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Physical Field Characterization of Boulders in Tropical Weathering Profile - A Case Study in Ulu Tiram, Johor Malaysia

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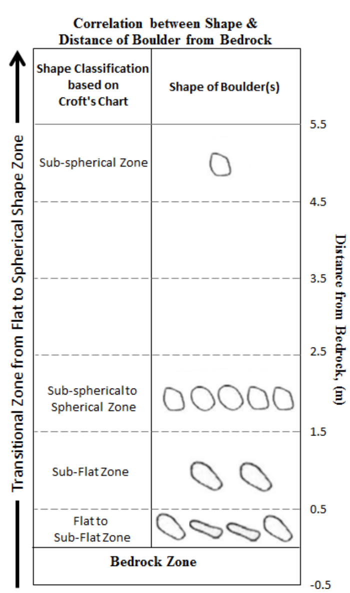
Graphical abstract



Abstract

Boulder is known as one of the weathered products that formed by the disintegration and decomposition process of jointed rock mass, forming into spherical form by the reaction of concentric spheroidal weathering process. However, the physical characteristic of boulder in weathering profile where it is formed is not well understood. This paper is aimed to investigate the physical field characterization of boulders in term of its size, shape and distance from bedrock in the weathering profile. The study has been carried out towards six panels located at a granite quarry in Ulu Tiram, Johor. The initial finding indicated that the shape and the diameter of boulder were changing by the increment of the distance from bedrock but the pattern of the shape of the boulder showed that it did not depend on its diameter. It can be concluded that there are significant pattern and correlation between shape, size and the distance of boulder in the weathering profile.

Keywords: Boulder; shape; size; distance; bedrock; weathering profile

Abstrak

Batu bundar dikenali sebagai produk luluhawa terbentuk dengan cara proses perpecahan dan penguraian jisim batuan bersendi, menjadikan bentuk sfera melalui tindakan proses luluhawa sfera sepusat. Walau bagaimanapun, ciri-ciri fizikal batuan bundar dalam profil luluhawa di mana ia terbentuk tidak begitu difahami. Kertas kerja ini bertujuan menyiasat pencirian fizikal batuan bundar di lapangan dari segi saiz, bentuk dan jaraknya dari batuan dasar dalam profil luluhawa. Kajian ini telah dijalankan terhadap 6 buah panel batuan terluluhawa yang terletak di sebuah kuari granit di Ulu Tiram, Johor. Hasil penemuan awal menunjukkan bahawa bentuk dan diameter batuan bundar berubah dengan peningkatan jarak dari batuan dasar tetapi bentuk bantuan bundar menunjukkan ia tidak bergantung kepada diameter. Dapat disimpulkan bahawa terdapat corak dan hubungkait yang ketara antara bentuk, saiz dan jarak batuan bundar dalam profil luluhawa.

Kata kunci: Batu bundar; bentuk; saiz; jarak, batuan dasar; profil luluhawa

1.0 INTRODUCTION

The characteristics of boulder like shape, size and distance from bedrock can provide useful information in civil engineering works especially in construction that involve sub-surface structure such as deep foundation construction and tunneling. The occurrence of boulder has been investigated by previous researchers in order to predict and determine the size, frequency and distribution of boulders beneath ground surface for sub-surface construction [1],[2],[3],[4],[5].

Boulders in humid tropics are commonly found more than 10 m and up to 60 m from ground surface and embedded in moderately to completely weathered profile (zone 3 to 5) of weathering granite [6],[7][8]. 70% to 90% of unweathered boulders are mostly located near the bedrock and less than 20% of weathered boulders are found embedded near the ground surface but there are almost no or rarely found embedded residual soil zone (grade VI) [9],[10],[11]. The boulders located near the ground surface are commonly found as spherical shaped and rounded edges while near the bedrock is in form of cubic shape with angular edges [6],[8],[12]. There are several factors influencing the formation of boulder in various shapes and sizes. The main factors that influencing the formation of boulder in block shape are the interaction between the joint orientation, joint set spacing and persistence of the rock mass [13],[14][15]. For boulder with spherical shape, it is formed by the reaction of fracturing, exfoliating, flaking, spalling, and concentric spheroidal weathering around the rock block [16],[17][18],[19].

