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Editorial Note: Discussion on this Technical Note will be welcomed.

Technical Note

A suggested method for the classification of rock mass weathering by a ratings system

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Abstract

The author expresses the doubts that many have with regard to the efficacy of the present methods of describing rock mass weathering. As an alternative to these methods the author recommends the use of a ratings system which classifies weathering in terms of engineering significance. The author also recognizes that all ratings systems which are successful have been developed over the years as a consequence of the experience of many users, but proposes, as a starting point for further discussion, a ratings system developed during engineering geological fieldwork in Spain.

Introduction

The present system of classifying rock mass weathering stems from that proposed by the Working Party on Core Logging of the Engineering Group of the Geological Society (Anon 1970). These recommendations were taken over, in principle, into the report of the Engineering Group Working Party on 'The Description of Rock Masses for Engineering Purposes' (Anon 1977) and thence into the British Standards for

TABLE 1. *Standard terminology for description of weathering of rock cores, outcrops and material*

Weathering description	Grade number	Rock core grades	Rock outcrop grades	Rock material descriptive terms
Fresh	IA	No visible sign of weathering	No visible sign of weathering	Rock material weathering can be described by using terms such as 'discoloured', 'decomposed' and 'disintegrated', with appropriate qualifications (very, slightly, etc.).
Faintly weathered	IB	Weathering limited to the surface of major discontinuities	Weathering limited to the surface of major discontinuities	
Slightly weathered	II	Weathering penetrates through most discontinuities, but only slight weathering of rock material	Weathering penetrates through most discontinuities, but only slight weathering of rock material	
Moderately weathered	III	Weathering through discontinuities and material, but the material is not friable	Less than half the rock decomposed to soil. Discoloured, perhaps fresh rock, present as a continuous framework	
Highly weathered	IV	Weathering through discontinuities and material and some material friable	More than half the rock weathered to soil. Discoloured, perhaps even some fresh rock, present as discontinuous framework	
Completely weathered	V	All material decomposed and friable but rock texture and structure preserved	All rock weathered to soil. Structure and texture largely intact	
Residual soil	VI	A soil with all traces of original structure and texture destroyed	All rock weathered to soil. All texture and structure destroyed. No significant transportation of soil visible	

Site Investigation (BS 5930:1981) to form their 'Scale of weathering grades of rock mass'. The classifications currently recommended for use are given in succinct form in Table 1.

Both systems were a good idea at the time and the basic concept that weathering starts at the joints and migrates from the joints into the rock material is still valid. However, after some twenty years experience of trying to describe weathering in cores and rock masses using these systems, the author has come to the conclusion that:

(1) the scales have no direct relevance to engineering significance;
(2) they are not appropriate to all types of rock;
(3) mass weathering cannot be deduced from core logging from multiple boreholes and that the similarity in terminology between core and mass weathering terminology leads to misinterpretation and, consequently;
(4) the time is ripe to think of something new.

The engineering significance of weathering

The main problems in rock engineering are connected with the characteristics of discontinuities and the properties and distribution of rock materials; together they are key elements of mass properties. Weathering is a non-uniform deterioration of the rock mass which will add further complexity to an already complex situation. The function of engineering geology and site investigation is to detect problems of geological origin which are of significance in civil and mining engineering; accordingly a classification of weathering should aid problem recognition in terms of engineering significance.

In its early stages, weathering is confined to discontinuities. At first they are stained by weathering products; with advancing weathering the materials of the wall rock become weaker. It can be argued that in the early stages of weathering its effects are most significant in engineering problems related to discontinuity strength, thus in relation to the stability of surface and underground excavations. As the rock materials decay with increasing weathering, the problems generated incorporate those of material strength and deformability, which affect not only excavations but also the allowable bearing capacity of the rock mass. This line of argument can lead to a weathering grade scale with three major classes related to engineering significance, namely:

Class	Description	Engineering significance
A	Effectively unweathered	Not significant
B	Significantly weathered	Problems of excavation stability
C	Severely weathered	Problems of excavation stability and foundation bearing capacity

The problems encountered in these three classes would be generated by the various states of weathering of both rock material and discontinuities. In its most weathered condition the rock mass becomes a residual soil, which may or may not have relict discontinuities. Two further classes may thus be recognized, namely:

Class	Description	Engineering significance
D1	Geotechnical soil	Problems as for class C, but to be handled by soil mechanics techniques
D2	Geotechnical soil with relict discontinuities	As above, but complicated in excavations by relict discontinuities as planes of weakness

Grade D2 would be worse, in terms of engineering significance, than D1 although grade D1 would be considered to be a more advanced weathering grade than D2.

