DOI : https://doi.org/10.7186/wg481202201

Rock-soil transition in weathering of a porphyritic biotite granite

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Abstract: Concentric layers of weathered materials around core-stones show the porphyritic biotite granite to experience sequential, but gradational, changes in visible features, textures and mineralogy as it transforms from 'rock' into 'soil'. The changes start with the opening-up of grain boundaries and micro-cracks (stage 1) followed by their dark brown staining (stage 2) and the subsequent alteration (to sericite and clay minerals) of groundmass plagioclase feldspar grains (stage 3). Biotite flakes are then bleached and altered (to chlorite and clay minerals) (stage 4) before there starts alteration (to sericite and clay minerals) of groundmass alkali feldspar grains (stage 5) and finally alteration (to sericite and clay minerals) of the alkali feldspar phenocrysts (stage 6). Quartz grains are not altered during these stages of weathering, but disaggregate and reduce in size due to continual opening-up of grain boundaries and micro-cracks. Increasing stages of weathering are marked by decreasing dry unit weights, dry densities and uniaxial compressive strengths, but increasing apparent porosities. The transition between 'rock' and 'soil' occurs during stage 6 when all plagioclase, and most alkali feldspar, groundmass grains have been altered as are some alkali feldspar phenocrysts. Stage 6 is marked by large apparent porosities (>18%) but low values of dry unit weight (<20.81 kN/m^3), dry density (<2,122 kg/m^3) and uniaxial compressive strength (<1.8 MPa).

Keywords: Porphyritic biotite granite, weathering, rock-soil transition

INTRODUCTION

The changes in mineralogy and texture that occur when rocks are weathered have been investigated with the aid of various chemical and petrological methods as well as laboratory index tests or assessed indirectly in the field (Bell, 2000). Several indices have been derived to quantify the changes in purely geological properties; some of them applied to correlate with, and indirectly determine, the engineering properties of weathered rock (Irfan, 1996). A review of the various methods used to characterize the weathering of rock is given in Martin & Hencher (1986) as well as Irfan (1996), and Bell (2000).

Several workers have applied essentially physical criteria to characterize the weathering of rock as Melton (1965) who used staining and friability of rock fragments to identify the degree of chemical weathering, and Ollier (1965) who proposed a similar scale based on friability alone to describe the weathering of granite. Onodera *et al.* (1974) used the number and width of micro-cracks as an index of the physical weathering of granite, while Uriel & Dapena (1978) proposed a void index to quantify the degree of physical weathering of granite. Iliev (1966) proposed a coefficient of weathering for granitic rock based on ultrasonic velocities in fresh, and weathered rock, whilst Irfan & Dearman (1978a) proposed a micro-petrographic index based on the ratio of primary to secondary minerals, micro-cracks and voids, to assess the grade of weathering of granite. After an extensive testing program, Irfan & Dearman (1978b) concluded that the quick absorption, Schmidt hammer, and point load strength, tests were reliable field tests for determination of a quantitative weathering index for granite. The main limitation in the use of such physical criteria to define the degree of weathering is that they can only be applied to material that is still sufficiently cohesive to be regarded as rock (Thomas, 1974).

Chemical analyses and calculation of various elemental, compound or molecular ratios, have also been widely used to define the state of weathering of rock material. Irfan (1996) applied several of these indices in the assessment of weathered granites in Hong Kong and concluded that the silica-to-alumina ratio as well as the Parker index (Parker, 1970) and the mobiles index (Irfan, 1996) were good indicators of the degree of weathering. Duzgoren-Aydin *et al.* (2002), however, applied thirty different chemical indices of weathering in their study of a weathering profile over crystal-vitric tuff in Hong Kong and concluded that application of these indices to directly scale changes in the physical state of rock material may not be warranted due to the complications involved.

0126-5539; 2682-7549 / Published by the Geological Society of Malaysia.

Duzgoren-Aydin & Aydin (2006) in a comprehensive re-assessment of chemical weathering indices for felsic igneous rocks in Hong Kong furthermore, concluded that chemical weathering indices were not be as useful in determining weathering grades as was originally thought, though they could be used as tools to detect chemical heterogeneities.