Unfortunately, the correlation between the size, shape and distance of boulder from bedrock in the weathered material where it is formed is not well understood. Therefore, the aim of this study is to investigate the physical characterization and the typical pattern of granite boulder in the tropics.

2.0 RESEARCH METHOD

2.1 Field Identification and Site Investigation

The study has been carried out at a granite quarry site at Ulu Tiram, Johor, located at southeast of peninsular Malaysia on June, 2014 (Figure 1).

The geology of the study area is classified as intrusive granite rock [20]. Visual observation and qualitative examination that have been carried out at the site have also proved the classification of the rock type.

In order to investigate and identify the physical characteristics of the granite boulder in weathering profile systematically, the Ulu Tiram site denoted as Panel A has been divided into six smaller panels (001 to 006) with each panel is between 5 m to 6 m width and 5 m to 10 m high (Figure 2). The division of the panels enables the investigation and the data acquisition for boulders identification to be easier and more systematic. The selections of the panels are based on availability and distribution of boulders in weathering profile.

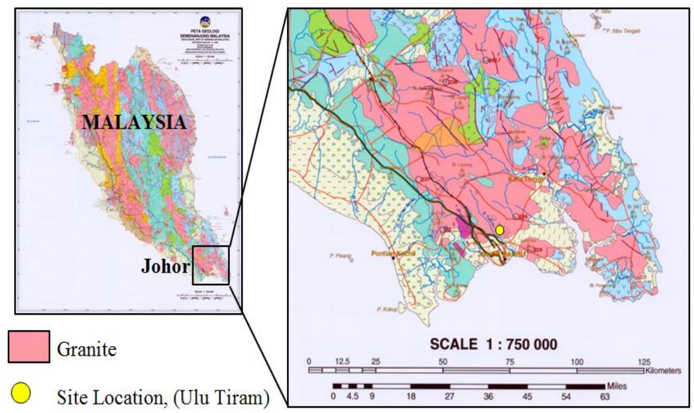


Figure 1 Location of study area in Ulu Tiram, Johor, Malaysia

According to the observation in Panel A, there are 12 boulders exposed to the weathering profile. The exposure of boulders on the weathering profile was due to the evacuation of friable weathered debris on the boulder surface. There is one boulder found in Panel A(001) and Panel A(005), two boulders in Panel A(002) and Panel A(004) and three boulders in Panel A(003) and Panel A(006). Two boulders were found in isolated position from the other boulder groups such as B9 and B12. Several boulders were formed in a cluster or group but in a scattered position from other clusters such as B2 and B3 in Panel A(002), B4,B5 and B6 in Panel A(003), B7 and B8 in Panel A(004) and B10 and B11 in Panel A(006).

