"SCHISTOSE" ROCKS AS A RESOURCE

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Abstract

Until the beginning of the 20th century, schist was a common building material in the Northeast and Centre regions of Portugal, due to the abundance of schist outcrops in these regions.
The area of study is the NE Portugal characterized by the occurrence of abundant schist of different types and also of greenish basic rocks both having the ability to split according to more or less defined planes.
Currently, the development of a R&D project financed by FCT (Portugal) – the "SCHISTRESOURCE" – involving the Universities of Porto and Évora and the LNEG is in course. The main objectives of the project are:
1- Characterizing the schist occurrences performing structural, mineralogical and petrographical studies aiming the schist utilisation as ornamental and/or building stone;
2- Carrying out a technological characterisation of the rocks and a systematic evaluation of the occurrences with good potential;
3- Promoting schistose rocks as a geological resource in areas from Northern Portugal.
A first phase consisted on the selection of sites showing favourable geological and macroscopical characteristics enabling industrial exploitation. In the selected sites a detailed geological cartography accompanied by sampling of the most representative rock types for laboratorial studies was done. Petrography, chemical composition and physical-mechanical characterisation (compressive strength, flexural strength, apparent density, water absorption, abrasion resistance and impact resistance) were performed.
In a second phase, the evaluation of the volume of rock with good characteristics for each potential application, within some of the selected areas, will be performed by geophysical methods using a vast number of short seismic refraction profiles in a predetermined regular grid.
In this contribution, we present as a "Case study" the "Tanha quarry" where a lithology of "Complexo Xisto-Grauváquico" affected by thermal metamorphism is exploited as industrial stone, but where a preserved area for ornamental stone exists.

Keywords: Schistose stones, exploration, NE Portugal.

1. Introduction

The geology of Portugal is favourable to the occurrence of abundant outcrops of many metamorphic terrains, namely of schistose composition. The Hercynian orogeny is responsible for the recrystalization and deformation of many Palaeozoic and Proterozoic sediments. Consequently, it is frequent the occurrence of abundant schists of different types and colours and also of greenish basic rocks, both having the ability to split according to more or less defined planes.
Until the beginning of the 20th century, "schist" was a common building material in the Northeast and Centre regions of Portugal. However, in spite of its singularity and beautifulness, this stone is not frequently used in the present days. Consequently, its exploitation as ornamental rock is scarce.
The purpose of this project is to contribute to a resurgence of the utilization of schist as an ornamental stone. Thus, a characterization, adopting normalized specifications, is being conducted.
In this contribution we present an example of the studied sites, the "Tanha quarry" where a lithology of "Complexo Xisto-Grauváquico" is exploited as industrial stone but where a preserved area for ornamental stone exists.

2. Methodology

A geological exploration of schist formations already defined in the available published geological cartography (1/200000 and 1/50000) was performed. After, we performed a selection of sites with schist showing favourable geological and macroscopical characteristics enabling the industrial exploitation and a sampling survey was planned. In the selected, sites a detailed cartography (1/10000) accompanied by sampling of the most representative rock types for laboratorial studies was done.

Polarized light microscopy (PLM) remains an efficient and necessary technique for identification of crystalline materials and provides a wide range of information about samples. The petrographical analysis is necessary for the determination of size and morphology of the particles and the structure, as well as, information about the eventual presence of harmful particles or minerals. A Nikon Eclipse E400 POL optical microscope and a Zeiss Stemi SV11 Apo stereomicroscope, both coupled with microphotograph digital systems, were used to carry out petrography studies.

Also important for materials characterization is chemical composition and physical-mechanical tests (compressive strength, flexural strength, apparent density, water absorption, abrasion resistance and impact resistance).

X-Ray Fluorescence was used to carry out chemical analysis of the schist samples, for that a PANalytical PW2404 sequential wavelength dispersion X-Ray spectrometer was used.

European standards (EN) were used to determine physical and mechanical properties of the schist samples. In this study, the determined properties can be grouped according to their purpose: (i) Identification and (ii) Durability. On the first group, uniaxial compressive strength, flexural strength under concentrated load, apparent density and open porosity and water absorption at atmospheric pressure were carried out. On the second group, abrasion resistance and resistance to ageing by thermal shock were performed.

Uniaxial compressive strength (EN 1926) — Cubic test specimens were laid and centred on the plate of an ELE International ADR 200 compressive testing machine. A uniformly distributed and continuously increased load was applied until specimen failure occurred. Compressive strength is the ratio between the failure load and the surface area submitted to load.

Flexural strength under concentrated load (EN 12372) — Parallelepiped specimens were placed on two supporting rollers of an ELE International Tritest 50 Digital flexural testing machine. The distance between these rollers (span) depends upon the specimen thickness. By means of a third roller in the middle of the specimen a load was applied. The load was progressively increased until failure occurred. Flexural strength is calculated by the following equation:

$$R_f = \frac{3 \times \text{failure load} \times \text{span}}{2 \times \text{width} \times \text{thickness}^2}$$

Apparent density and open porosity (EN 1936) — Cubic test specimens were dried to constant mass and then placed in a vessel to absorb water while submitted to a standard vacuum. After a period of time, also standard, saturated and immersed weighing was taken. Apparent density and open porosity are calculated according to the following equations.

Apparent density:

$$\rho_b = \frac{\text{dried mass}}{\text{saturated mass - immersed mass}} \times \text{water density}$$

Open porosity:

$$p_o = \frac{\text{saturated mass - dried mass}}{\text{saturated mass - immersed mass}} \times 100$$

Water absorption at atmospheric pressure (EN 13755) — This test method is similar to the method described for apparent density and open porosity determination. The main differences were that vacuum was not used and specimens were left to saturate in water until constant mass was reached. Water absorption was calculated by the ratio between the mass of absorbed water and the mass of the specimen.

