 to 15 m, and from 18 to 19.5 m, cores show fractured yellow brown shale (RQD=0) interpreted to represent slightly weathered phyllite. Between 15 and 18 m depth is a yellow brown to grey, hard, sandy silt (N=50/95 mm) considered to represent moderately weathered phyllite and quartzite (Table 6).

In borehole C, which is located in a broad plain, the top 5 m thick, loose to medium dense sand (N=8 and N=11) represents Holocene beach sands that overlie some 5 m of very stiff, sandy silt (N=22) and medium dense, silty sand (N=25) considered to represent completely weathered phyllite and quartzite (Table 7). Below the completely weathered strata is some 3 m of very dense silty sand

**Table 4:** Seismic refraction survey along line 2 (through borehole BH B).

| Layer | Velocity | Thickness | Interpretation |
|---|---|---|---|
| 1st (Top) | 488 m/s | 1 - 3 m | Pedological soil zone |
| 2nd (Middle) | 1160 m/s | 7 - 25 m | Saprock zone - Moderately to highly & completely weathered quartzites & phyllites |
| 3rd (Bottom) | 3724 m/s | 12 - 28 m depth | Bedrock zone - Slightly weathered to fresh quartzites & phyllites |

**Table 5:** Field log of borehole A.

| Depth (m) | SPT (N) | Description | Interpretation |
|---|---|---|---|
| 0.0-1.0 | - | Top soil. sandy SILT | Pedological soil |
| 1.0-2.5 | 13 | Stiff, yellow brown to grey, sandy SILT | |
| 2.5-7.0 | 50/90 mm | Hard, yellow brown & grey, sandy SILT | HW phyllite & quartzite |
| 7.0-10.0 | 50/15 mm | Hard, reddish brown to grey, sandy SILT | MW phyllite & quartzite |
| 10.0-12.25 | 50/90 mm | | |

Note: HW = Highly Weathered; MW = Moderately Weathered

**Table 6:** Field log of borehole B.

| Depth (m) | SPT (N) | Description | Interpretation |
|---|---|---|---|
| 0.0-1.0 | - | Top soil. Sandy SILT | Pedological Soil |
| 1.0-2.0 | 13 | Stiff, yellow brown to grey sandy SILT | |
| 2.0-4.0 | 22 | Stiff, yellow to dark grey, sandy SILT | CW phyllite & quartzite |
| 4.0-5.5 | 50/225 mm | Hard, yellow to dark grey, sandy SILT | HW phyllite & quartzite |
| 5.5-8.5 | 50/180 mm | Hard, yellow brown, sandy SILT | |
| 8.5-11.5 | 50/90 mm | Hard, reddish to grey, sandy SILT | MW weathered phyllite & quartzite |
| 11.5–13.5 | 50/95 mm | Hard, reddish to yellow, sandy SILT | |
| 13.5-15.0 | Core | Fractured, brown shale. RQD=0% | Slightly weathered phyllite |
| 15.0-18.0 | 50/95 mm | Hard, brown to grey, sandy SILT | MW phyllite & quartzite |
| 18.0-19.5 | Core | Fractured, brown shale. RQD=0% | Slightly weathered phyllite |

Note: CW = Completely Weathered; HW = Highly Weathered; MW = Moderately Weathered

(N=50/225 m and N=50/190 mm) representing highly weathered quartzite that is inter-bedded with some 7 m of very dense, silty sand (N=50/90 mm and N=50/95 mm) representing moderately weathered quartzite (Table 7).

## DISCUSSION

### Idealized weathering profile correlation with p-wave velocities and SPT (N) values

Inherent differences in pedological and geological features allow the zones and sub-zones of the idealized weathering profile to be correlated with the seismic refraction surveys (Tables 3 and 4) and borehole logs (Tables 5, 6 and 7). The seismic refraction surveys in particular demarcate clearly the three broad weathering zones; the pedological soil with low p-wave velocities (<500 m/s), the bedrock with high p-wave velocities (>2300 m/s) and the saprock with intermediate velocities (700-1200 m/s) (Table 8).

The pedological soil furthermore, has low SPT values (N<15) whilst the saprock has larger values (N>20) and the bedrock zone requires coring. The SPT tests also allow indirect evaluation of the extent of weathering of the inter-bedded quartzites and phyllites; completely weathered quartzites and phyllites having moderate SPT values (N=20-30), whilst highly, and moderately, weathered quartzites and phyllites are characterized by very large SPT values of N=50/>100 mm, and N=50/<100 mm, respectively (Table 8).

### Idealized weathering profile and assignment of rock mass classes

It has been earlier pointed out that considerable modifications are required when the standard classifications for weathering of rock mass (IAEG, 1981; ISRM, 1981) are applied to meta-sedimentary bedrock in humid tropical areas in view of their continuous weathering to form residual soils (Komoo & Morgana, 1988). Modifications are also needed in view of the heterogeneous and anisotropic character of meta-sedimentary bedrock that results from the inter-bedding of different lithologic units

**Table 7:** Field log of borehole C.

| Depth (m) | SPT (N) | Description | Interpretation |
|---|---|---|---|
| 0.0-1.0 | - | Top soil. Sandy SILT | Top Soil |
| 1.0-2.0 | 8 | Loose, silty Sand | Holocene beach sands |
| 2.0-5.0 | 11 | Medium dense, silty SAND | Holocene beach sands |
| 5.0-8.0 | 22 | Stiff to very stiff, sandy SILT | CW phyllite |
| 8.0-10.0 | 25 | Medium dense, silty SAND | CW quartzite |
| 10.0-11.5 | 50/225mm | Very dense, silty SAND | HW quartzite |
| 11.5-14.5 | 50/90 mm | Very dense, silty SAND | MW quartzite |
| 14.5-16.0 | 50/190mm | Very dense, silty SAND | HW quartzite |
| 16.0-19.5 | 50/95 mm | Very dense, silty SAND | MW quartzite |
| 19.5-19.81 | 50/165mm | Very dense, silty SAND | HW quartzite |