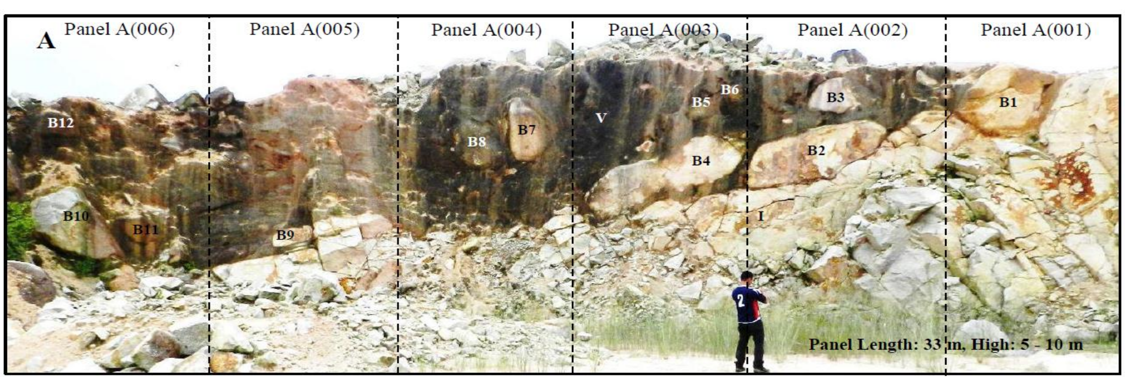


Figure 2 Division of Panel A for boulders assessment

This finding verifies the reports by Twidale [21] where the boulders could stand either in isolation or in groups or clusters in weathering profile.

In order to characterize the physical properties of boulder, there were several in-situ tests that had been carried out. The determination of the physical properties of the boulders includes the classification of shapes, measurement of boulders sizes, the depth and distance of boulder from the ground surface and bedrock, respectively.

2.2 Shape Classification

In order to determine and classify the shape of boulder, two (2) parameters were considered, namely the roundness and the sphericity [22],[23],[24],[25]. The sphericity can be briefly defined as how close a rock to form spherical shape while roundness is the measurement of smoothness of the rock edges [26]. Croft's chart is used in order to classify the shapes of boulders as carried out by Yang and Wu [27] as shown in Figure 3.

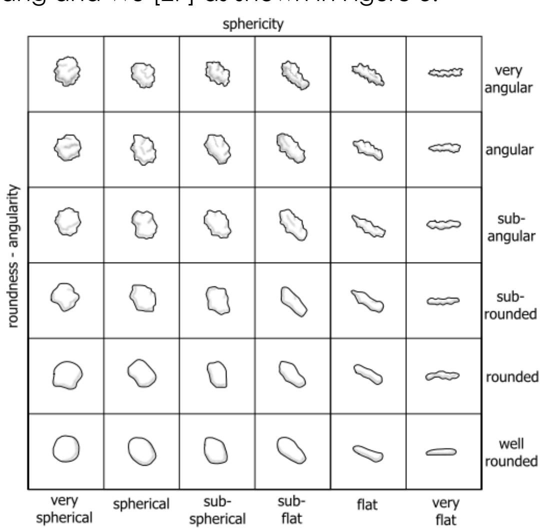


Figure 3 Classification of shapes by using Croft's chart [25]

The Croft's chart is very practical to be used in order to estimate and classify the shapes of the boulders in-situ without using any equipment. It is very simple, practical, fast and cheap. The data from the in-situ test is recorded in Table 1.

2.3 Measurement of Size and Depth of Boulder

In order to measure the size and the depth of the boulders systematically, window sampling technique as recommended by Priest [28] was adopted. Through the window sampling technique, a square window was selected and fixed on the selected weathering profile. Measuring tape was used to measure the longest diameter and depth of boulder in weathering profile [29]. The diameter and the distance of boulders from the bedrock and excavated surface in Panel A at TBI site are as recorded in Table 1. Due to the lack of information on the excavation level, only distance of the boulders from bedrock was analyzed in details. The measurement on the longest diameter, L showed that most of the boulders found and measured possess diameter larger than 300 cm as it is already classified by previous researchers [1],[2],[30]. The smaller boulder recorded in this Panel is B6 with diameter 0.86 m located 2.23 m from bedrock.

3.0 RESULTS AND DISCUSSION

The correlations among shape, size and distance of boulders from bedrock have been analyzed, discussed and demonstrated in the following sections.

