Analysis of the relationship between durability and petrological characteristics of weak rocks

Analyse de la relation sur la durabilité et les caractères petrologiques de les roches tendres

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ABSTRACT

We have studied the role of petrographical and textural characteristics on the slake durability of weak rocks. We have used samples from 45 cutslopes distributed along several roads of the Catalan sector of the Tertiary Ebro Basin in Spain. Durability of intact and aged samples by drying-wetting and freeze-thaw cycles have been compared according their Slake Durability Test (SDT). Three different lythologies (sandstones, wackes, and mudstones) showing different textural characteristics have been tested. The analysis of the SDT has shown that the durability of the weak rocks is controlled by a set of parameters, being the rock texture one of the most relevant. Coarse grained homogeneous textures show the highest durability values of the sampled rocks. Forced ageing of the samples in the laboratory and, in particular, freeze-thaw cycles, has allowed to discriminate the long-term the durability behaviour between rock showing medium durability in intact samples.

Keywords: durability, weak rocks, texture, petrography, mineralogy, Slake Durability Test

1 INTRODUCTION

Slopes excavated in argillaceous rocks often display degradation mechanisms and local falls which affect both safety and maintenance costs of the roads. However, such behaviour may not be generalized. Some cutslopes remain unaffected for years while others degrade very rapidly. The degradation process occurs in both marine and continental sedimentary geological formations, which involve a variety of lithologies and textures of a complexity that is not reflected in the simple terms used to designate them (i.e. claystones, siltstones, shales or marls). Previous investigations have shown that relationships between the materials properties and their long-term behaviour in cutslopes are not evident (Martínez-Bofill et al. 2004).

Several authors have looked for relations between the petrological characteristics of rocks, and their durability. These investigations have involved both regionally-based extensive studies with a great variety of rocks, textures, and even structural settings (Santi, P.M. & Higgins, J.D., 1998; Santi, P.M. 2003, Dick & Shakoor, 1992, 1995), and specific geotechnical problems (Russell, D.J. 1982; Moon, V. & Beattie, A. G. 1995; Dhakal, G et al., 2002; Gökçeoğlu, C. et al., 2000; Sadisun et al, 2005). Even though these studies have provided valuable information on the rock behaviour, a relationship between petrology and durability has not been found yet.

In this paper we will discuss the influence of the texture in the mid-term durability of weak and argillaceous rocks, and its possible influence on the behaviour of cutslopes.

2 METHODOLOGY

A total of 45 samples were selected to analyze the mid-term durability and its relationship with the lithological and textural characteristics of the weak rocks. The samples were taken from several slopes of the Catalan Central Basin, which forms the eastern end of the Ebro Basin, NE of Spain. This area has a Mediterranean-continental transition climate, showing high thermal contrast between cold and foggy winters, with high humidity and freezing days, and hot and dry summers, with temperatures commonly rising over 30ºC degrees. The Ebro Basin is the southern foreland basin of the Pyrenees range, filled with both marine and continental sediments.

The sampled geological formations have remained basically undeformed and only affected by burial diagenesis.

Selection of the samples was based on: (i) presence of argillaceous layers; (ii) presence of either marine or continental formations; (iii) lithological variety that includes siltstones, claystones, marls, shales, in order the assess the influence of the mineralogical and textural components; (iv) absence or a low degree of structural deformation of the layers that, otherwise, would introduce an additional scattering factor in the assessment of the durability of the materials.

The working hypothesis is that degradation of weak rocks depends on both lithology (grain size, mineralogy and cementation degree) and textural characteristics that usually are related to the environmental conditions of the area. The argillaceous layers in the slopes were systematically sampled with a portable drilling machine. The samples were first identified and then tested with the Slake Durability Test (from now on SDT) as described by Franklin & Chandra (1972). From each slope three sets of samples were tested. One set was tested without any treatment (from now on, intact samples). To simulate the moisture changes in the slopes, a second set was subjected to an ageing process of 15 wetting-drying cycles of 24 hours duration and then tested for the SDT (from now on W-D samples). Each cycle consisted in storing the samples in an oven at a temperature of 105º C for 12 hours and then placed into a controlled humidity room at a temperature of 22º C for the same span of time. Finally, a third set of samples were subjected to an ageing process of 15 freeze-thaw cycles (ASTM, 1997) of 24 hours duration before testing (from now on F-T samples). The samples were first soaked in the 0,5% isopropyl alcohol solution prior to the storage for 12 hours in a freezer at a temperature of – 18ºC and then placed into a controlled humidity room at a temperature of 22º C for the same span of time.