It is well known that weathering causes different engineering problems depending on the original nature of the rock mass. These are briefly described in very general terms in Table 2, in relation to igneous, sedimentary, metamorphic and limestone rock masses.

A ratings system for the description of rock mass weathering

The present classification for weathering is based on visual impression. However, an approach which seems to be successful for many engineering applications is the use of a rating system to place a rock mass within a classification. Accordingly, it is suggested that giving a grade to a rock mass in a weathering classification related to engineering significance might be most appropriately undertaken by a ratings system. Ratings could be given using Tables 3 to 5.

In the three tables the rock mass being examined must get a rating from each column in the appropriate

TABLE 2. *Weathering classification based on the recognition of engineering significance*

Class	Rating	Descriptive term	Igneous	Sedimentary	Metamorphic	Limestone
A	140	Effectively unweathered	Engineering problems related to material properties, discontinuity properties etc. No influence of weathering.	Engineering problems related to material properties, discontinuity properties etc. No influence of weathering.	Engineering problems related to material properties, discontinuity properties etc. No influence of weathering.	Engineering problems related to material properties, discontinuity properties etc. No influence of weathering.
B	100	Significantly weathered	Reduction in joint strength gives problems in slope stability, tunnelling.	Reduction in joint and bedding plane strength gives problems in slope stability, tunnels, foundations on slopes.	Reduction in strength of foliation planes, joints gives problems in slope stability and tunnelling, foundations on slopes.	Opening of bedding planes and joints give major increases in permeability and discontinuity strength problems in tunnelling. Problems in excavation using explosives.
C	50	Severely weathered	Major slope stability problems by release of corestones, irregular bearing capacity particularly for small dimension foundations. Corestone/soil strength contrast difficult for tunnelling.	Major impairment of bearing capacity for foundations. Slope stability approaches stability of residual soils. Poor ground for tunnelling.	Influence of basic anisotropy in rock type and contrasts between weathering sensitivity of layers give major problems in slopes, foundations and tunnelling, particularly in mica rich schists and gneisses.	Rock mass cavernous. Problems for all types engineering work. Localized subsidence problems.
D1	20 0	Geotechnical soil - without relict discontinuites	Weathered material geotechnically a soil so all engineering works designed on soil parameters.	Weathered material geotechnically a soil so all engineering works designed on soil parameters.	Weathered material geotechnically a soil so all engineering works designed on soil parameters.	Residual soil very different from original rock, often highly ferruginous and clayey.
D2	−20	Geotechnical soil - with relict discontinuities	Weathered material geotechnically a soil so all engineering works designed on soil parameters, but with added handicap of potential sliding planes of relict discontinuities.	Weathered material geotechnically a soil so all engineering works designed on soil parameters, but with added handicap of potential sliding planes of relict discontinuities.	Weathered material geotechnically a soil so all engineering works designed on soil parameters, but with added handicap of potential sliding planes of relict discontinuities.	Not applicable to crystalline limestones. May be calcareous mud with some relict planes in much softened calcilutites and calcisiltites. Major problems for all engineering works.