In weathering profiles over granite, different stages of weathering of rock material are often present at similar depths, as in the concentrically developed stages of weathering around core-stones and core-boulders (Dearman, 1974). Dearman (1976), and Lee & de Freitas (1989), have thus, emphasized the need to differentiate between "weathering of rock material" and "weathering of rock mass". Martin & Hencher (1986) have also pointed out that weathering profiles are characterized by heterogeneous earth materials at various stages of decomposition and/or disintegration as weathering processes are rarely sufficiently uniform to give gradual and predictable changes in mineralogical and textural properties.

In an earlier publication Raj (1985) has described the characterization of the weathering profile developed over porphyritic biotite granite at Km 31 of the Kuala Lumpur - Karak Highway. In the publication, Raj (1985) briefly described the different stages of weathering of bedrock that developed around core-stones and core-boulders, and that extended inward from discontinuity planes in the bedrock mass. In this short note, the concentric rings of weathered materials around core-stones are further discussed in order to define more clearly the transition between 'rock' and 'soil' in the weathering of the porphyritic biotite granite.

METHODOLOGY

Several core-stones were first collected from the weathering profile over porphyritic biotite granite at Km 31 of the Kuala Lumpur - Karak Highway (Figure 1). These litho-relicts were taken to the laboratory where they were diamond-sawn into slabs of variable thicknesses. The concentric rings of weathered materials around the rims of the slabs were then examined with a hand lens to identify differences in visible features as staining, colour, texture

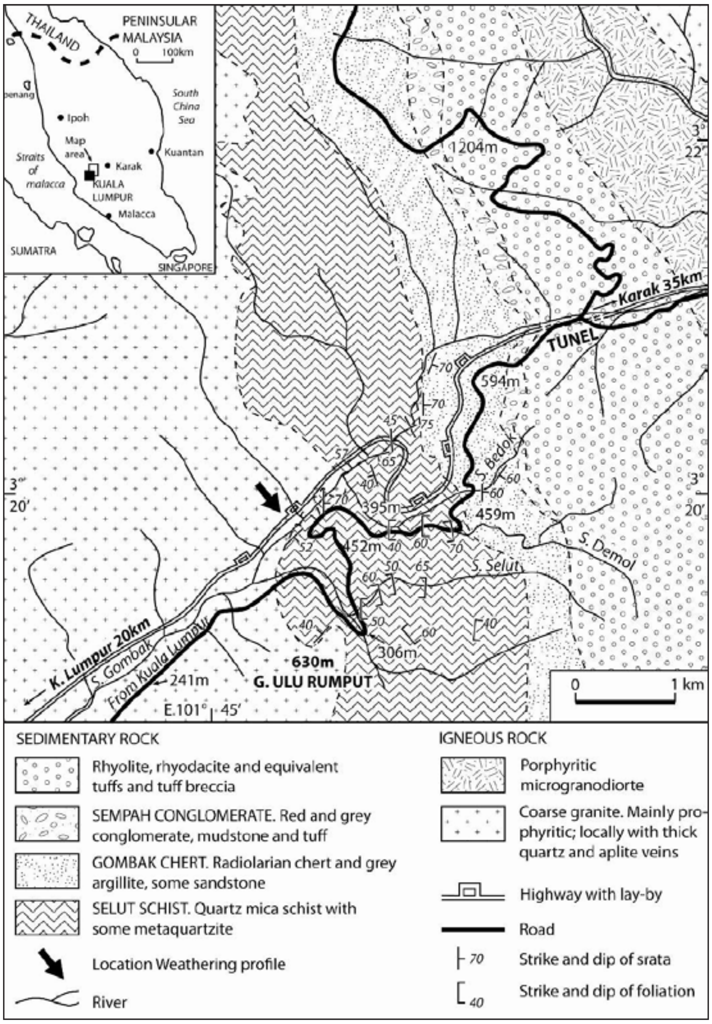

Figure 1: Geology Map of Genting Sempah area, Pahang & Selangor (Haile *et al*., 1977).

and appearance of mineral grains. The extent of alteration of feldspar phenocrysts and groundmass grains was also determined following the method of Irfan & Dearman (1978b) (Table 1). Thin-sections were then prepared of the concentric rings of weathered materials and a petrological microscope used to identify changes in texture and mineralogy of the phenocrysts and groundmass grains.

Variations in visible features as well as textural and mineralogical changes were then used to define different stages of weathering of the granitic bedrock. This procedure of identifying different stages of weathering follows that of earlier workers as Ruxton & Berry (1957) who defined stages of weathering of granitic rock material in terms of staining and alteration of mineral grains as well as the friability of material. Baynes *et al.* (1978), Irfan & Dearman (1978a) and Dearman *et al.* (1978) furthermore, have adopted a similar procedure to define different stages of weathering of granite in southwest England on the basis of separate assessments of the effects of physical disintegration and chemical decomposition.

