Overview of the evaluation of the state of rock weathering by visual inspection

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Abstract: This paper is intended as a contribution to the discussion of the reliability of assessing the state of weathering of rocks by visual inspection.

The study was made by using both shales and greywackes belonging to the Baixo Alentejo Flysch Group, in the south of Portugal. Samples of these two rock materials, with different states of weathering, were collected during a fieldwork programme. This was followed by a laboratory testing programme, which included mineralogical analysis by X-ray diffraction and physical tests.

The authors asked a group of qualified people to classify the rock samples under study by ordering them in a sequence according to their state of weathering. A comparison was then made between the qualitative classification of those assessors and that obtained by using the void ratio given by the quick absorption test, a quantitative index parameter which is usually seen as a good way to characterize the state of weathering of the rock material.

The conclusions that are made in the paper about the results of the study show many divergent opinions among the assessors. It emphasizes the qualitative feature of visual evaluations of the state of weathering of rocks usually makes them quite subjective. This subjectivity becomes more important as the heterogeneity of the rock material increase, giving rise to quite different evaluations, even for a rock with the same state of weathering.

Résumé: Cet article souhaite apporter une contribution à la thématique de la fiabilité de la description de l'état d'altération des pierres basée uniquement sur l'examen visuel.

L'étude a été réalisée sur les schistes et grauwackes appartenant au Groupe du Flysch du Bas Alentejo, au sud du Portugal. Des échantillons de ces deux matériaux rocheux ont été recueillis, présentant des différents états d'altération, pendant la campagne de travaux de terrain, suivit d'un programme d'essaies en laboratoire, qui a compris des analyses minéralogiques par diffraction de rayons-X et des essaies physiques.

Les auteurs ont demandé à un groupe de personnes qualifiées de classer les échantillons de pierre de cette étude et de les ordonner selon leurs états d'altération respectifs. Une comparaison a été faite entre le classement qualitatif mené par les différents évaluateurs et le classement obtenu à partir des indices de vides, un paramètre indicateur quantitatif qui est, en général, considéré comme une bonne méthode pour caractériser l'état d'altération des matériaux rocheux.

Quelques considérations sont formulées à propos des résultats obtenus par cette étude, qui a mis en évidence une divergence d'opinions parmi les différents évaluateurs. Le caractère qualitatif des évaluations de l'état d'altération des pierres par l'examen visuel est accentué, ce qui les rend, en principe, très subjectives. Cette subjectivité s'est révélée très importante lorsque l'hétérogénéité du matériel rocheux augmente, qui se traduit par une occurrence fréquente d'évaluations très différentes, même pour des pierres avec un même état d'altération.

Keywords: rock description, weathering, shale, index tests

INTRODUCTION

The description and classification of the state of weathering of rocks and rock masses for engineering purposes has been a subject under discussion since the first recommendations about the most appropriate procedures to use in practice were proposed.

The important contributions to this matter, made by the working parties from the Engineering Group of the Geological Society of London in the 1970s (Anon 1970, 1972, 1977) and more recently (Anon 1995) analyzing how the state of weathering is described and classified in engineering practice, deserve to be highlighted.

The fact that the state of weathering significantly alters the geotechnical behaviour of rocks and rock masses is well known. Indeed, weathering can be very significant even in the case of temperate climates, where the intensity of weathering processes is lower. This is why it is fundamental that the state of weathering be described and classified in an objective and consistent way.

It is not often that weathering processes are sufficiently uniform to produce gradual and predictable modifications in the geotechnical properties alongside the weathering profile of a rock mass. The weathering profiles are, as a rule, heterogeneous, because the rock masses are formed by materials with different rates of weathering. This complexity depends on several factors such as lithology, jointing, topography, climate and the oscillations of the water table. As a result, a rocks state of weathering is rarely characterized in a convenient way, and this is one of the main reasons for the relative aspects due to weathering needing special attention in the description of the geological materials.

