Geological Society, London, Engineering Geology Special Publications

Principles for Description and Classification of Weathered Rock for Engineering Purposes

R. P. Martin and S. R. Hencher

Geological Society, London, Engineering Geology Special Publications
1986, v.2; p299-308.
doi: 10.1144/GSL.1986.002.01.53

Notes

Geological Society, Engineering Geology Special Publication No. 2, 1986

Principles for Description and Classification of Weathered Rock for Engineering purposes

R. P. Martin* and S. R. Hencher†

Abstract

There is a clear need for separate descriptive schemes for the degree of weathering at a small scale (material grades) and at a large scale (mass zones). Such weathering classifications should be established according to clear principles using well defined terminology. The schemes recommended in BS 5930 for this purpose are considered inadequate due to confusing terminology, loosely defined material grades and unjustified mass zonal boundaries. In this paper, published schemes both at the material grade scale and the mass zonal scale are reviewed and proposals made for standardised terminology. Examples of three schemes for classifying materials, and which meet many of the criteria advocated here, are presented. An idealised zonal scheme for heterogeneous weathered rocks is presented and the engineering significance of each proposed zone boundary is discussed.

Introduction

Weathering effects are important for the engineering assessment of rock. In tropical and sub-tropical regions, for example, properties such as compressive strength and permeability may vary by three orders of magnitude over depths of tens of metres, solely as a result of weathering. Even in temperate and arctic climates, it is unusual to find fresh rock at the ground surface and weathering effects can be very significant. For site investigation and design assessments, variability in engineering properties due to weathering is often the key factor; therefore it is essential that the degree of weathering is described and classified clearly and consistently.

This paper discusses the principles for the description of weathered rocks and, in particular, questions the adequacy of BS 5930 (British Standards Institution, 1981) in dealing with the subject. Alternative methods for describing weathering on both small (materials) and large (mass) scales are reviewed in detail, and recommendations are made for good practice.

Weathering processes are rarely sufficiently uniform to produce gradual and predictable changes in engineering properties throughout the weathering profile. Such profiles often comprise heterogeneous materials at various stages of decomposition and disintegration. The level of complexity will depend on many factors—in particular original geological characteristics such as lithology and joint pattern. Other important factors will include local topography, climatic influences and fluctuations in groundwater. As a result, the degree of weathering in rocks can seldom be mapped using conventional geological methods, and this is one of the major reasons why the subject of weathering needs special consideration for soil and rock description. A second important reason, as noted by Dearman (1974), is that the degree of weathering is a useful short-hand descriptor encompassing many engineering characteristics.

Principles for Description

The need to describe weathered profiles meaningfully, and to group materials into units with distinct engineering properties for major projects, has led to a wide range of weathering classifications being proposed for many different rock types over the last 20–25 years. Table I summarises the main features of several standard schemes adopted by authoritative bodies in recent years and demonstrates the diversity of opinion as to the optimum methods for dealing with weathering. It is the authors' opinion that the resultant confusion and ambiguity of terminology stems from a failure on behalf of those bodies to address the problem objectively.

The principles for description of weathered rocks and for setting up weathering classifications will form the main theme of this paper.

Firstly, it is essential to recognise that there is a need for quite different classifications of degree of weathering at two different engineering scales.

At the small scale, the weathering of individual minerals, loss of grain bonding and growth of microfractures is important and indicative of the degree of weathering in hand-sized or drillcore samples. This scale is the scale at which detailed logging and most testing is carried out. For such purposes, weathering description should be in terms of material grades, which are essentially uniform and definable within quite precise limits. Rarely, however, will uniform grades extend through a sufficiently large volume of rock for their properties to be considered representative for engineering design.

At a larger scale, it is often necessary to group mixtures of different material grades into mass zones, which, for engineering purposes, can be considered to

* Geotechnical Control Office, Hong Kong Government.
† Dept. Earth Sciences, Leeds University.

TABLE I. *Comparison of selected standard schemes for description of degree of weathering in rocks and soils*