TABLE 3. *Ratings for all rock materials*

Proportions	Fresh	Discoloured (some loss of strength)	Friable (and discoloured) (considerable loss of strength, geotechnically an engineering soil, UCS <1.25 PMa) or absent by solution
± All	40	0	0
± $\frac{3}{4}$	30	5	5
± $\frac{1}{2}$	20	10	10
± $\frac{1}{4}$	10	15	15
± None	0	20	20

TABLE 4. *Ratings for joints in igneous rocks and relict discontinuities in all rocks*

	Igneous rocks – joints only			All discontinuities in all types of rock
Proportions	Unweathered	Surface stained	Rock material weathered to depth > joint waviness	Proportion of discontinuities present as relicts in geotechnical soil*
± All	20	0	0	−20
± $\frac{3}{4}$	15	5	5	−15
± $\frac{1}{2}$	10	10	10	−10
± $\frac{1}{4}$	5	15	15	−5
± None	0	20	20	0

* To be applied only if material chart gives > $\frac{3}{4}$ material friable and discoloured.

TABLE 5. *Sedimentary and metamorphic rocks (including limestones)—ratings for joints and bedding or foliation planes*

	Joints			Bedding or foliation planes		
Proportions	Unweathered	Surface staining or surface modified by solution	Rock material weathered to depth > waviness or open by solution	Unweathered	Surface staining or surface modified by solution	Rock material weathered to depth > waviness or open by solution
± All	10	0	0	10	0	0
± $\frac{3}{4}$	7	3	3	7	3	3
± $\frac{1}{2}$	5	5	5	5	5	5
± $\frac{1}{4}$	3	7	7	3	7	7
± None	0	10	10	0	10	10

table. The tables require the observer to judge the proportions of the rock mass to which the observation applies. These proportions have been kept very simple, to fall within what the author believes to be attainable accuracy and should be applied with some degree of freedom and flexibility.

Table 3 is to be completed for all rocks of whatever nature. If all the rock is fresh then the maximum rating is $40 + 20 + 20 = 80$. If $\pm\frac{1}{2}$ is fresh, $\pm\frac{1}{4}$ discoloured and $\pm\frac{1}{4}$ friable and discoloured then the rating is $20 + 15 + 15 = 50$. If none is fresh, $\pm\frac{1}{4}$ discoloured and $\pm\frac{3}{4}$ friable and discoloured then the rating would be $0 + 15 + 5 = 20$. Table 4 applies to igneous rock discontinuities and works in a similar way to Table 3, but each factor relates to discontinuity wall conditions. Fresh igneous rock discontinuities get a total rating of 60; discontinuities weathered to a depth deeper than joint waviness, thus making shearing through asperities much easier, receive a total rating of 0. Taking Tables 3 and 4 together the best possible rating for an igneous rock mass is 80 + 60 = 140. For a residual soil mass of igneous origin the total rating is 0; if relict discontinuities are present a negative value, up to −20, is possible. The system is so arranged to give a worse rating for geotechnical soils with relict discontinuities, for such a mass would be considered to give more problems than a residual soil mass without them.

Should the material be of sedimentary or metamorphic origin, including limestones, then discontinuity weathering would be expected to affect not only joint but also bedding or foliation planes and not necessarily to an equal degree. In such a case Table 5 would be used to assess a rating. The maximum rating for the best possible rock mass is 60, the worst 0. This rating would be combined with that of Table 3 for the total rating. If the rock material is weathered to a geotechnical soil then the right hand 'relict discontinuity' section of Table 4 would be applied to add a negative value to the end rating.

Limestones present a major problem, for while crystalline limestones generally only exhibit solution weathering, the clastic limestones (calcarenites, calcilutites etc.) may weather in ways similar to other sedimentary rocks but perhaps with some solution cavities. To deal with these problems 'absent by solution' may apply in Table 3 instead of 'friable', while in Table 5 both the parameters 'surface staining' and 'rock material weathered to a depth greater than waviness' may be substituted respectively by 'surface modified by solution' and 'open by solution' for those limestones that show karstic phenomena.

The total ratings chosen by the author to give the approximate boundaries between weathering classes are shown in Table 2.

Examples of use of the system

The system has been applied to exposures of igneous, sedimentary and lightly metamorphosed rocks seen on engineering geological fieldwork in the area around Falset, Catalonia in northeastern Spain.