The need to describe the weathering profile in an objective and precise way, as well as classifying of the rock materials in relation to the state of weathering has been the basis of a great deal of classification that has been proposed during the last 50 years. This was due to the recognition that the effect of weathering has on the geotechnical behaviour of those materials in engineering work. Martin & Hencher (1986) present a synthesis of the main aspects of some classification systems proposed by some accredited international bodies for the standardization of the procedures concerning the description of the state of weathering.

In spite of some uniformity within some of those systems such as those from the British Standard Institution (BSI 1981), the International Society for Rock Mechanics (ISRM 1978) and the International Association of Engineering Geology (IAEG 1981), views about the ideal method of treating this subject are varied. Several authors such as Cragg & Ingman (1995) consider these systems very simplistic and inadequate and recommend the need for their revision. However, it is apparent that some agreement exists concerning the fact that the degree of weathering of intact rock should be classified into five grades, from the fresh degree to the completely weathered degree.

The influence of lithology on the weathering of rock materials must be considered and understood. The effects of weathering can be so different for different types of rocks that a classification at the material scale for all the rock materials does not seem viable. Moreover, it is essential to recognize the need for the classification of the state of weathering to take into account two different dimensions: i) small dimension (rock material); ii) large dimension (rock mass).

At the dimension of the rock material, the weathering of the minerals, the breakdown of the boundaries between grains and the growth of micro-fractures are important and indicative aspects of the state of weathering in small samples. This is the dimension where the most detailed descriptions are provided and most testing is carried out. Therefore, the rock-weathering description should be given in terms of material weathering grades that are uniform and with well defined boundaries. Several authors, such as Moye (1955), Melton (1965), Little (1969), Newbery (1970), Wakeling (1970), Geotechnical Control Office (Anon 1979), and Hencher & Martin (1982), studied this subject and proposed systems, focusing on the description of the weathering at the material scale in the first instance instead of assessing the rock mass weathering features.

At a rock mass scale, involving larger volumes, there is a need to group together different material grades in mass zones that can be considered distinguishable for engineering purposes. A material grade classification is necessary but, as a rule, it is only applicable to small volumes of material. In contrast, a mass zone classification is not applicable to small samples such as hand-sized or borehole core samples, but it is useful to group together large volumes of weathered rock mass with, in general, similar geotechnical characteristics (Martin & Hencher 1986).

In this way, and as far as the state of weathering is concerned, the classification systems for zone classification of rock mass are more appropriate than the material weathering grade systems for engineering construction or geotechnical mapping purposes. This is the main reason why many authors, such as Vargas (1953), Ruxton & Berry (1957), Knill & Jones (1965), Ward, Burland & Gallois (1968), Chandler (1969), Barata (1969), Saunders & Fookes (1970), Fookes & Horswill (1970), Neilson (1970), Deere & Patton (1971), Lovegrove & Fookes (1972) and Sancio & Brown (1980), prefer to treat the problem of the weathering description at this scale.

Most of these classifications were established for specific cases, but the standard classification systems that have been recommended by several international bodies in the last thirty years have a wide utilization.

The present paper intends to make a contribution to the description of the state of rock weathering by visual inspection and emphasises the qualitative and subjective characteristics of the description and classification methods based only on visual inspection.

GEOLOGICAL SETTING

The rock material selected for this study belongs to the Baixo Alentejo Flysch Group (BAF), a stratigraphic unit with an approximate area of 8000 Km^2, which extends across more than a half of the South Portuguese Zone depositional area (Pinho 2003).

This group comprises gravity flow sediments that form a continuous turbiditic succession (Oliveira 1990). Sedimentological and stratigraphic characteristics indicate three basin-wide formations: the Mértola Formation of late Visean age, the Mira Formation of latest Visean to Namurian age and the Brejeira Formation of mid Namurian to early Westphalian age (Oliveira, Horn & Paproth 1979; Oliveira 1983). These lithostratigraphic units of the BAF are constituted, as a rule, by thick sequences of turbidites where greywackes beds, usually of few tens of centimetres thick but sometimes reaching some metres thick, with lenses or pockets of fine grained conglomerates, are intercalated with thin, black / dark-grey shale beds.