3.1 Shape and Size of the Boulders

According to the field analysis, the boulders present in Panel A (001-006) formed in various sizes and shapes (sphericity) (Figure 4). From the field analysis, there are two factors that govern the size and the shape of the boulders: (1) the shape and size of a boulder located near the bedrock is governd by the presence of joints

Table 1 Physical characteristics of granite boulder in weathering profile

Panel	Boulder	Size of Boulder (m)		Distance from, (m)		*Shape (Sphericity & Roundness)	
		Longest, L	Shortest, S	Excavated Surface	Bedrock	Sphericity	Roundness
A(001)	B1	1.62	1.29	0.11	0.23	Spherical	Rounded
A(002)	B2	3.64	0.89	1.94	0.14	Flat	Sub Rounded
A(002)	B3	1.14	0.68	0.23	1.85	Sub Spherical	Sub Rounded
A(003)	B4	5.12	1.25	2.09	0.16	Flat	Sub Rounded
A(003)	B5	1.09	0.65	0.88	2.43	Sub Spherical	Rounded
A(003)	B6	0.86	0.68	0.51	2.23	Spherical	Well Rounded
A(004)	B7	2.26	1.34	0.92	2.03	Sub Spherical	Rounded
A(004)	B8	2.10	1.67	1.63	2.13	Spherical	Rounded
A(005)	B9	0.94	0.37	3.31	0.12	Sub Flat	Rounded
A(006)	B10	2.63	1.04	2.39	1.14	Sub Flat	Sub Angular
A(006)	B11	1.29	0.51	3.03	1.25	Sub Flat	Sub Rounded
A(006)	B12	1.07	0.64	0.34	4.64	Sub Spherical	Rounded

*Classification based on Croft's chart [25]

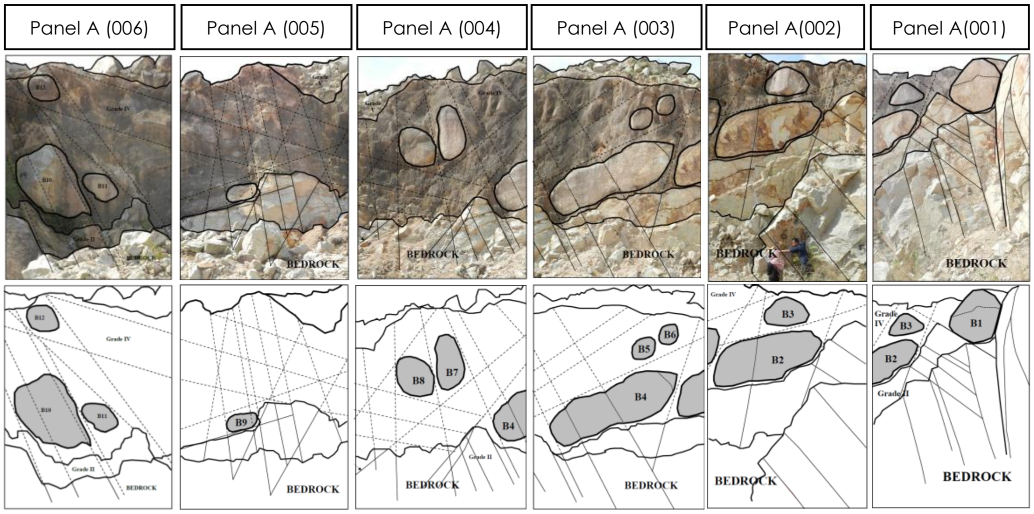


Figure 4 Influence of joints characteristics to the size and the shape of the boulders

characteristics such as joints frequency, joints orientation and joint spacing. This finding is consistent with the findings by previous studies [13],[14],[15]; (2) for boulder located near the ground surface, the size and shape are governed by the fractures and angular edges surrounding the boulder surface. The angular edges and corners on the boulder surface exposed greater surfaces and provided more surfaces to be attacked by weathering reaction especially by spheroidal weathering. This is consistent with the findings by Alejano *et al.* [31].

However, the correlation between the formation of boulder and the discontinuity characteristics is not discussed in detail in this paper. This study only focuses on the relationship between the shape and the diameter of the boulder in weathering profile of the weathered granite in tropics.