Cylindrical core samples of 30 mm of diameter, and 30 mm height, were prepared in order to compare visually the evolution of samples during the ageing process. Results are given by Sehudes Index. In this work, a total of five SDT cycles in each sample has been carried out, obtaining the durability index Id_5. Samples showing low durability were also tested in the soil mechanics laboratory (Atterberg limits, grain size analysis, expansivity test…)

At the same time, mineralogical and textural characteristics of the samples were studied. Modal analysis of the rock components was also carried out in the polarizing microscope, by counting about 1000-2000 points in each sample, depending on grain size distribution and heterogeneity of the sample. The objective of the microscopical analysis was to properly classify each type of rock, as well as describe the textural characteristics that could be related to the durability of the samples.

3 TEXTURE TYPES

Textural characteristics are closely related to the grain-size distribution. We have analyzed and split our samples in different textural groups, in order to compare them. Petrographical analysis of examinated samples of marls and shales, shows that have to be classified as wackestones

Two main types of textures have been identified which, at their turn, have been divided into eigth secondary types (figure 1). These different types are described below.

Main Texture	**Secondary texture**	
Homogenous	Sandy	
	Wacky	Cemented
		Muddy
	Muddy	Cemented
		Uncemented
Heterogeneous	Sandy	
	Wacky	
	Muddy	

Figure 1: Textural classification of the investigated samples.

The main textural feature which can be identified with a fast microscope observation or even in a counterlight nude eyesigth of the sample is the homogeneity. Samples may be homogeneous or heterogeneous.

Homogeneous textures are characterized by a regular and uniform grain-size and mattrix distribution, without remarcable disturbing signs. In the other hand, heterogeneous textures show an irregular mixture of different types of textures and grain-size distribution

Other secondary features of the texture have required a detailed observation and counting with the polarizing microscope.

The most distinctive features to classify homogeneous textures are grain-size distribution that can be coarse (sandy) or fine (muddy), or presence of fine matrix between coarse grains (wacky). Fine grained fraction can be cemented, formed by micrite and spar carbonate grains, or indurated but not-cemented, composed by silt and clay without carbonate cement. Thus homogeneous textures are divided in the following secondary textures according to the nature of the predominant components:

- **Homogeneous sandy texture:** in this type, sand grain-sized clearly dominates, with content over 75%. Rock structure is grain-supported.
- **Homogeneous wacky texture:** is represented by an important amount of sand-sized terrigenous-clastic grains, embedded into a fine-grained matrix. It can be grain-supported or matrix-supported. As it will be discussed latter on, the amount and type of matrix is fundamental to explain the durability of the sample. It may be composed by silt, clay, by carbonate cement (figure 2) with micrite or spary cement, and most commonly, a mixture of them.
- **Homogeneous muddy texture:** in this group, matrix dominates over detritical grains (figure 3) which show a content which is under 25% of sand sized particles. Matrix can be cemented, or silty or clayey. Some other features are banded composition and presence of opaque grains (metallic minerals).

Heterogeneous textures are characterized by an irregular mixture of different types of textures and grain-size distribution. In spite of this, it is possible to distinguish several predominant types.

- **Heterogenous sandy texture:** it shows an irregular high content of terrigenous-clastic grains, mixed with a fine-grained matrix that may be locally predominant. Clayey soft nodules may be found as well. (Figure 4)
- **Heterogeneous wacky texture:** is represented by sand-sized terrigenous-clastic grains, embedded into a fine-grained matrix, mixed with irregular silty and clayey areas.
- **Heterogeneous muddy texture:** Fine grained materials dominate over irregular sandy areas, ocasionally isolated. (Figure 5)

Some special features that may be observed in both heterogeneous granular and muddy textures are:

- **Heterogeneous bioturbated texture:** the original texture is affected by bioturbation processes originated by fossil tracks (worms) commonly named as burrows. Fossil tracks destroy the original sediment texture, mixing sandy and clayey zones. Although the presence of bioturbation is expected to be a local feature, it is very common and has been frequently observed in continental sediments. A bioturbated texture may be either mostly muddy or mostly granular.
- **Chaotic texture:** In this case, it is not possible to define what the dominant texture looks like. It shows a greatly disordered microstructure.

Other interesting features to consider are the presence of opaque grains (metallic minerals mainly pyrite), gypsum or anhidrite, argillitic soft grains, rock discontinuities, like veins, cracks, joints (continuity, width, orientation, morphology, filling...)