CASE STUDY

Description of samples

A set of samples of shale and greywacke which represent different states of weathering, belonging to the Mértola and Mira formations of BAF, were collected in excavation slopes of some main roads near Santiago of Cacém in the Alentejo region in the South of Portugal (Figure 1). The samples are fully described in Pinho (2003).

Each sample was designated by an initial digit, indicating the sampling place, followed by the letter W and one or two digits, as in the classification proposed by ISRM (ISRM 1981). This group of symbols was intended to describe the state of weathering of the sample by visual inspection at the sampling date. Finally, the letters S (Shale) or G (Greywacke) indicate the lithology of the sample (e.g., 14W4-5X).

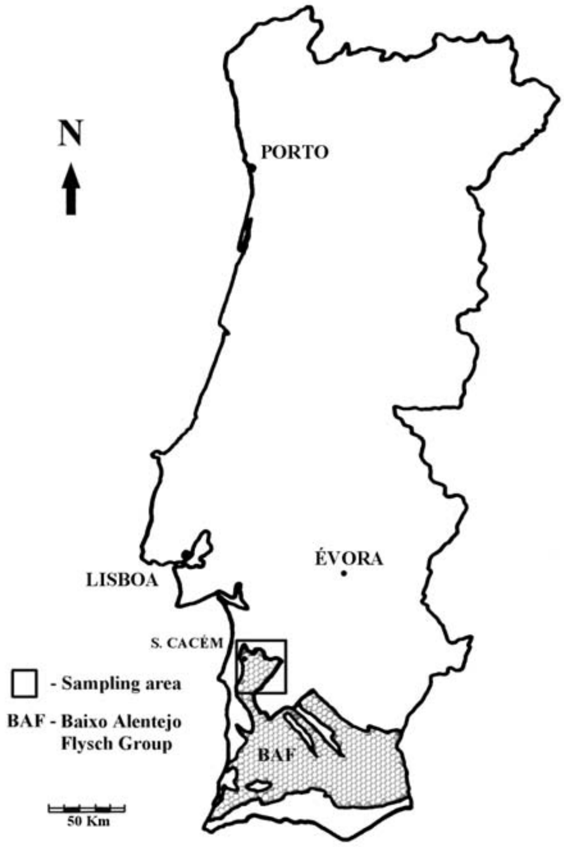

Figure 1. Location of the studied area

Laboratory testing and results

A laboratory testing programme on the collected samples, which included mineralogical analysis and physical tests, were performed. X-ray diffraction analyses were done in all of the samples, in order to identify the mineralogical composition, namely the clay minerals.

The mineralogical composition of shales and greywackes is similar, with the relative proportion of the occurring minerals varying. Both rock types are formed by quartz, feldspar (mainly calcium feldspars), micas and clay minerals, particularly kaolinite, illite and chlorite. In some samples, carbonates (mainly calcite, and siderite), pyrite and haematite occur in smaller percentages.

The greywackes are formed mainly by quartz and calcium feldspar that were involved by a cemented material mainly composed of phyllosilicates, but also of calcite, siderite and pyrite.

The shales, on the contrary, are mainly constituted by phyllosilicates, namely micas and clay minerals, with smaller amounts of quartz and feldspar. In smaller percentages, calcite, siderite and haematite were identified.

Laboratory testing was carried out to determine the fundamental physical properties inherent in the rock material (bulk density, apparent porosity and void index) according with the methods suggested by ISRM (ISRM 1979) which are described in detail in previous works (Pinho 2003; Pinho, Rodrigues-Carvalho & Gomes 2004). The results obtained in the physical tests are summarized in Table 1.