Figure 1 is a neat version of the field sheet giving

Rock	Zone	Material			Joints			Relict discontinuities - all types	Bedding or Foliation			Rating
		Fresh	Discoloured	Friable	Unweathered	Surface stained	Weathering > waviness	Relicts in soil	Unweathered	Surface stained	Weathering > waviness	
GRANITE	α	10	5	5	0	0	0	-10				10
	β	10	10	15	0	0	0	0				35
	γ	30	15	15	0	0	15	0				75
	δ	20	10	15	0	0	5	0				50
	ϵ	0	0	5	0	0	0	-5				0
	η	0	5	5	0	0	0	-10				0
	θ	20	10	20	0	0	20	0				70
	κ	10	5	10	0	0	10	0				35
	λ	0	0	10	0	0	10	0				20

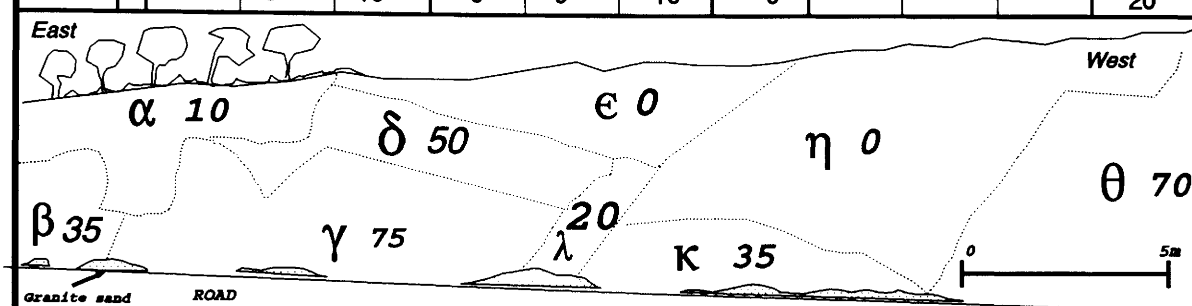

FIG. 1. Field sheet used for recording weathering data on granite outcrop.

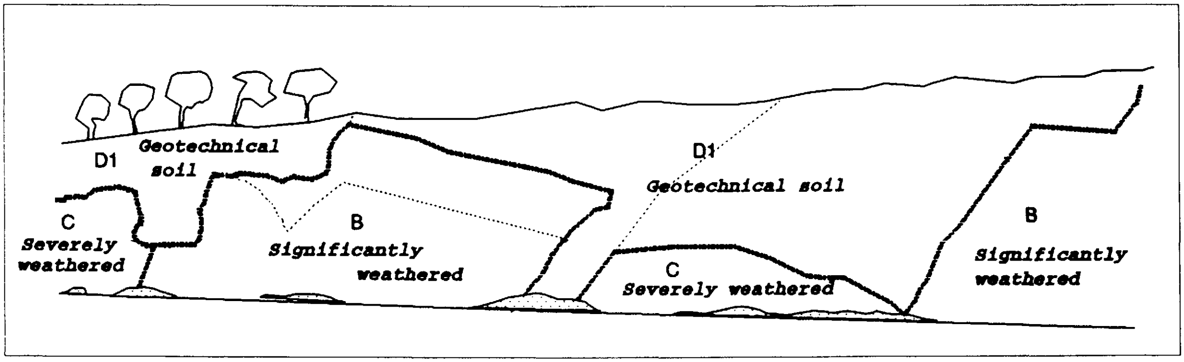

FIG. 2. Weathering classification for the outcrop in Fig. 1.