In order to analyze the relationship between the shape and the diameter of the boulders, the diameter of boulder (the longest, L and shortest, S) and the shape have been measured and classified. Figure 5 shows the classification of the boulder based on the shape and the diameter. As mentioned before, the shape was classified based on the longest, L and the shortest, S of the boulders. There were 6 boulders with diameter less than 1.5 m formed in sub-flat shape (2 nos.), sub-spherical shape (3 nos.) and spherical shape (1 nos.). No boulders with size less than 1.5 m found in flat shape group. It is due to the high disintegration and decomposition of the weathered boulder near the bedrock especially for smaller boulder.

This study also revealed that the presence of boulder with size less than 1.5 m in form of sub-flat to spheroidal shape is due to the fracturing and spheroidal weathering process. This is proving the findings by Røyne *et al.* [17].

Figure 5 indicates that the transition of the boulder shape from flat to spheroidal shape is relative with the decrement of the boulder size. But this is valid for the boulders that possess diameter larger than 1.5 m. This initial finding shows that the shape and the size of boulder can be indicators for the determination and classification of the weathering profile.

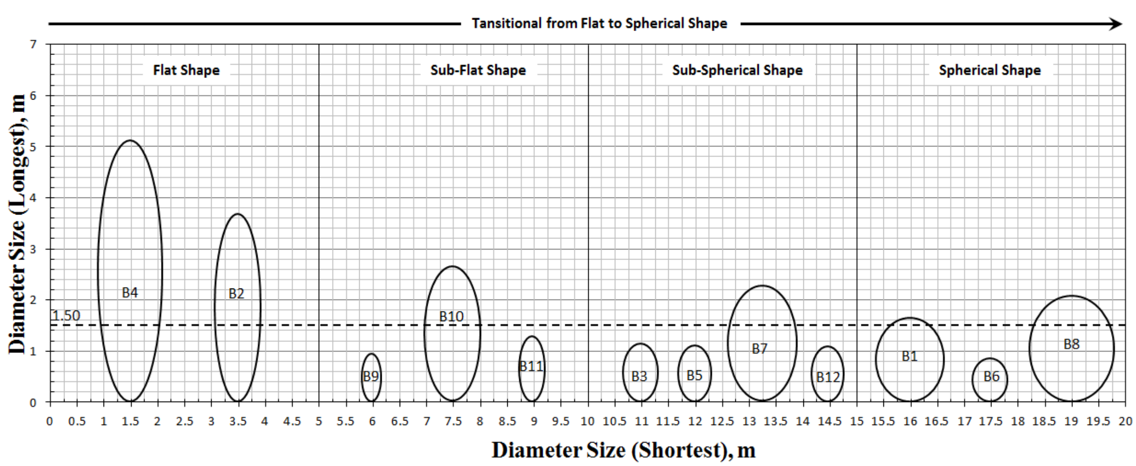


Figure 5 Correlation between the size and the shape of the boulders

3.2 Diameter Size and the Distance of Boulder from Bedrock

The data from Table 1 has been analyzed and its results are presented in Table 2 and Figure 6 for the analysis of the correlation between the longest diameter, L and the distance of boulders from bedrock in Panel A. The initial analysis shows that there is a converging pattern of the range size of boulder when the distance of boulder is increased from the bedrock.

The increment of the distance of the boulders from the bedrock as far as 0.12 m to 4.64 m was significantly reducing the range of boulder diameters. The increment of the distance from less than 1.0 m, 1.0 m to 2.0 m, 2.0 m to 3.0 m, 4.0 m to 5.0 m reduced the average diameter of the boulder from 2.83 m, 1.69 m, 1.58 m and 1.07 m, respectively.

The percentage of size the reduction is about 6% to 40 % when it is located more than 4.0 m from bedrock. It should be noted that this finding does not represent the other weathered granite profile but this initial finding can be an indicator for further research. Table 2 shows the summary of the diameters and the distances of boulders from bedrock in Panel A at Ulu Tiram site.