Table 1. Summary of physical parameters in shale and greywacke samples

Parameter	Range in shales	Range in greywackes
Bulk density	1693 – 2631 kg/m^3	1485– 2653 kg/m^3
Apparent porosity	4.4 – 29.6 %	2.1 – 25.5 %
Void index	0.4 – 16.7 %	0.1 – 11.1 %

Evaluation of the state of rock weathering by visual inspection

The weathering effects should be considered in the evaluation of the geotechnical behaviour of the rocks and rock masses. In fact, even in temperate climates, where the intensity of the weathering processes is smaller, it is not common to find fresh rock near the surface, and the weathering effects may be quite significant. In site investigation for engineering purposes, the variability of the geotechnical properties associated with the geological materials, due to weathering, is an aspect of paramount importance, as was already referred to. So, it is fundamental that the state of weathering be described and classified in an objective and consistent way.

Aspects related to the description of the main characteristics of rock by visual inspection, such as the resistance or the state of weathering, have been pointed out by Hawkins (1986), Norbury, Child & Spink (1986), Rodrigues-Carvalho (1986) and more recently Cragg & Ingman (1995) and Anon (1995), among others.

The classification system proposed by ISRM, designated as Basic Geotechnical Description of Rock Masses (BGD), is used worldwide. Besides the state of weathering, it includes other characteristics of the intact rock and rock mass and is a method for geotechnical general descriptions that can serve as a basis for descriptions and classifications for specific types of rocks or for geotechnical work (ISRM 1981).

According to BGD, the description and classification of the rock mass state of weathering is done by considering five weathering degrees with a defined terminology (fresh, slightly weathered, moderately weathered, highly weathered and completely weathered), with the corresponding symbols W_1, W_2, W_3, W_4 and W_5, as shown in Table 2.

Table 2. Classification of the state of rock weathering, according to BGD (ISRM 1981)

Term	Description	Symbols
Fresh	No visible sign of rock material weathering; perhaps slight discolouration on major discontinuity surfaces	W_1
Slightly weathered	Discolouration indicates weathering of rock material and discontinuity surfaces. All the rock material may be discoloured by weathering and may be somewhat weaker than its fresh condition.	W_2
Moderately weathered	Less than half of the rock material is decomposed and/or disintegrated to a soil. Fresh or discoloured rock is present either as a discontinuous framework or as corestones.	W_3
Highly weathered	More than a half of the rock material is decomposed and/or disintegrated to a soil. Fresh or discoloured rock is present either as a discontinuous framework or as corestones.	W_4
Completely weathered	All rock material is decomposed and/or disintegrated to soil. The original mass structure is still largely intact.	W_5

Although these weathering degrees have been established for the description of the state of weathering of rock masses, particularly for the classification of their weathering profile, it is frequent in practice to use them for the description of the state of weathering of rock.

In this study, the evaluation of the state of weathering by visual inspection of some of the samples revealed itself not to be an easy task. Evaluation errors happened, mainly in the more heterogeneous and fine grained samples. For example, the heterogeneous aspect of the weathering verified in samples 2AW3/W2X, 3W4G led to their being assigned a higher state of weathering when compared with that attributed later to the referred samples based on the results of the physical tests. In fact, the use of index tests for the evaluation of the state of rock weathering of the rocks studied revealed itself to be a quantitative complement to the most qualitative description by visual inspection (Pinho *et al.* 2004).

With the aim of contributing to the discussion of the reliability of assessing the state of weathering of rock by visual inspection, the authors asked a group of 21 qualified people with similar professional experience, to classify a set of 25 rock samples (14 shales and 11 greywackes) in agreement with the classification system BGD only by ordering them according to their state of weathering.

Accepting that the opinion of the majority of the assessors is that which best characterizes the state of weathering of the rock, the subjectivity of evaluating the state of rock weathering by visual inspection was analyzed based on the differences of evaluation errors verified regarding the most consensual opinion. This criterion thus allowed the definition of three classes of evaluation errors:

- when an opinion differs from the opinion expressed by the majority only by one weathering class, the evaluation error was considered as of little significance;
- when an opinion differs from the opinion expressed by the majority by two weathering classes, the evaluation error is considered as significant;
- when an opinion differs by three weathering grades, the evaluation error is considered as very significant.