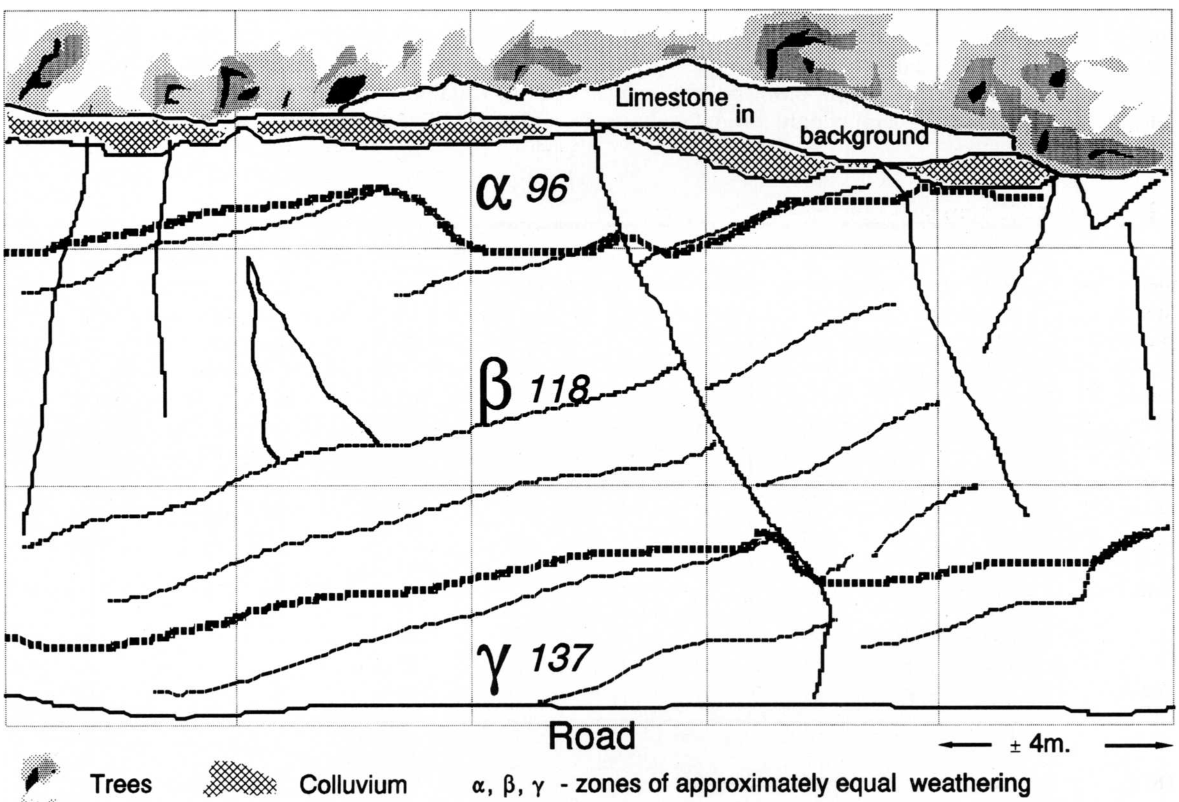

FIG. 3. Weathering ratings of a near-vertical limestone outcrop, beds dip right to left.

rating data and weathering zone boundaries for a granite outcrop. These boundaries are those of zones of equal weathering. Figure 2 is the final rock mass weathering drawing giving the boundaries of the weathering classes as established in Table 2.

Figure 3 shows a cutting in limestone with few solution features on bedding planes and joints. Three zones were recognized: A, B and C, with end ratings of 96, 118 and 137 respectively. The whole rock mass may be considered to be effectively unweathered. Other cuttings in other rocks have been mapped.

Two approaches to the application of the ratings are possible. One is to divide the exposure into unit areas (say 1 m^2 or 4 m^2), assess a rating for each square and then contour. The other is to estimate weathering zone boundaries visually and assess zone ratings. The latter method has been used by the author.

Application to borehole logging

Cores show only a linear section through a mass weathering profile, and it is very difficult to gauge mass weathering from an array of boreholes without some idea of the style of weathering that a rock mass is likely to have in relation to its lithology. The systems currently in use have the disadvantage that the describer is required to give what appears to be a mass weathering evaluation without seeing the mass. The advantage of the numerical rating approach is that this gives a factual record of what was seen and that the link to engineering significance is valid for that borehole location. Ratings may be assessed per unit depth run of the cores, per lithology, or both.

Link to rock mass classification systems

Bieniawski (1989) gives a review of many rock mass classification systems. Most of these are concerned with underground works, weathering playing but a minor role in most of these systems. However, some systems concerned with near-surface works, such as those concerned with excavatability above or below water, introduce weathering grade as a parameter. Future systems will no doubt address the problem of classifying rock masses for all types of near-surface works, such as foundations, cut and natural slopes, and there would seem to be every advantage in describing weathering grade numerically for future incorporation into such systems.