Small tetrahedral blocks of the different stages of weathering were also sawn-out from the slabs and their unit weights, densities and apparent porosities determined by the saturation and buoyancy method of ISRM (1979). Several of these tetrahedral blocks were also loaded to failure in a compression machine following standard procedure in order to determine uniaxial compressive strengths (ISRM, 1981).

GEOLOGICAL SETTING

The weathering profile at the slope cut at Km 31 of the Kuala Lumpur – Karak Highway is developed over porphyritic biotite granite (Figure 1). This bedrock forms part of the eastern lobe of the Late Triassic (199-210 Ma) Kuala Lumpur Granite (Ng, 1992) and has given rise to a fluvially dissected, hilly to mountainous terrain of steep slopes and narrow, deep valleys. The bedrock continues to outcrop to the west over a distance of about 10 km, but to the east, is in contact with a sequence of schists, and sedimentary and volcanic rocks, that occur as a roof pendant within the Main Range Granite (Haile *et al.*, 1977). The granitic bedrock is strongly jointed and cut by a number of moderately to steeply dipping faults of variable strike. A number of epidote and quartz feldspar veins with tourmaline as well as aplite and leucocratic microgranite dykes are also seen within the bedrock.

The grey bedrock is medium to coarse grained and usually porphyritic with large alkali feldspar phenocrysts (up to 4 cm in length). The essential minerals are quartz, alkali feldspar, plagioclase feldspar and biotite, whilst the accessory minerals include apatite, tourmaline and zircon. Quartz occurs as anhedral crystals, filling interstices in the groundmass and sometimes forms small phenocrysts. The alkali feldspars include microcline, orthoclase and perthites, and occur both as phenocrysts and as fine to medium grained crystals in the groundmass. The alkali feldspars sometimes contain quartz, biotite and plagioclase inclusions. The plagioclase feldspars, of an albite to andesine composition, are usually found as euhedral to subhedral, fine to medium grained crystals in the groundmass and are often sericitized. The biotites occur as fine to medium grained, generally euhedral crystals and are found both as disseminated grains and as aggregates within the bedrock material. Close to the faults, hydrothermal alteration of the plagioclase feldspar and biotite grains has occurred.

RESULTS

Stages of weathering

Variations in visible features as well as textural and mineralogical changes allowed differentiation of six generalized stages of weathering of the porphyritic biotite granite (Tables 2 and 3). These stages of weathering, as illustrated in Plate 1, start with the opening-up of grain boundaries and micro-cracks (stage 1) followed by their dark brown staining with secondary iron oxides and hydroxides (stage 2). The groundmass plagioclase feldspar grains then start to alter (to sericite and clay minerals) (stage 3) before there is bleaching and alteration (to chlorite and clay minerals) of biotite flakes (stage 4). There is then the alteration (to sericite and clay minerals) of the groundmass alkali feldspar grains (stage 5) before there starts alteration (to sericite and clay minerals) of alkali feldspar phenocrysts (stage 6). Quartz grains are not altered

Table 1: Extent of alteration of feldspar grain (after Irfan & Dearman, 1978b). (Material from probed feldspar grain rubbed between thumb and finger).

Feel	Description	Interpretation
Gritty	Partially decomposed	Feldspar grain altered to sericite & clay along micro-fracture & cleavage planes only
Powdery (Silky)	Completely decomposed	Feldspar grain entirely altered to mainly sericite & some clay
Clayey	Completely decomposed	Feldspar grain entirely altered to clay & some sericite

during these stages of weathering, but do disaggregate and reduce in size due to the continual opening-up of grain boundaries and micro-cracks.

Physical properties of different stages of weathering

Physical properties of samples from the different stages of weathering are gradational in nature though there are some differences between stages (Table 4). Unaltered (stage 0), and stage 1 weathered, bedrock material is characterized by large dry unit weights (>25.63 kN/m^3) and dry density (>2,613 kg/m^3), but low apparent porosities (<2.1%). Stage 6 weathered bedrock material, however, is characterized by relatively low dry unit weights (<20.81 kN/m^3) and dry density (<2,122 kg/m^3), but large apparent porosities (>18.4%).

Table 2: Stages of weathering of the porphyritic biotite granite.