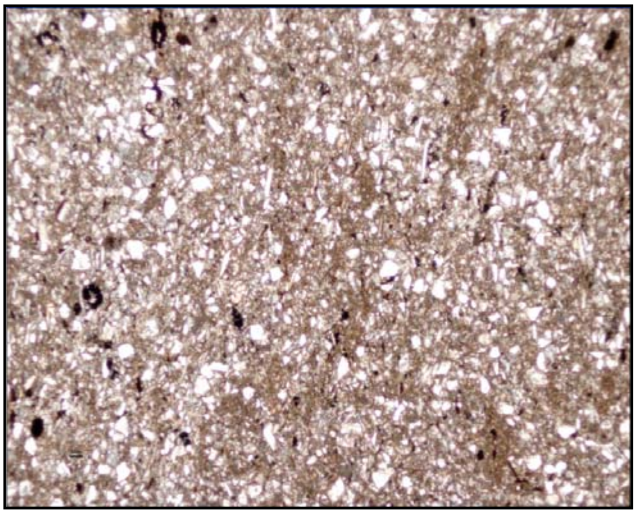

Figure 2: Homogeneous textures: homogeneous wacky carbonated texture, composed by quartz sand-sized grains with argillaceous cemented matrix

Figure 3: Homogeneous textures: homogenous muddy (argillaceous) texture.

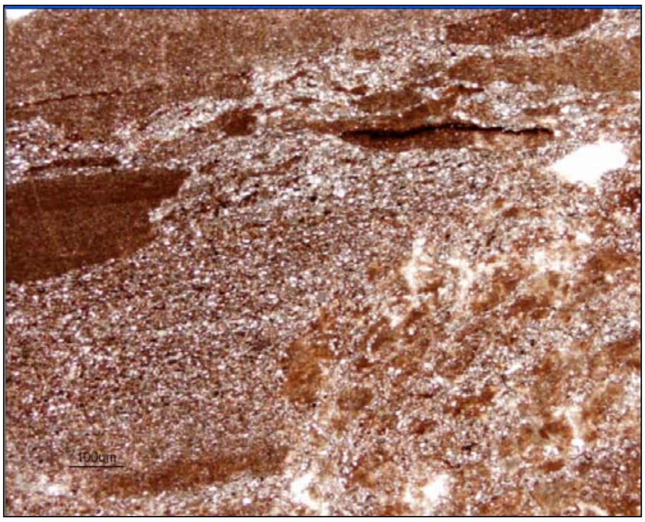

Figure 4: Heterogeneous textures: heterogenous sandy-predominant texture.

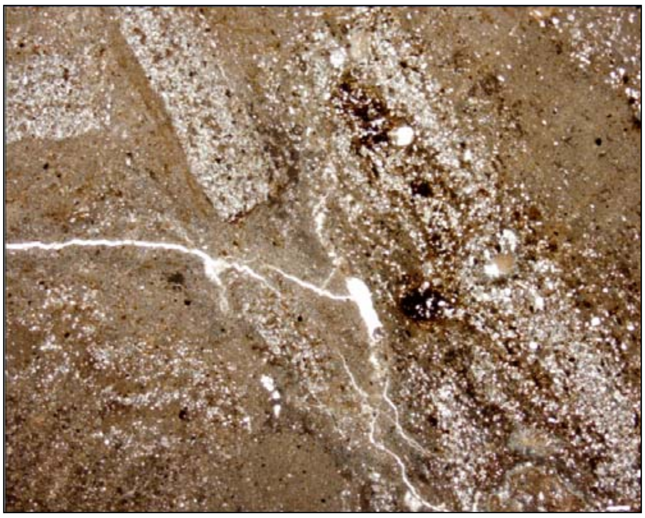

Figure 5: Heterogeneous textures: heterogeneous muddy-predominant texture.

4 RESULTS

The SDT values of the intact samples have been checked against the textural characteristics of the samples with the following results (figure 6):

- Samples of high durability: Samples of high durability are defined as those with a SDT Id5 value over 90. Most of the high-durability samples have homogeneous coarse sandy and wacky texture (84,6 % of the samples). Both homogeneous and heterogeneous textures may be highly durable. Those samples correspond to wackestones, with a high content of sandy grains and, commonly, a grain-supported texture, and carbonated matrix.
- Samples of medium durability: Samples of medium durability are those with values of SDT Id5 ranging between 60 and 90 for intact samples. In this case, textural features have an important influence on durability. These SDT values are found in homogeneous muddy carbonated cemented samples, and for heterogeneous granular wacky samples. This second set of samples, are classified as wackestones, and have a similar composition than heterogenous samples of high durability. So we find two different rocks (mudstones and wackestones) with different textures and composition showing similar durability.