Discussion

The intent of the author is to propose an idea for consideration by the engineering geological fraternity which may, after some years of use by many practitioners, develop into a recognized system. The idea presented suffers from the same deficiencies as all ratings systems, namely the choice of the relative weighting of the ratings and the way of manipulating them to achieve the end rating. The reader will see that the author has chosen to give rather more weight to material weathering than to discontinuity weathering; others might have chosen a different emphasis. Rating values are perhaps rather high in comparison with the values of ratings chosen by other rock mass classification systems, but this has been done to gain extra sensitivity. The introduction of these ratings into another system could be achieved by division by a factor.

Other workers may wish to introduce other factors. A colleague of the author, R. Hack of the International Institute for Aerospace Survey and Earth Sciences in the Netherlands, has suggested that a factor that could be taken into account in a mass weathering classification system is the increase in near-surface discontinuity frequency which may be developed as a result of weathering. This has not been done in the system suggested, for the author's intent is to incorporate the weathering index into a rock mass classification for mapping purposes in which discontinuity spacing

TABLE 6. *An approximate comparison between the present descriptive system (left) and the suggested ratings system (right) for rock mass weathering*

Grade	Weathering description	Equivalent rating	Rating	Descriptive term	Class
IA	Fresh	140	100–140	Effectively unweathered	A
IB	Faintly weathered	120–140			
II	Slightly weathered	90–120	50–100	Significantly weathered	B
III	Moderately weathered	40–90			
IV	Highly weathered	20–40	20–50	Severely weathered	C
V	Completely weathered	−20 to 0	0 to +20	Geotechnical soil (without relict discontinuities)	D1
VI	Residual soil	0 to +20	0 to −20	Geotechnical soil (with relict discontinuities)	D2

already plays a role. However, the development of additional discontinuities is certainly a consequence of what may be considered to be a weathering process and could be included in the system.

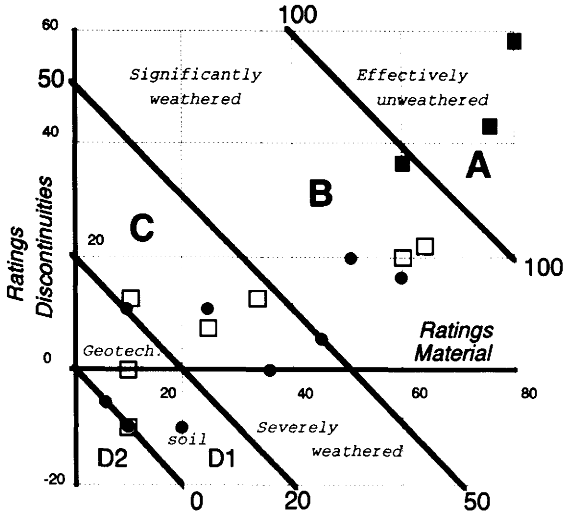

FIG. 4. The ratings system in graphical form: plotted points (●) come from Fig. 1, (■) come from Fig. 3 and (□) are from Carboniferous shale outcrops.

While the suggested system allows the user to zone an outcrop by class, the use of the ratings themselves may be considered to give greater sensitivity than verbal description. The system is portrayed graphically in Fig. 4, which also shows the ratings given in Figs 1 and 3, and some ratings measured on Carboniferous slatey shale outcrops. The ratings fall in a broad band ascending from left to right and it is likely that most ratings for all rocks will have a similar distribution. The ratings evaluations made so far by the author generally agree with his own opinion, based on his experience, of the engineering significance of the weathering of the rock masses viewed.

An approximate comparison between the present descriptive system and the suggested ratings system is given in Table 6.

The 'equivalent ratings' are but estimates; grade or class boundaries are similar because they are based on similar principles for the evaluation of weathering. The present descriptive system has more divisions but the ratings system could allow the user to establish intermediate boundaries relative to the problems posed by a particular rock mass with regard to a particular engineering work. This flexibility, together with possible incorporation of the ratings into an engineering process related rock mass classification may prove to be a great argument in favour of weathering classification by means of a ratings system.

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