For the distance between 3.0 m to 4.0 m from bedrock, there are no boulders formed. This is due to the highly fractured of rock mass at the upper zone which led to severe weathering process. This process transformed the highly fractured rock into decomposed materials without forming any boulder with size larger than 300 cm. This finding is consistent with the report by Komoo [11].

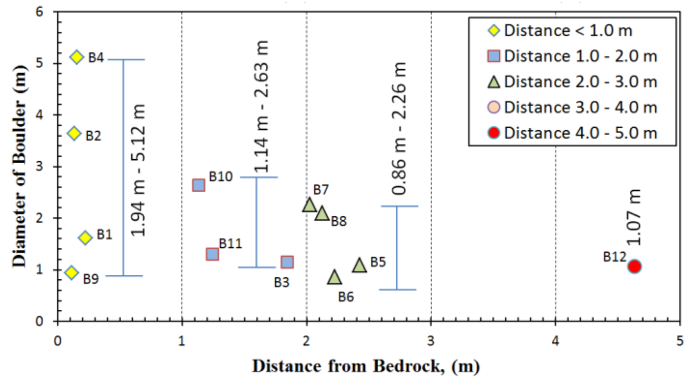


Figure 6 Correlation between diameter and distance of the boulder from the bedrock

Further investigation found that there is only one boulder with diameter size 1.07 m located more than 4.0 m from bedrock. According to the study of relict structure, this phenomenon is due to the presence of wide spacing of the joints which delaying the weathering process on the boulder. In other words, the formation of the single boulder at the upper zone is due to the presence of the wide spacing of joint around the boulder and made it late to be decomposed and disintegrated during weathering process. Such phenomenon is classified as mechanical weathering as reported by Dearman [32]. Generally, this study found that the diameter size of boulders decreased with the increment of distance from bedrock.