From these results it can be concluded that for wackestones, the effect of the heterogeneous texture allows a wider range of rock durability values, ranging from very high to medium durability values, while those obtained for the same texturally homogeneous rock type, range between very-high and high durability.

Main Texture	Secondary texture		SDT Int. Id5	SDT W-D Id5	SDT F-T Id5
Homogenous	Sandy		>90	>90	>70
	Wacky	Carbonate cemented	100-89	97-72	97-67
		Muddy	94-75	60-0	88-60
	Muddy	Carbonate cemented	94-79	93-68	0
		Pure	74-28	52-47	13-0
Heterogeneous	Wacky cemented		93	75	0
	Wacky		92-62	80-20	0
	Muddy		53-0	49-0	0

Figure 6: Comparison between observed texture and SDT durability laboratory results on intact sample and after F-T and W-D ageing processes.

- <u>Samples of low and very low durability:</u> Samples of low durability are those with values of SDT Id5 in intact samples lower than 60. In this category we have found 9 samples, 2 of them with pure homogeneous muddy texture, and 7 of heterogeneous muddy texture. These samples are classified as mudstones and wackestones, with a low content of sandy grains, and matrix supported texture.

If we analize the variation of terrigeneous content against durability, we conclude that a lower sandy content is related to a lower durability, for both homogeneous and heterogeneous textures. Some rock types (wackestones) with a very wide range of composition also show a wide range of durability values. It seems that the heterogeneous texture allows a faster degradation of the rock when compared to homogeneous textures.

<u>The effect of ageing tests in rock durability</u>:

The analysis of durability of samples after being subjected to F-T and W-D ageing processes suggests four different behaviours that are described rigth now:

- First group correspond to samples with high and very high durabilty values, which after being subjected to F-T ageing processes, they keep high durability values. These samples are sandy and cemented wackestone homogeneous textures.
- Second group are samples of high durability as intact sample that show a significant decrease in durability after F-T cycles. They mostly correspond to heterogeneous sandy and wacky textures.
- Third group is represented by samples of medium to high durability in intact samples, that after being subjected to F-T ageing process they are completely slaked. Those samples correspond both to muddy carbonate cemented homogeneous textures, and wacky heterogeneous textures.
- Fourth group corresponds to those samples with low durablity in intact samples. These samples have obviously low durability value after ageing tests. This behaviour corresponds to homogeneous uncemented-muddy texture and to heterogeneous muddy-predominant texture.

There are no significant changes in durability of samples after being subjected to W-D ageing cycles.

5 DISCUSSION AND CONCLUSIONS

There is no single parameter that controls the durability of rocks. However, in this research we have found that durability is strongly influenced by both the composition and textural features of the weak rocks.

Coarse homogeneous textures are more durable than heterogeneous ones. As a first interpretation, we think that the heterogeneous texture creates pathways through which the weathering agents may penetrate into the rock and allows the existence of weak points in the contact between different textures. The heterogeneous texture also reduces the effectiveness of cement as binding element.

The highest values of durability are found in homogeneous sandy and wacky textures (Id5 intact sample>90). High durability values (Id5 intact sample from 80 to 90) are associated to both homogeneous and heterogeneous sandy-predominant textures. The lowest values of durability are found in uncemented muddy materials (Id5 intact sample commonly <50). In latter case, the texture is not a critical factor as both homogeneous and heterogeneous textures show very low values of durability.

Mid-durability SDT values of intact samples are associated to both homogeneous and heterogeneous textures with variable amount of fine components and cement. Muddy cemented rocks, yield medium to high SDT values (Id5 intact sample 70-80). Commonly, these materials are classified as marls, mudstones, claystones in field description. However, petrographical analysis has shown that they correspond to mudstones and wackestones.

The presence of fine matrix has a significant effect on the long-term durability, especially considering daily or seasonal temperature changes. When subjected to freeze-thaw ageing process, the durability of the coarse homogeneous samples is notably higher (Id5 F-T >70) than heterogeneous ones (Id5 F-T <50).

When mid-durability materials are subjected to freeze-thaw cycles, the response is heterogeneous. Some samples give a low SDT values while some of them may become completely disaggregated. The latter corresponds to the textures having a high percentage of fine-grained matrix.

Consequently, the textural analysis may help in predicting the long-term durability of the cutslopes. However, microscopical observation appears to be necessary to properly classify each type of rock and define its textural characteristics. Field and hand sample description, even supported by cartographic lithological information may not be enough to characterize the texture of the sample.

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