Reference	Engineering Group	Scale or Level of Classification	Number of Classes	Name of Class Unit	Descriptive Weathering Terms	Descriptive Symbols	Comments
Anon, 1970 (Geol. Soc.)	Rocks	Mass	7	State	F, Fa, S, M, H, C, R	IA, IB, II, III, IV V, VI	Mass descriptions inappropriate for rock core. No material description
Anon, 1972 (Geol. Soc.)	Rocks	Mass	6	Grade	F, S, M, H, C, R	WI, WII, WIII, WIV WV, WVI	Differing number of classes confusing.
	Soils	Mass	5	Grade	F, S, M, H, C	WI, WII, WIII, WIV, WV	No material description
Anon, 1977 (Geol. Soc.)	Rocks	Material	←not applicable, general discussion only in text→				Terms for description of material weathering not explicitly defined
	Rocks	Mass	7	Grade	F, Fa, S, M, H, C, R	IA, IB, II, III, IV, V, VI	
Anon, 1979 (IAEG)	Rocks	Material	4	State	D, CH, M, A	D, CH, M, A	No mass description
		Material	5	Degree	S, M, H, C, R	1, 2, 3, 4, 5	
Anon, 1981 (IAEG)	Rocks	Material	3	State	D, CH, M	None used	Differing number of classes for mass descriptions confusing
	Rocks	Material	5	Degree	F, S, M, H, E	None used	
	Rocks	Mass	6	Grade	F, S, M, H, E, R	I, II, III, IV, V, VI	
	Soils	Material	3	State	D, CH, M	None used	
	Soils	Material	5	Degree	F, S, M, H, E	None used	
	Soils	Mass	5	Grade	F, S, M, H, E	I, II, III, IV, V	
Anon, 1978 (ISRM)	Rocks	Material	4	Stage/ Grade	F, D, CH, M	None used	Incomplete list of qualifying terms to accompany stage of material weathering
	Rocks	Material	3?	None used	S, M, H (incomplete?)	None used	
	Rocks	Mass	6	Grade	F, S, M, H, C, R	I, II, III, IV, V, VI	
Anon, 1981 (ISRM)	Rocks	Mass	5	Degree	F, S, M, H, C	W1, W2, W3, W4, W5	No material description

Notes: F = Fresh, Fa = Faintly, S = Slightly, M = Moderately, H = Highly, C = Completely, E = Extremely, R = Residual Soil, D = Discolouration, CH = (Chemical) Decomposition, M = (Mechanical) Disintegration, A = Alteration.

have distinctive characteristics. Zonal classifications are particularly important for preliminary description of weathered rock masses either on a map or by report. They also have application for general design purposes where they have been established on the basis of grouped engineering characteristics; for example, in excavation works when deciding methods of extraction or for estimating allowable foundation loads.

Zones clearly will incorporate more 'mass' features than will grades, although this factor cannot be regarded as a precise distinction between the two scales of description, as discussed by Knill (1982). For example, jointing, which is usually considered a 'mass' feature rather than a 'material' feature, may be of importance for grade description and an example will be given later.

In summary, it is clear that a material grade classification is required for, and will generally only be applicable to, small volumes of material. Conversely, a mass zone classification will not be applicable to small samples such as those obtained from drillcore, but is useful for grouping large volumes of weathered rock of broadly similar characteristics.

Treatment of Weathering in BS 5930

In order to meet the needs for small- and large-scale description identified above, BS 5930 makes recommendations under two headings:

- Section 44.2.4—subsection of 'Description of Rock Materials', and
- Section 44.3.4, Table 10—subsection of 'Description of Rock Masses'.

In section 44.2.4, which deals with weathering of materials, the four terms 'fresh', 'decomposed', 'discoloured' and 'disintegrated' are recommended for describing the effects of chemical weathering (discolouration, decomposition) and mechanical weathering (disintegration), when compared with unweathered (fresh) material. These terms are called 'grades'. It is further recommended that the degree, or 'stage' of each 'grade' be indicated by a supplementary term such as 'slightly', 'partially', or 'wholly' and it is suggested that these terms may be quantified if necessary, although no advice is given as to how this can be done.

In cases where weathered materials exhibit discolouration, decomposition and disintegration simultaneously, all three 'grades' must be used together for full description.

The BS 5930 method of material description can therefore be regarded as essentially a qualitative, multiple-choice classification based on non-technical 'dictionary' definitions.

In section 44.3.4, Table 10, BS 5930 recommends a six-fold classification for rock mass weathering, with classes again termed grades. 'Grades' are distinguished by degree of discolouration in grades I/II, differing proportions of 'soil' and 'rock' for grades II/III/IV/V, and the loss of mass structure from grades V to VI. The 'grade' terms employed are 'fresh', 'slightly', 'moderately', 'highly' and 'completely weathered' to 'residual soil'.

This scheme differs from that for material weathering in that it is a single choice classification based on definitions which have an implied technical basis. However, no justification is given for these particular 'zonal' groupings and this subject will be discussed in detail later.

Assessment of Weathering Descriptions in BS 5930

In a broad sense BS 5930 meets the need to have separate descriptive weathering schemes for uniform material and for large heterogeneous masses. However, when considered in detail, there are a number of criticisms which can be applied to these schemes, as follows:

- confusing terminology
- lack of clear definition or guidance for the description of material grades
- unjustified and apparently arbitrary boundaries for mass weathering zones.