The analysis of the results of the study is summarized in Table 3 for shales and Table 4 for greywackes. In order to make possible a comparison between the qualitative classification of those assessors, the tables referred to present the samples ordered according to the void index values obtained in the quick absorption test (ISRM 1979), a quantitative index parameter which is usually seen as a good way to characterize the state of weathering of the rock material.

Table 3. Results in percentages of the classification made by assessors of the state of rock weathering of shale samples according to BGD (ISRM 1981)

Sample	Description of weathering state (%)					Evaluation error (%)		
	W_1	W_2	W_3	W_4	W_5	little significant	significant	very significant
7W2/W1X	59.5	40.5	-	-	-	40.5	-	-
2AW3/W2X	57.1	38.1	4.8	-	-	38.1	4.8	-
13W2/W3X	7.1	35.7	47.6	9.5	-	45.2	7.1	-
4W2X	52.4	38.1	9.5	-	-	38.1	9.5	-
1W3/W2X	23.8	47.6	28.6	-	-	52.4	-	-
2AW4/W3X	2.4	21.4	57.1	19.0	-	40.4	2.4	-
12W4X	-	4.8	23.8	50.0	21.4	45.2	4.8	-
2W3/W2X	11.9	26.2	47.6	14.3	-	40.5	11.9	-
2W4X	2.4	7.1	14.3	66.7	9.5	23.8	7.1	2.4
3W4/W3X	-	4.8	14.3	66.7	14.3	28.6	4.8	-
11W3X	-	19.0	52.4	28.6	-	47.6	-	-
8W3/W4X	4.8	4.8	52.4	28.6	9.5	33.4	14.3	-
14W4-5X	4.8	9.5	33.3	42.9	9.5	42.8	9.5	4.8
5W4X	-	4.8	9.5	61.9	23.8	33.3	4.8	-

If all the samples under study are considered, it must be stressed, as a first conclusion, that in any case the assessors assigned the same classification for a particular sample. Besides, significant evaluation errors occurred in 72% of the samples while very significant errors happened in 12% of the samples, which points out the subjectivity of the description of the state of weathering of rocks by visual inspection.

In order to enable comparisons about the agreement/disagreement among the assessors to be made, the percentage of assessors who agreed with the most voted class of weathering for a given sample was considered:

- clear agreement – more than 75% of the assessors;
- fair agreement –50% to 75% of the assessors;
- disagreement – less than 50% of the assessors.

Analyzing the two rock types separately, in relation to the shales, the following was verified (see Table 3):

- in none of the samples does a clear agreement (more than 75% of the assessors voting for the same weathering class) exist;
- in 71% of the samples, a fair agreement is verified among the assessors (50% to 75 % of the assessors agreed with the weathering class) (samples 2W4X, 3W4/W3X, 5W4X, 7W2/W1X, 2AW3/W2X, 2AW4/W3X, 4W2X, 11W3X, 8W3/W4X and 12W4X);
- in 29% of the samples there was disagreement among the assessors (less than 50% agreed) (samples 13W2/W3X, 2W3/W2X, 1W3/W2X and 14W4-5X);
- for the highly weathered shale samples, a tendency was verified for a divergence of opinion based on the occurrence of very significant evaluation errors (samples 2W4X and 14W4-5X).

Table 4. Results in percentages of the classification made by assessors of the state of rock weathering of greywacke samples according to BGD (ISRM 1981)