Stage	Hand specimen description	Thin-section description
6	Yellowish 'rock' material with open grain boundaries & micro-cracks. Some brown stains. Groundmass feldspar grains all appear altered (gritty to clayey). Some feldspar phenocrysts altered (powdery to gritty). Quartz grains & some feldspar phenocrysts appear unaltered. 'Rock' material has weak fabric & can disaggregate when dry samples are agitated in water.	All groundmass plagioclase & alkali feldspar grains are altered (to sericite & clay minerals). A few alkali feldspar phenocrysts are similarly altered. Biotite flakes all appear altered (to sericite & clay minerals). Quartz grains appear unaltered. Grain boundaries & micro-cracks are all open.
5	Yellowish rock material with brown stains along some grain boundaries & micro-cracks. Stains prominent close to bleached biotite flakes. Quartz grains & alkali feldspar phenocrysts appear unaltered. Groundmass feldspar grains (≈50% of all feldspars) are altered, yellow & gritty to powdery.	Brown stains along grain boundaries & micro-cracks, often extending out from altered biotite flakes. All plagioclase, & most alkali feldspar, groundmass grains are altered (to sericite & clay minerals). Quartz & alkali feldspar phenocrysts appear unaltered. Grain boundaries & micro-cracks are open.
4	Brownish grey rock material with brown stains along grain boundaries & micro-cracks. Most essential mineral grains appear unaltered with vitreous to sub-vitreous lustres. Many feldspar grains (≈30% of all feldspars) are white to yellow & gritty.	Brown stains along most grain boundaries & micro-cracks. Most essential mineral grains appear unaltered. Most groundmass plagioclase grains are altered (to sericite & clay minerals). Some bleached biotite flakes. Many open grain boundaries & micro-cracks.
3	Dark brownish grey rock material. Brown stains along grain boundaries & micro-cracks. Essential mineral grains appear unaltered with vitreous to sub-vitreous lustres. Some feldspar grains (≈10% of all feldspars) are white to yellow & gritty.	Brown stains along most grain boundaries & micro-cracks. Most essential mineral grains appear unaltered. Many groundmass plagioclase grains are altered (to sericite & clay minerals). Many open grain boundaries & micro-cracks.
2	Brownish grey rock material. Brown stains along some grain boundaries. Essential mineral grains appear unaltered with vitreous to sub-vitreous lustres.	Brown stains along some open grain boundaries & micro-cracks. Essential mineral grains appear unaltered except for several sericitized plagioclase grains.
1	Grey rock material. Essential mineral grains appear unaltered with vitreous to sub-vitreous lustres. Some open micro-cracks.	Essential mineral grains are unaltered. A few sericitized plagioclase grains. A few open grain boundaries & micro-cracks.
0	Grey rock material. Essential mineral grains (quartz, biotite, alkali feldspar & plagioclase) unaltered with vitreous to sub-vitreous lustres. (Unweathered).	Essential mineral grains (quartz, biotite, alkali feldspar & plagioclase) are unaltered. A few sericitized plagio-clase grains. Tight grain boundaries & micro-cracks.

Table 3: Variations in visible features, textures and mineralogy during weathering.

Stage	Grain boundaries & micro-cracks	Essential (Primary) Minerals						Secondary Minerals	
		Groundmass Plagioclase	Alkali Feldspar		% Felspar Grains Altered	Biotite	Quartz	Silt Size (Sericite)	Clay Size
			Groundmass	Phenocrysts					
6	Most open with yellow stains	All altered	All altered	A few altered	≈70%	All altered	Unaltered	Abundant	Some
5	Some open with brown stains	All altered	Most altered	Unaltered	≈50%	Many altered	Unaltered	Many	A few
4	Most open with brown stains	Most altered	Some altered	Unaltered	≈30%	Some altered	Unaltered	Some	A few
3	Many open with brown stains	Some altered	Unaltered	Unaltered	≈10%	Fresh	Unaltered	A few	A few
2	Some open with brown stains	Unaltered	Unaltered	Unaltered	0%	Unaltered	Unaltered	A few	None
1	A few open. No stains	Unaltered	Unaltered	Unaltered	0%	Unaltered	Unaltered	A few	None
0	Tight. No stains	Unaltered	Unaltered	Unaltered	0%	Unaltered	Unaltered	A few	None