Concerning terminology, the use of the term 'grade' to describe both a type rather than a scale of weathering in rock material and to classify a zone of a heterogeneous weathered rock mass is extremely confusing and needs revision. The authors propose that the term grade should only be used for materials and zone only for masses.

The criticism of lack of clear definition applies both to the material and mass schemes, but most importantly to the former. When making engineering descriptions, it is very important to ensure that the user fully understands what has been described in the field. It is the authors' experience that the assessment of degree of material weathering can be a subjective matter unless index tests are used for quantification and that misidentification can have serious implications. An example will be given later. Concerning the mass weathering grades of BS 5930, the criticism of lack of definition applies to the terms 'rock' and 'soil' used throughout the classification. Without adequate definition, the terminology allows ambiguous interpretation.

The third major criticism concerns the apparently arbitrary nature of the boundaries between the mass weathering 'grades' (zones in the authors' terminology). Principles for setting up such schemes for engineering purposes are discussed in the final section of this paper. It should also be noted that the scheme in BS 5930 is of limited application for rocks which do not weather with the development of corestones.

Further to these specific points, a more general criticism of the recommendations in BS 5930 is that only scant reference is made to situations where complex ground conditions make it difficult or impossible to apply a rigid zonal classification (Fookes & Horswill, 1970). In such cases attention must be paid to careful materials description combined with lithological and structural mapping. BS 5930, with its emphasis on zonal schemes, does not prepare the inexperienced engineer or geologist for such occurrences.

Review and Recommendations for the Description of Weathered Rocks

In accordance with the previous discussion regarding the need for different descriptive schemes for weathered rocks at both small and large scales, the following review and recommendations will consider material grade schemes and mass zonal schemes separately.

Material Description (Grades)

Various authors have approached the description of weathered rocks by setting up essentially 'material' classifications in the first instance before assessing mass features. These include Moye (1955), Melton (1965), Little (1969), Newbery (1970), Wakeling (1970), Geotechnical Control Office (1979), Hencher & Martin (1982) and Krank & Watters (1983).

Although written with 'material' bias, many of these authors have also tried to incorporate some features more applicable to mass descriptions in their schemes. This has been in an attempt to overcome the difficulties of applying a uniform, material classification to large heterogeneous volumes of weathered rock and in some cases may demonstrate a reluctance or ignorance of the need to use different schemes at different scales.

Following review of the above publications and taking account of the axiomatic need for a well-defined method for describing uniform grades of weathered material, the authors propose the following guidelines as standards for good practice:

- Grade descriptions must apply to uniform materials.
- Index tests should be used whenever practical to define precise grade boundaries.
- Grade boundaries should be established according to engineering relevance wherever possible.
- Constant grade numbering and nomenclature must be used.
- A six-fold division of grades should be used in accordance with common practice and as justified on grounds of previous experience.
- A single classification should be used wherever possible to cover all types (decomposition, disintegration) and degrees of material weathering.

The principle that grades should be uniform is illustrated particularly by the examples A and B given in Table II. Wakeling's (1970) scheme (C) for chalk does include some heterogeneous features such as "lumps of intact chalk" in otherwise remoulded chalk, and jointing characteristics, but in this scheme these are generally small-scale structural features and applicable to hand-sized samples.

Concerning the definition of boundaries, only scheme A of the three given in Table II has boundaries defined in the precise manner recommended here. Further examples of potentially useful index tests and their relationships to particular engineering properties are given by Irfan & Dearman (1978). The consequence of loose definitions of grades can be important. For example, Lumb (1983), professing to employ Moye's (1955) material classification, presents data covering a range of engineering properties for grades I to IV granite and volcanic rocks from Hong Kong. On the basis of these data, one of his main conclusions is that 'highly decomposed' (grade IV) rock has a compressive strength which is "adequately high for most engineering works in Hong Kong". This conclusion is based on tested samples identified by Lumb and his co-workers as highly decomposed and having compressive strengths between 2 and 50 MPa. However according to Moye, highly decomposed (weathered) rock, at its least weathered, can be broken and crumbled by hand. Its boundary with completely decomposed rock is marked by disintegration on immersion in water.

The authors consider that many of the samples tested by Lumb must therefore have been less than highly decomposed as it would be impossible to break intact core of compressive strength greater than a few MPa by hand. The conclusion relating to 'highly decomposed' rock stated above is therefore invalid due to wrong identification of decomposition grade and could have serious implications in terms of engineering risk. Elsewhere in his paper Lumb states that "experienced engineers and geologists are reasonably consistent in their classifications" and then goes on to demonstrate, quite clearly, that they are not.

With regard to the principle that grades should have engineering relevance, this can only be satisfied practically following long term experience and correlation between laboratory tests and field descriptions. Some index tests, however, are intuitively relevant to engineering practice (e.g. slakeability).