Sample	Description of weathering state (%)					Evaluation error (%)		
	W_1	W_2	W_3	W_4	W_5	little significant	significant	very significant
7W1G	71.4	23.8	4.8	-	-	23.8	4.8	-
2AW2/W1G	66.7	33.3	-	-	-	33.7	-	-
3W2/W3G	4.8	57.1	38.1	-	-	42.9	-	-
1W2/W3G	4.8	42.9	42.9	9.5	-	14.3	-	-
2W2/W3G	2.4	21.4	57.1	14.3	4.8	35.7	7.2	-
6W2/W1G	2.4	50.0	33.3	14.3	-	35.7	14.3	-
13W2G	-	28.6	47.6	19.0	4.8	47.6	4.8	-
1W3/W4G	2.4	26.2	42.9	28.6	-	54.8	2.4	-
8W3G	-	4.8	47.6	40.5	7.1	45.3	7.1	-
5W4G	2.4	11.9	33.3	42.9	9.5	42.8	11.9	2.4
15W4G	-	-	-	73.8	26.2	26.2	-	-

Relative to the greywackes, it is verified that (Table 4):

- as for the shales, a clear agreement does not exist about the weathering class for any of the samples;
- for 55% of the samples, a fair agreement among the assessors (between 50% to 75%) was verified (samples 7W1G, 15W4G, 2AW2/W1G, 3W2/W3G and 2W2/W3G and 6W2W1G); this is more evident for the fresh or slightly weathered greywacke samples (samples 7W1G, 2AW2/W1G and 3W2/W3G);
- for 45% of the samples, disagreement was found (between 25% and 50%) among the assessors (samples 1W2/W3G, 13W2G, 1W3/W4G, 8W3G and 5W4G);
- for the fresh or slightly weathered greywacke samples, there is a tendency for the evaluation errors to be of little significance (samples 7W1G, 2AW2/W1G and 3W2/W3G), but the same does not apply to the moderately to highly weathered, where they are significant or very significant (samples 5W4G, 6W2W1G, 2W2/W3G, 8W3G and 13W2G); it must be highlighted that in one case (sample 1W2/W3G), about 86% of the assessors split into two equal tendencies: 42,9% attributed to the sample a moderate degree of weathering (W_3), while a similar percentage assigned a slight degree of weathering (W_2) to it.

CONCLUSIONS

The state of weathering is a feature of a great importance in engineering work, particularly in selecting geological materials for construction, in studies for foundations, in slope stability studies, etc., because its influence on the physical, mechanic and hydraulic characteristics of rocks and rock masses is very well known.

In site investigation for engineering purposes, the variability of the geotechnical properties of geological materials due to the weathering processes is an aspect of paramount importance and this is why the state of weathering must be described and classified in an objective and consistent way.

The description of a rock material is always somewhat subjective. In any situation, a careful description using a standardized terminology should always be made in a way to minimize this subjectivity. However, even in the situations where a well defined and standardized terminology is used, two qualified persons, with a similar experience, do not describe a rock material in the same way and so a divergence of opinions may happen, chiefly for those characteristics which are more difficult to assess.

In the case under study, some evaluation errors occurred in the evaluation of the state of weathering by visual inspection, mainly in the more heterogeneous and fine grained samples. Sometimes the state of weathering of the rock samples assigned by the assessors is not confirmed by the values obtained by the physical tests.

With the aim of contributing to the discussion of the reliability of evaluating the state of weathering of rocks by visual inspection, the authors requested a group of 21 qualified people to classify the state of weathering of a set of 25 samples (14 shales + 11 greywackes).

The results of the study showed many divergent opinions among the assessors. This points out the qualitative character of the visual evaluation and its subjectivity. In spite of the consensus that exists among the majority of the assessors, significant evaluation errors happened for 72% of the samples and very significant errors occurred for 12% of the samples. It was verified that the subjectivity of this assessment depends to a considerable degree on the lithology, the state of weathering and the heterogeneity of the samples. In respect of the lithology, the more divergent opinions happened for shales than for greywackes because the former has the finest grain, making evaluation by visual inspection difficult. In respect of the state of weathering, the distinction between the moderately, highly and completely weathered degrees is not difficult in certain rock types, but it is almost impossible in the case of mudrocks such as the shales of BAF. In the case under study, it was found that opinions diverged more about the moderately to highly weathered than about the slightly weathered samples. Regarding heterogeneities, the subjectivity of the classification becomes more important as the heterogeneities of the rock material increase.

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