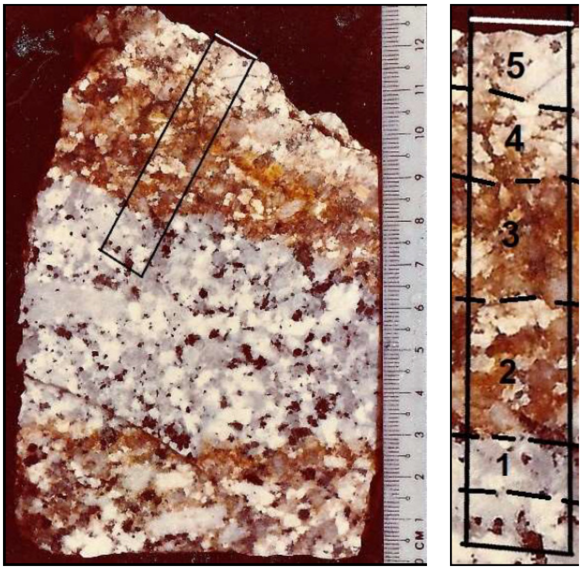

Plate 1: Weathering stages 1 to 5 around core-stone.

Table 4: Physical properties of different stages of weathering.

Sample Number	Stage of Weathering	Dry Unit Weight (kN/m^3)	Dry Density (kg/m^3)	Apparent Porosity (%)
A1	0	25.71	2,621	1.8
A2	0	25.65	2,615	2.1
A3	0	25.90	2,641	1.1
A4	0	25.95	2,646	0.9
A5	1	25.65	2,615	2.1
A6	1	25.63	2,613	2.1
A7	2	25.37	2,586	2.4
A8	2	25.34	2,584	2.5
A9	2	25.14	2,564	3.5
A10	2	25.30	2,580	3.0
A11	3	23.64	2,411	8.3
A12	3	23.83	2,430	7.6
A13	3	24.48	2,496	5.8
A14	3	24.60	2,508	5.4
A15	3	24.31	2,479	6.5
A16	3	23.96	2,443	7.8
A17	4	22.91	2,336	12.2
A18	4	22.83	2,328	12.5
A19	4	22.63	2,307	12.9
A20	4	22.68	2,313	12.4
A21	4	22.38	2,282	12.6
A22	4	22.50	2,294	12.4
A23	5	22.00	2,243	14.7
A24	5	21.90	2,233	15.1
A25	5	21.93	2,236	14.3
A26	5	21.80	2,223	15.2
A27	5	21.95	2,238	14.2
A28	5	21.98	2,241	14.5
A29	6	20.61	2,101	19.2
A30	6	20.73	2,114	19.0
A31	6	20.81	2,122	18.4
A32	6	19.86	2,025	21.8
A33	6	19.50	1,988	20.7

Stages 2 to 5 weathered bedrock bedrock material furthermore, show intermediate and decreasing values of dry unit weight and dry density, but increasing values of apparent porosity (Table 4). Stages 2, 3, 4 and 5 weathered, bedrock material are thus characterized by dry unit weights ranging from 25.14-25.37 kN/m^3 through 23.64-24.60 kN/m^3 and 22.38-22.91 kN/m^3 to 21.95-22.00 kN/m^3, respectively. Their corresponding dry densities range from 2,564-2,586 kg/m^3, through 2,411-2,508 kg/m^3 and 2,282-2,336 kg/m^3 to 2,223-2,243 kg/m^3, respectively. Values of apparent porosity decrease distinctly from stages 2 through 3 and 4 to 5 with values of 2-4 %, 5-9%, 12-13% and 14-16%, respectively.

Uniaxial compressive strength

Samples of the different stages of weathering show gradational changes in uniaxial compressive strengths, though there are differences between the various stages (Table 5). Unaltered (stage 0), and stage 1 weathered, porphyritic biotite granite is characterized by large uniaxial compressive strengths (>94.1 MPa), whilst stage 6 weathered bedrock material is characterized by very low strengths (<1.8 MPa).

Stages 2 to 5 weathered bedrock bedrock material furthermore, show intermediate, but decreasing values of uniaxial compressive strength (Table 5). Stages 2, 3, 4 and 5 are thus characterized by uniaxial compressive strengths ranging from 53.5-67.6 MPa through 22.2-46.1 MPa and 7.5-14.5 MPa, to 3.2-4.6 MPa, respectively.