Concerning terminology and grade titles, Roman numerals I–VI are used in each scheme in Table II and it is recommended that these should always apply to material grades. The end terms of 'fresh rock' and 'residual soil' should also be adopted as standard. Intermediate grades should be qualified by the terms 'slightly', 'moderately', 'highly', and 'completely', with the main grade terms being chosen as either 'decomposed' or 'disintegrated' according to the dominant weathering type or 'weathered' in the more general sense. These terms should only be applied to the description of weathered materials. Alternative

TABLE II. *Comparison of selected schemes for grade classification of rock material weathering*

Reference		A Hencher & Martin (1982)	B Little (1969)	C Wakeling (1970)
Area		Hong Kong	Tropical Regions—General	U.K.
Rock Types		Granite and Volcanic Rocks	'Residual Tropical Soils'	Chalk
Grade Symbol	Description	Typical Characteristics	Typical Characteristics	Typical Characteristics
VI	Residual Soil (A) Soil (B & C)	A soil mixture with the original texture of the rock completely destroyed	Surface layer contains humus and plant roots; no recognisable texture; unstable on slopes when vegetable cover destroyed	Extremely soft structureless chalk containing small lumps of intact chalk
V	Completely Decomposed (A) Completely Weathered (B & C)	No rebound from N. Schmidt hammer; slakes readily in water; geological pick easily indents when pushed into surface; rock is wholly decomposed but rock texture preserved	Rock completely decomposed but texture still recognisable; in granite types feldspars completely decomposed to clay minerals; cores cannot be recovered by ordinary rotary drilling methods; can be excavated by hand	Structureless remoulded chalk containing lumps of intact chalk
IV	Highly Decomposed (A) Highly Weathered (B & C)	N. Schmidt rebound value 0 to 25; does not slake readily in water; geological pick cannot be pushed into surface; hand penetrometer strength index >250 KN/m^2; rock weakened so that large pieces broken by hand; individual grains plucked from surface	Rock so weakened by weathering that fairly large pieces can be broken and crumbled in the hands; sometimes recovered as core by careful rotary drilling; stained by limonite	Rubbly partly weathered chalk with bedding and jointing, joints 10–60 mm apart, open to 20 mm and often infilled with soft remoulded chalk and fragments
III	Moderately Decomposed (A) Moderately Weathered (B & C)	N. Schmidt rebound value 25 to 45; considerably weathered but possessing strength such that pieces 55 mm diameter cannot be broken by hand; rock material not friable	Considerably weathered; possessing some strength—large pieces (e.g. NX core) cannot be broken by hand; often limonite stained; difficult to excavate without use of explosives	Rubbly to blocky unweathered chalk; joints 60–20 mm apart, open to 3 mm and sometimes infilled with fragments
II	Slightly Decomposed (A) Slightly Weathered (B & C)	N. Schmidt rebound value >45; more than one blow of geological hammer to break specimen; strength approaches that of fresh rock	Distinctly weathered with slight limonite staining; some decomposed feldspar in granites; strength approaching that of fresh rock; explosives required for excavation	Blocky medium hard chalk, joints more than 200 mm apart and closed
I	Fresh Rock (A, B & C)	No visible signs of weathering; rarely encountered in surface exposures	Fresh rock may have some limonite stained joints immediately beneath weathered rock	As for grade II but hard and brittle
Comments		Relies heavily on index tests	Incorporates occasional 'mass' features (e.g. jointing, excavation type)	Relies heavily on small-scale structural features

terminology for zonal classifications is presented in the next section.

Wherever possible a single grade classification should be used. Other authors have advocated the need for more than one scheme to be used simultaneously (e.g. Dearman, 1974; Dearman & Irfan, 1978), but it is the authors' experience that subordinate types of weathering can generally be dealt with by supplementary description and that this avoids unnecessary confusion.

No specific scheme of material classification can be expected to apply to all rock types, but adoption of the above guidelines should ensure that new schemes are set up consistently and objectively.

Mass Description (Zones)

Mass zonal schemes are more suitable than material grade schemes for the description of weathered rocks for engineering construction and for mapping purposes. This is the prime reason why so many authors have addressed the problem of weathering description at this scale, for example: Vargas (1953), Ruxton & Berry (1957), Knill & Jones (1965), Ward *et al.* (1968), Chandler (1969), Barata (1969), Saunders & Fookes (1970), Fookes & Horswill (1970), Neilson (1970), Deere & Patton (1971), Lovegrove & Fookes (1972) and Sancio & Brown (1980). Most of these schemes were set up for specific purposes, but in the last 15 years various international bodies have recommended standard schemes for more general usage (see Table I).