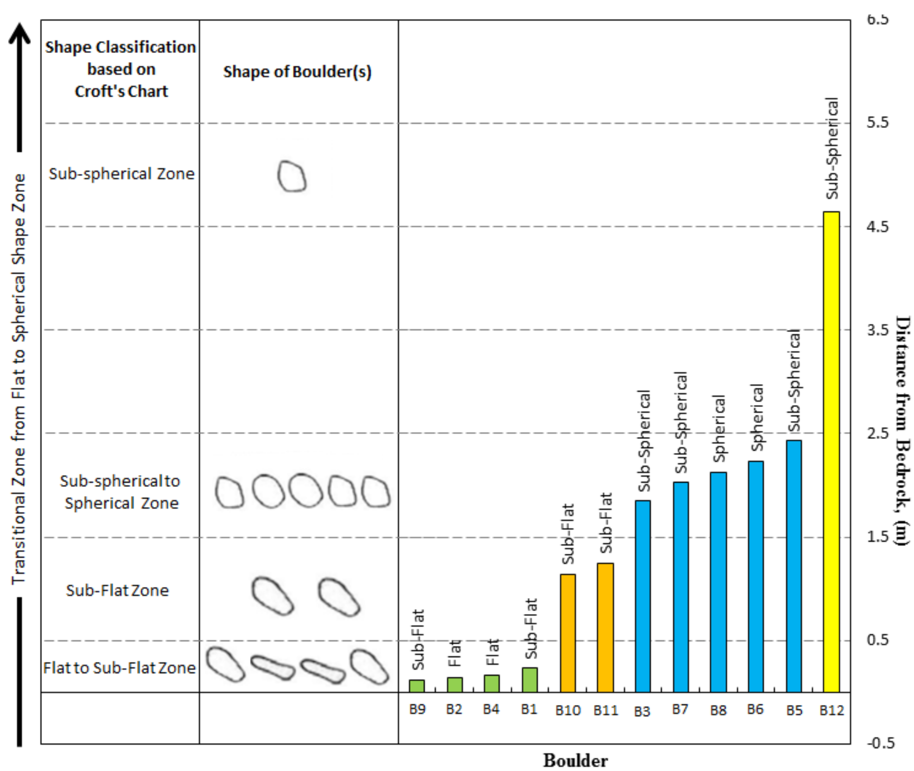


Figure 7 Relationship between the shape and distance of boulder from bedrock

Table 2 Summary of the distances and diameters of boulder in Panel A

Distance from Bedrock (m)	Boulder Diameter (m)		
	Max	Min	Mean
< 1.0	5.12	0.94	2.83
1.0 – 2.0	2.63	1.14	1.69
2.0 – 3.0	2.26	0.86	1.58
3.0 – 4.0	-	-	-
4.0 – 5.0	1.07	-	1.07

3.3 Shape and the Distance of Boulders from the Bedrock

The relationship between the shape and the distance of boulder from the bedrock can be demonstrated as shown in Figure 7. There are four boulders (B1, B2, B4 and B9) with flat to sub-flat shape and sub-rounded to rounded edges located less than 0.5 m from bedrock. Two boulders (B10 and B11) possess sub-flat shape located 0.5 m to 1.0 m from bedrock. Five boulders (B3, B5, B6, B7 and B8) with shape sub-spherical to spherical located 1.5 m to 2.0 m from bedrock and one boulder (B12) with sub-spherical shape located more than 4.5 m from bedrock

Mostly, boulders with flat to sub-flat shape with angular edges were found located near the bedrock. According to the field investigation, the formation of the boulders with flat to sub-flat shapes near the bedrock is due to the occurrence of the joint set spacing and the joint orientation within the boulder in the rock mass. The presence of the joint properties in the rock mass has disintegrated the rock to form the rock blocks or boulders with flat or sub-flat shapes. This is agreeing with the findings by Palmström *et al.* [15].

The increment of distance up to 1.5 m from bedrock relatively changes the shape of boulders (B10 and B11) to be sub-flat shape with sub-angular to sub-rounded edges. This is due to the disintegration and decomposition during spheroidal weathering at surrounding of the flat boulder. Additionally, the presence of joints and discontinuity around the boulder provides avenues for water to circulate and increases the reaction of disintegration and decomposition to form sub-flat shape. This verifies the findings by Raj [8] and Huber [33].

The shapes of the boulders are found in form of sub-spherical to spherical shape at the distance from 1.5 m to 2.5 m from the bedrock. At this stage, the spheroidal weathering is synchronous with the fracturing and spalling in order to form boulders in rounded shape. This is similar with the report by Røyne *et al.* [17]. In this process, spheroidal weathering was decomposing the outer surface of boulder to form concentric shells. It is gradually reducing the size and the volume of the boulder and forming the sub-flat boulder to become spherical shape. The shape of boulder became sub-spherical shape when the distance of boulder is more than 4.5 m bedrock zone. This is due to the continuous processes of disintegration and decomposition via the reaction of spheroidal weathering on the boulders which finally altering the shape and edges of boulder to become sub-spherical shape. Such process was revealed by Fletcher et al. [34] and Buss et al. [35]. Furthermore, weathering process at the upper zone near the ground surface is very severe compared to the lower zone. This leads to the formation of boulder in form of spherical shape with rounded surfaces.

4.0 CONCLUSION

The physical field characterizations of boulders had been done in Ulu Tiram, Johor. The shape of boulder is relatively changed from the shape from flat to spheroidal with the decrement of the boulder size, but this is valid for the boulders that possess diameter larger than 1.5 m. The increase of the distance from the bedrock will reduce the range diameter of the boulders. It's meant that the range diameter sizes of boulders become smaller when the distance of the boulders from bedrock increases. The initial conclusion that can be made that the shape of boulder is significantly changed when it distance from bedrock is increased. In other words, the shape of the embedded boulder in weathering profile changes from flat to spherical when its distance from the bedrock is increased.

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