Note: CW = Completely Weathered; HW = Highly Weathered; MW = Moderately Weathered

**Table 8:** Correlation between weathering sub-zones, p-wave velocities, borehole SPT (N) values and rock mass class (ISRM, 2007).

| Weathering Zone & Sub-zone | | Description | Zone Thickness | P wave Velocity | Borehole SPT | Rock Mass Class |
|---|---|---|---|---|---|---|
| Pedological Soil | IA, IB & IC | Agricultural soil horizons | ≈3 m | <500 m/s | N <15 | VI |
| Saprock | IIA | Completely weathered quartzites & phyllites | 7 - 25 m | 700 - 1200 m/s | N = 20 to 30 | V |
| | IIB | Highly weathered quartzites & phyllites | | | N = 50/>100 mm | IV |
| | IIC | Moderately weathered quartzites & phyllites | | | N = 50/<100 mm | III |
| Bedrock | IIIA | Slightly weathered quartzites & phyllites | 12 - 28 m depth | >2300 m/s | Coring | II |

as well as their variability in their orientations. The absence of fresh or unaltered meta-sedimentary bedrock at surface outcrops, and in boreholes also makes it difficult to define the boundary between rock and soil and thus disallows use of rock:soil ratios for classification of weathering (Komoo & Mogana, 1988).

Notwithstanding these limitations, the pedological soil (zone I) of the idealized weathering profile can be directly correlated with class VI of the ISRM (2007) scheme for classification and description of rock mass, or rock mass weathering grade VI of the IAEG (1981) and ISRM (1981) classification schemes. Sub-zone IIIA (bedrock) furthermore, is best correlated with class II, or grade II, of the said classification schemes in view of the slightly weathered quartzites and phyllites present. Saprock sub-zones IIA, IIB and IIC can then be correlated with classes V, IV and III, of the ISRM (2007) classification scheme, or mass weathering grades V, IV and III, respectively, of the IAEG (1981) and ISRM (1981) schemes.

### Idealized weathering profile and excavability

Field observations show excavations at Bukit Teluk Batu to have been created by scrapers and rippers attached to earth moving equipment of different manufacturers. These excavations can therefore, be classified as involving "common excavation" in terms of the Guidelines published by the Public Works Department of Malaysia (JKR, 2005). At the feet of most of the excavations furthermore, is found a very irregular ground surface with narrow to broad, protruding, linear stumps of slightly weathered quartzite separated by linear, shallow depressions along slightly weathered phyllite. This irregular ground surface marks the limits of "common excavation" for the surfaces of the protruding quartzite stumps are marked by the teeth marks of scrapers. The bedrock zone can thus be considered to be non-rippable, whilst the overlying pedological soil and saprock zones are rippable.

This difference in excavability can also be correlated with the charts of ripper performance based on seismic velocity developed by different manufacturers of earth moving equipment. In the case of the Caterpillar D8R Ripper for instance, schist, shale, sandstone and conglomerate are considered non-rippable when seismic velocities exceed 2400 m/s, but rippable when seismic velocities are less than 1800 m/s, and marginal when velocities are between 1800 and 2400 m/s (Caterpillar, 2000). In view of extreme variations amongst earth materials, however, the charts need to be recognized as being just one indicator of rippability (Caterpillar, 2000).

## CONCLUSION

Excavations in steeply dipping, interbedded quartzites and phyllites of the Lower Carboniferous Sungai Perlis Beds at Bukit Teluk Batu allowed formulation of an idealized weathering profile. The idealized profile consists of three broad zones, i.e., an upper pedological soil, an intermediate saprock, and the lower bedrock. The pedological soil is some 3 m thick and consists of yellow to red, firm to stiff, silty clays with quartz clasts and lateritic concretions. The saprock is some 7 to 25 m thick and consists of alternating bands of yellow to brown and grey, loose to dense, sands (representing completely to highly and moderately weathered quartzite), and soft to hard, clayey silts and silts (representing completely to highly and moderately weathered phyllite). Original bedrock minerals, textures and structures are distinctly preserved in the saprock which can be separated into sub-zones IIA, IIB and IIC. Bedrock is found at depths exceeding 12 m and is marked by an irregular surface of narrow to broad, linear stumps of slightly weathered quartzite separated by shallow depressions in slightly weathered phyllite.

Seismic refraction surveys show the pedological soil to be characterized by p-wave velocities of less than 500 m/s, whilst the bedrock zone has velocities exceeding 2300 m/s and the saprock, velocities of 700 to 1200 m/s. Boreholes show the pedological soil to have SPT (N) values of less than 15, whilst the saprock has (N) values exceeding 20, and the bedrock requires coring. Excavation of the pedological soil and saprock zones involved common excavation whilst the bedrock zone is non-rippable; its upper surface marked by the teeth marks of scrapers. It is concluded that the differentiation of weathering zones and sub-zones in areas of interbedded quartzites and phyllites will allow for prediction of their excavability.

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## AUTHORS CONTRIBUTION

JKR - project concept and writing-up (70%); ANH - seismic refraction surveys (15%); AZ - performed borehole investigations (15%).

## CONFLICTS OF INTEREST

The authors have no conflicts of interest to declare that are relevant to the content of this article.

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