For a scheme to be of practical use for engineering works rather than simply of descriptive interest, the following principles should apply:

- Zones must be recognisable in naturally occurring profiles.
- The complete range of expected materials must be accounted for.
- Boundaries must be defined such that they separate zones with significantly different engineering properties.

Furthermore, for a standard scheme to be acceptable, it must be applicable to a wide range of rock types in different climatic conditions.

The first two aims are self-explanatory although sometimes difficult to achieve. For example, it should be noted that a major weakness of zonal schemes generally is their inflexibility for dealing with complex geological conditions (Fookes & Horswill, 1970; Lovegrove & Fookes, 1972; Dearman, 1974). Field situations are often encountered where idealised zones are difficult to apply, especially where exposures are not continuous and the opportunities for correlation are poor. The point is made by Ollier (1969, p. 123) as follows: "It is certainly helpful to have the 'zone' idea in mind when describing weathering sections, although in some instances it may not be applicable, and though there are no sequences (of zones) that can be expected to apply in all cases."

Concerning the criteria used for distinguishing between zones, boundaries for 'local' schemes, as shown in Table III, have generally been set up in accordance with the particular needs of a project or field experience of the typical mode of weathering for a specific rock type. Despite differences in detail in Table III, it is clear that certain criteria have been found particularly useful, namely, proportions of rock and soil, presence or absence of mass structure and degree of discolouration on joint planes. Similarly most of these schemes employ either five or six zones, which appears to be the upper limit of practical recognition.

Although similar criteria as those in Table III have been adopted widely for the erection of standard schemes, it is considered that in none of these standard schemes have the specific boundary conditions been clearly justified. For meaningful engineering use, such criteria should be supported by empirical evidence or theory. It appears to the authors that many have been adopted for apparently arbitrary reasons or simply on grounds that they are easy to recognise.

As an example, BS 5930 (Table 10) distinguishes between 'grades' (zones) I and II solely on the basis of degree of discolouration, whilst both zones remain as 100% rock. The practical engineering significance of distinguishing between these zones is unclear.

By comparison, an example with which the authors are well acquainted, concerns the Building (Construction) Regulations of Hong Kong (Government of Hong Kong, 1976). These regulations, which are currently being revised, incorporate a table giving safe bearing pressures for foundations. A bearing pressure of 5 MPa is allowed for the best quality rock mass which is defined by a criterion of greater than 85% core recovery. This zone, in being far too broadly defined, does not allow for the appreciably higher bearing capacity that would normally be associated with rock of excellent quality (e.g. 100% recovery).

Whilst acknowledging that no standard scheme can be expected to be applicable for all purposes, the authors consider that improvements can be made by careful consideration of the principles outlined previously. As an illustration, a simple zonal scheme is presented in Table IV. It is suggested that this scheme has direct application for general-purpose zonal description of rocks whose weathering profiles typically comprise a heterogeneous mixture of materials. The zone sequence and numbering (in Arabic numerals) are recommended as standards to avoid confusion with the terminology used for material grades.

In essence, the zonal scheme in Table IV is based simply on varying proportions of rock and soil, as this feature can be expected to exert a major influence on such fundamental engineering properties as strength, deformability and permeability. Rock is generally defined as material grades I, II or III, except in zone 1 where all rock will be either grade I or II.

TABLE III. *Comparative summary of selected schemes for zone classification of rock mass weathering*

Reference	Rock Type	Area	Number of Zones	Zone Symbols and Boundary Criteria: Most weathered ←										→ Least weathered
Ruxton & Berry (1957)	Granite	Hong Kong	5	I	RS, S	II	RS, A	III	RS	IV	RS, JD	'Bed rock'		
Knill & Jones (1965)	Gneiss	Sudan	5	IV	RS, Sl, CR	IIIa	RS, CR	IIIb	RS, CR	II	JS, CR, JD	I		
Ward *et al.* (1968)	Chalk	U.K.	5	V	S	IV	F, JS, JA	III	F, JS	II	F, St	I		
Chandler (1969)	Keuper Marl	U.K.	5	IVb	RS	IVa	RS	III	RS, A	II	RS	I		
Barata (1969)	Gneiss	Brazil	5	I	S	II	RS	III	RS, JD	IV	JD	V		
Neilson (1970)	Mudstone	Australia	6	1A	RS	1B	St, S	2	D, St, S	3	D, St, S	4	D, St	5
Lovegrove & Fookes (1972)	Volcanic Tuffs & Sediments	Fiji	6	V	S	IVb	RS	IVa	RS	III	D, RS	II	JD, JA	I
Dearman *et al.* (1978)	Granite	— (general)	6	VI	S	V	RS	IV	RS	III	D, St	II	JD	I
Sancio & Brown (1980)	Calcareous Schist	Venezuela	4	RS	S	DR	RS	WR	D, St	FR				
Krank & Watters (1983)	Granodiorite	U.S.A.	6	VI	S	V	RS	IV	JD, RS	III	JD, St	II	JD	I

Notes

1. Near surface 'pedological' soil zones, as used in some schemes, are excluded.
2. Only those boundary criteria used in distinguishing between adjacent zones are considered.
3. Numbers adjacent to symbols indicate frequency of use in this table.