DISCUSSION

As weathering proceeds, a 'rock' material will become increasingly decomposed and/or disintegrated until ultimately a 'soil' is formed (Bell, 2000). The terms 'rock' and 'soil' material have been defined in various ways, though for geotechnical purposes, the best definitions are those by Terzaghi & Peck (1948). Terzaghi & Peck (1948, p. 4) have simply defined 'soil' as being "a natural aggregate of mineral grains that can be separated by such gentle means as agitation in water", whilst 'rock' would not be able to be so separated.

In the reduction process of a rock to a soil, various stages can be recognized, though it is almost inevitable that the boundaries between the stages are gradational (Bell, 2000). This has been shown in the present study where six sequential, but gradational, changes in visible features, textures and mineralogy can be differentiated in the concentric rings of weathered materials formed around core-stones of the porphyritic biotite granite (see Section 4.1).

Stage 6 weathered bedrock material represents the transition between rock and soil material for it comprises natural aggregates that can be disaggregated when dry specimens are agitated in water (Table 2). In this stage, almost all the plagioclase, and most alkali feldspar, groundmass grains have been altered (to sericite and clay minerals) as are a few alkali feldspar phenocrysts (Table 3). Strong bonds between individual mineral grains that existed in the earlier stages of weathering are thus no longer present in the stage 6 weathered bedrock material. Alteration of the groundmass feldspar grains has thus led to the loss of bonds between individual grains.

The rock - soil transition furthermore, is gradational in nature as shown by differences in the physical properties of samples from stage 6 weathered bedrock material (Table 4) and the decreasing uniaxial compressive strengths (Table 5). Interestingly enough, the samples from stage 6 weathered bedrock material samples with their low uniaxial compressive strengths (<1.8 MPa) would be classified as extremely weak to weak rock materials in existing classifications of earth materials as those by ISRM (1983) and IAEG (1989).

CONCLUSION

Concentric rings of weathered materials developed around core-stones show the porphyritic biotite granite to experience sequential, but gradational, changes in visible features, textures and mineralogy as it transforms from 'rock' into 'soil'. The changes start with the opening-up of grain boundaries and micro-cracks (stage 1) followed by their dark brown staining (stage 2) and the subsequent alteration (to sericite and clay minerals) of groundmass plagioclase feldspar grains (stage 3). Biotite flakes are then bleached and altered (to chlorite and clay minerals) (stage 4) before there starts alteration (to sericite and clay minerals) of groundmass alkali feldspar grains (stage 5) and finally alteration (to sericite and clay minerals) of alkali feldspar phenocrysts (stage 6). Quartz grains are not altered during these stages of weathering, but disaggregate and reduce in size due to continual opening-up of grain boundaries and micro-cracks. Increasing stages of weathering are marked by decreasing dry unit weights, dry densities and uniaxial compressive strengths, but increasing apparent porosities. The transition between 'rock' and 'soil' occurs during stage 6 when all plagioclase, and most alkali feldspar, groundmass grains have been altered as have been some alkali feldspar phenocrysts. Stage 6 weathered bedrock material is characterized by large apparent porosities (>18%) but low values of dry unit weight (<20.81 kN/m^3) and dry density (<2,122 kg/m^3) as well as low uniaxial compressive strengths (<1.8 MPa).

ACKNOWLEDGEMENTS

Grateful thanks are extended to the University of Malaya for an F-Vote research grant that provided financial assistance for fieldwork involved in preparation of this article. Grateful thanks are also extended to the two anonymous reviewers for their valuable comments.

Table 5: Uniaxial compressive strength of different stages of weathering.

Sample Number	Stage of weathering	Uniaxial Compressive Strength (MPa)
B1	0	174.30
B2	0	151.10
B3	0	128.30
B4	1	101.30
B5	1	94.10
B6	2	67.70
B7	2	53.50
B8	3	46.10
B9	3	44.79
B10	3	37.41
B11	3	29.85
B12	3	26.65
B13	3	22.21
B14	4	14.50
B15	4	11.48
B16	4	10.04
B17	4	9.26
B18	4	8.11
B19	4	7.52
B20	5	4.56
B21	5	4.40
B22	5	4.29
B23	5	3.93
B24	5	3.66
B25	5	3.18
B26	6	1.82
B27	6	1.79
B28	6	1.48
B29	6	1.42
B30	6	0.82
B31	6	0.29

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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Manuscript received 4 September 2021;
Received in revised form 11 January 2022;
Accepted 13 January 2022
Available online 26 April 2022