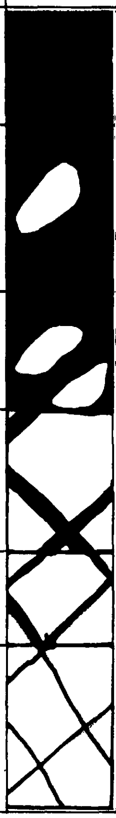
RS(22) = 'rock'/'soil' proportions (relative amounts of 'soil' matrix material and lithorelicts/corestones/fragments of 'rock' material; qualitative assessment only).
S(10) = structure (presence/absence) of rock mass structure and material fabric)
JD(9) = degree of discolouration of joint planes
St(8) = strength (qualitative)
D(6) = degree of discolouration of rock material
CR(4) = percentage core recovery
JS(3) = joint spacing
F(3) = friability (degree of breakdown of rock mass)
JA(2) = joint aperture
A(2) = angularity of corestones
Sl(1) = 'slakeability' (susceptibility to breakdown in water)

Zone 1 comprises virtually unweathered materials and its engineering properties will depend solely upon the lithological origin and tectonic history of the rock mass. Strength will normally be controlled by the degree and orientation of jointing. The shear strength of individual joints is likely to be high due to good interlocking and impersistence.

In zone 2, it requires only slight weathering for the engineering properties of the rock mass to be altered considerably. Permeability will increase—the weathering products themselves often being indicative of the passage of water. The shear strength of individual joints will be reduced due to loss of roughness, infilling and actual joint extension through rock 'bridges'. The change of modulus from rock to soil is marked, and as a result allowable foundation pressures may be reduced considerably.

Zones 3, 4 and 5 comprise different percentages of rock corestones in a soil matrix. The 90% cut-off between zones 2 and 3 is arbitrary but separates what is still a good quality rock mass from a poorer quality mass where the weathering is more general and of

TABLE IV. *Proposed zonal scheme for the classification of heterogeneous weathered rocks*



Zone Symbol	Zonal Characteristics
6	• Soil derived from *in situ* weathering: 100% soil (grades IV, V or VI) • May or may not have lost rock mass features completely
5	• Soil with corestones: less than 30% rock (grades I, II or III) • Shearing can be effected through matrix • Rock content significant for investigation and construction
4	• Poor quality rock mass: 30% to 50% rock (grades I, II or III) • Corestones affect shear behaviour of mass
3	• Moderate quality rock mass: 50% to 90% rock (grades I, II or III) • Severe weathering along discontinuities • Locked structure
2	• Good quality rock mass: greater than 90% rock (grades I, II or III) • Weathering along discontinuities
1	• Excellent quality rock mass: 100% rock (grades I, II) • No visible signs of rock weathering apart from slight discolouration along joints • Joint surfaces strongly interlocking

much higher significance. Zone 3, in having more than 50% corestones, can still be considered a locked structure, with restriction against rotation of rock fragments (Dearman, 1974), but joint blocks will tend to be separated. Shearing through any significant proportion of the mass within zone 3, other than along relict joints, will be controlled largely by the distribution of corestones, and the general dilation which would therefore be required for movement to occur.

Zone 4, comprising less than 50% corestones, can be considered an 'unlocked' structure, and this can have important implications for ease of excavation according to Dearman (1974). The lower cut-off, marked by a corestone content of 30%, is considered the limit below which the contained corestones cannot be expected to provide any additional strength above that of the matrix during shearing (Hencher & Martin, 1982). This conclusion is based on idealised drawings of regular and irregular corestone configurations, together with experimental evidence that for soils containing from 30% to 50% fragments there is an increase in strength above that of the matrix (Holtz & Ellis, 1961; Patwardhan *et al.*, 1970; Donaghe & Torrey III, 1979).

Within zone 5, the presence of less than 30% corestones, although of relatively minor importance in terms of ultimate engineering behaviour, might significantly affect the required methods of site investigation. For example, occasional corestones may limit the usefulness of shell and auger or cone penetrometer rigs and may also cause problems for construction, particularly if that low percentage comprises rare, very large corestones. Problems may also arise from the misinterpretation of corestones as bedrock or from driven piles coming to refusal at too shallow a depth.

Zone 6 comprises rock weathered completely to a soil, and in tropical climates it is quite common to encounter such materials, without corestones, to depths of more than ten metres. Such a zone may be quite variable depending upon the nature of 'soil'. For instance, significant differences in behaviour can be expected between a zone 6 comprising highly decomposed granite with many relict joints, and a zone 6 comprising structureless, residual soil.

Conclusions

In this paper, principles for the description of weathered rocks have been discussed and carefully-defined terminology and guidelines have been presented for setting up classifications at both material and mass scales.

Rock and soil material should be classified according to *grades* which are applicable to uniform samples. Grade boundaries must be well-defined, preferably on the basis of index tests. An objective classification of material weathering grades allows flexibility for the description of any exposure, excavation or drillcore, no matter how complex. Standard terminology has been proposed and examples of material weathering schemes have been presented, although it is not considered appropriate to recommend a single scheme for general use.

Mass *zonal* schemes are more applicable to the normal scale of engineering works, although their application may be limited by geological factors. Examples have been given to illustrate the inadequacies of some existing schemes in the selection and justification of zone boundaries. A simple, standard classification for zonal description has been proposed for heterogeneous mixtures of materials based on the principles presented in this paper. It is recognised, however, that more detailed site-specific schemes will often be appropriate.

It is recommended that the proposals in this paper should be considered in any revision of the schemes for weathering description in BS 5930.

References

ANON (1970): The logging of rock cores for engineering purposes. (Geological Society Engineering Group Working Party). *Q. Jl. Engng. Geol.*, **3**, 1–24.

ANON (1972): The preparation of maps and plans in terms of engineering geology. (Geological Society Engineering Group Working Party). *Q. Jl. Engng. Geol.*, **5**, 295–382.

ANON (1977): The description of rock masses for engineering purposes. (Geological Society Engineering Group Working Party). *Q. Jl. Engng. Geol.*, **10**, 355–388.

ANON (1978): Suggested methods for the quantitative description of discontinuities in rock masses. (ISRM Commission on standardization of laboratory and field tests). *Int. J. Rock Mech. Min. Sci.*, **15**, 319–368.

ANON (1979): Classification of rocks and soils for engineering geological mapping. Part 1: Rock and soil materials. (IAEG Commission of engineering geological mapping). *Bull. Int. Assoc. Engng. Geol.*, **19**, 364–371.

ANON (1981): Rock and soil description and classification for engineering geological mapping. (IAEG Commission on engineering geological mapping). *Bull. Int. Assoc. Engng. Geol.*, **24**, 235–274.

ANON (1981): Basic geotechnical description of rock masses. (ISRM Commission on classification of rocks and rock masses). *Int. J. Rock Mech. Min. Sci.*, **18**, 85–110.

BARATA, F. E. (1969): Landslides in the tropical region of Rio De Janeiro. *Proc. 7th Int. Conf. Soil Mech. Found. Engng.*, Mexico, II, 507–516.

BRITISH STANDARDS INSTITUTION (1981): BS 5930:1981. Code of Practice for Site Investigations. British Standards Institution, London, 147 pp.

CHANDLER, R. J. (1969): The effect of weathering on the shear strength properties of Keuper marl. *Géotechnique*, **19**, 321–334.

DEARMAN, W. R. (1974): Weathering classification in the characterisation of rock for engineering purposes in British practice. *Bull. Int. Assoc. Engng. Geol.*, **9**, 33–42.

DEARMAN, W. R. (1976): Weathering classification in the characterisation of rock: a revision. *Bull. Int. Assoc. Engng. Geol.*, **13**, 123–127.

DEARMAN, W. R. & IRFAN, T. Y. (1978): Classification and index properties of weathered coarse-grained granites from South-West England. *Proc. 3rd Int. Cong. Int. Assoc. Engng. Geol.*, Madrid, II(2), 119–130.

DEARMAN, W. R., BAYNES, F. J. & IRFAN, T. Y. (1978): Engineering grading of weathered granite. *Engng. Geol.*, **12**, 345–374.

DEERE, D. U. & PATTON, F. D. (1971): Slope stability in residual soils. *Proc. 4th Pan. Am. Conf. Soil Mech. Found. Engng.*, Puerto Rico, I, 87–170.

DONAGHE, R. T. & TORREY III, V. H. (1979): Scalping and replacement effects on strength parameters of earth–rock mixtures. *Proc. 7th European Conf. Soil Mech. Found. Engng.*, (Design Parameters in Geotechnical Engineering), Brighton, 2, 29–34.

FOOKES, P. G. & HORSWILL, P. (1970): Discussion on engineering grade zones. *Proc. Conf. In Situ Investigations in Soils and Rocks*, London, 53–57.

FOOKES, P. G., DEARMAN, W. R. & FRANKLIN, J. A. (1971): Some engineering aspects of rock weathering with field examples from Dartmoor and elsewhere. *Q. Jl. Engng. Geol.*, **4**, 139–185.

GEOTECHNICAL CONTROL OFFICE (1979): Geotechnical Manual for Slopes. Hong Kong Government Printer, 227 pp.

GOVERNMENT OF HONG KONG (1976): Building (Construction) Regulations. Laws of Hong Kong, Chapter 123 (part), Table IX. Hong Kong Government Printer.

HENCHER, S. R. & MARTIN, R. P. (1982): The description and classification of weathered rocks in Hong Kong for engineering purposes. *Proc. 7th Southeast Asian Geot. Conf.*, Hong Kong, I, 125–142.

HOLTZ, W. G. & ELLIS, W. (1961): Triaxial shear tests on clayey gravelly soils. *Proc. 5th Int. Conf. Soil Mech. Found. Engng.*, Paris, I, 143–149.

IRFAN, T. Y. & DEARMAN, W. R. (1978): Engineering classification and index properties of a weathered granite. *Bull. Int. Assoc. Engng. Geol.*, 17, 79–90.

KNILL, J. L. (1982): Moderator's report on engineering geology and rock mechanics. *Proc. 7th Southeast Asian Geot. Conf.*, Hong Kong, II, 159–165.

KNILL, J. L. & JONES, K. S. (1965): The recording and interpretation of geological conditions in the foundations of the Roseires, Kariba and Latiyan dams. *Géotechnique*, **15**, 94–124.

KRANK, K. D. & WATTERS, R. J. (1983): Geotechnical properties of weathered Sierra Nevada granodiorite. *Bull. Assoc. Engng. Geologists*, XX, 173–184.

LITTLE, A. L. (1969): The engineering classification of residual tropical soils. *Proc. 7th Int. Conf. Soil Mech. Found. Engng.*, Mexico, I, 1–10.

LOVEGROVE, G. W. & FOOKES, P. G. (1972): The planning and implementation of a site investigation for a highway in tropical conditions in Fiji. *Q. Jl. Engng. Geol.*, **5**, 43–68.

LUMB, P. (1983): Engineering properties of fresh and decomposed igneous rocks from Hong Kong. *Engng. Geol.*, **19**, 81–94.

MELTON, M. A. (1965): Debris-covered hillslopes of the southern Arizona desert—consideration of their stability and sediment contribution. *J. Geol.*, **73**, 715–729.

MOYE, D. G. (1955): Engineering geology for the Snowy Mountains scheme. *J. Inst. Engrs., Australia*, **27**, 281–299.

NEILSON, J. L. (1970): Notes on weathering of the Silurian rocks of the Melbourne district. *J. Inst. Engrs., Australia*, **42**, 9–12.

NEWBERY, J. (1970): Engineering geology in the investigation and construction of the Batang Padang hydroelectric scheme, Malaysia. *Q. Jl. Engng. Geol.*, **3**, 151–181.

OLLIER, C. D. (1969): Weathering. Longman, London, 304 pp.

PATWARDHAN, A. S., RAO, J. S. & GAIDHANE, R. B. (1970): Interlocking effects and shearing resistance of boulders and large size particles in a matrix of fines on the basis of large scale direct shear tests. *Proc. 2nd Southeast Asian Conf. Soil Engng.*, Singapore, 265–273.

RUXTON, B. P. & BERRY, L. (1957): Weathering of granite and associated erosional features in Hong Kong. *Bull. Geol. Soc. Am.*, **68**, 1263–1292.

SANCIO, R. T. & BROWN, I. (1980): A classification of weathered foliated rocks for use in slope stability problems. *Proc. 3rd Australia–N.Z. Conf. Geomechanics*, Wellington, 2, 2-81–2-86.

SAUNDERS, M. K. & FOOKES, P. G. (1970): A review of the relationship of rock weathering and climate and its significance to foundation engineering. *Engng. Geol.*, **4**, 289–325.

WAKELING, T. R. M. (1970): A comparison of the results of standard site investigation methods against the results of a detailed geotechnical investigation in the Middle Chalk at Mundford, Norfolk. *Proc. Conf. In Situ Investigations in Soils and Rocks,* London, 17–22.

WARD, W. H., BURLAND, V. B. & GALLOIS, R. W. (1968): Geotechnical assessment of a site at Mundford, Norfolk for a large proton accelerator. *Géotechnique,* **18,** 399–431.

VARGAS, M. (1953): Some engineering properties of residual clay soils occurring in Southern Brazil. *Proc. 3rd Int. Conf. Soil Mech. Found. Engng.*, Zurich, I, 67–71.