Abrasion resistance (EN 14157) — A Tecnilab 440C Capon wearing machine was used to abrade the faces intended to be exposed in use of specimen slabs. In this machine type, abrasion is caused using both a rotating abrasion wheel (with standard dimensions and made of a standard steel) and a standard abrasive powder (white fused alumina). The test was carried out under standard conditions. A Certified Reference Material was used — “Marbre du Boulonnais” both to achieve standard conditions on the testing machine and to make a correction on test results. Abrasion resistance value is the chord measured in the middle of the groove produced in the slab surface.

Resistance to ageing by thermal shock (EN 14066) — After drying to constant mass, specimen slabs were submitted to 20 successive cycles. Each cycle consisted of a drying period at (105±5) ºC immediately followed by an immersion in water at (20±5) ºC. The drying and immersion periods used were the ones defined on the EN 14066. At the end of the 20 cycles, test results were presented both as the percentage of mass variation (usually loss) and the changes in visual appearance experienced by the tested specimens. The changes in visual appearance before and after cycling were evaluated by means of a "control specimen" not submitted to test.

3. Geology

Tectonic characteristics of the Hercynides are those of a classical obduction-collision belt and it is described as a stacking of large-scale thrust crustal napes.
Most of the pre-Mesozoic basement of Iberian Massif is composed of Neoproterozoic to Carboniferous terrains, which were deformed, metamorphosed and intruded by many Hercynian granitoids.
Several structural levels and metamorphic domains are represented from the more external zone, "Cantabrian Zone" (CZ), to more internal zones the "Central Iberian Zone" (CIZ) and "Galicia-Trás-os-Montes Zone" (GTMZ) (Julivert et al, 1974; Farias et al., 1987). The CIZ is the most important zone of the Hesperic Massif and it is characterised by the presence of autochthonous metamorphic formations, Neoproterozoic in age ("Complexo Xisto-Grauváquico"). The "Galicia Trás-os-Montes Zone" (GTMZ) is characterised by Precambrian allochthonous predominantly mafic and ultramafic massifs, surrounded by parautochthonous metasedimentary sequences mostly from Ordovician-Silurian, the "Peritransmontano domain" (Ribeiro 1974).
Three main phases of deformation D1, D2 and D3 are usually considered responsible for the structuration of the NW of the Iberian Peninsula (Noronha et al. 1981). At the autochthonous the D1 structures are well preserved; at the allochthonous and parautochthonous, the D1 structures were transposed by D2 near the thrusts giving rise to the regional schistosity (S2). D3 is Carboniferous in age and is responsible by latter folds with vertical axial planes and sub-horizontal axis.
The "Tanha" quarry is situated in the CIZ, more precisely in the south limb of the "Vila Real-Carviçais" antiform, not very far from an important regional NNE-SSW lineament, the "Verín-Régua-Penacova" fault. The outcrops consist of formations belonging to the "Dúrico-Beirão" Super Group ("Complexo Xisto-Grauváquico – "Douro" Group) integrated in the so-called Autochtonous Domain (Sousa & Sequeira 1989). Sintectonic granitoid rocks outcrops in the region (Figure 1).
Locally, the outcrops exhibit a N50°W; 15°E bedding-plane subparallel with S_1. They belong to the "Pinhão" Formation, consisting in a green coloured, thin bedding sequence, characterized by an alternating psamitic (quartz-rich) and pelitic (mica-rich) layering. Magnetite crystals and more sporadically pyrite crystals are present in the psamitic and pelitic layers.

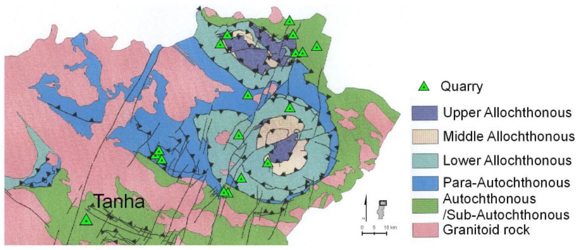

Figure 1: Geological map of NE Portugal and sampling sites.

4. Results

4.1. Petrography

From the petrographic point of view Tanha lithology is characterized by quartz-rich and mica-rich layers alternation that corresponds to the bedding-plane foliation (S_0) subparallel with a S_1 foliation. The quartz-rich layers are predominantly quartzwackes and impure quartzites. Microscopically, they present quartz crystals and also chlorite and scarce biotite. Opaque minerals are present as accessory constituents. The mica-rich layers are, macroscopically, green coloured. At the optical microscope, they are in fact chloritic phyllites and quartz-phyllites presenting a granolepidoblastic texture. The mineralogical association consists of quartz, chlorite, muscovite and abundant biotite porphyroblasts. Opaque minerals (magnetite and pyrite) are also present as accessory constituents. The blastesis of biotite has, in general, no preferred orientation and is associated with a late thermal event. Microscopically, a crenulation cleavage (S_3) can be identified (Figure 2 and 3).

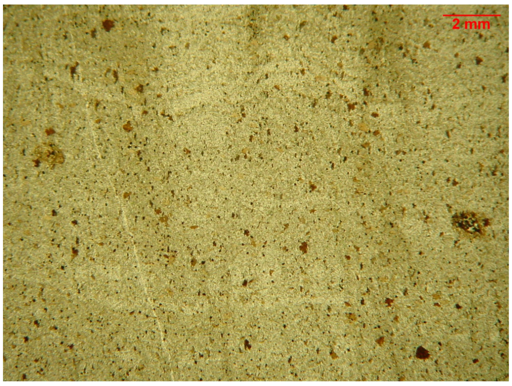

Figure 2: Quartz-phyllite sample (stereomicroscope).

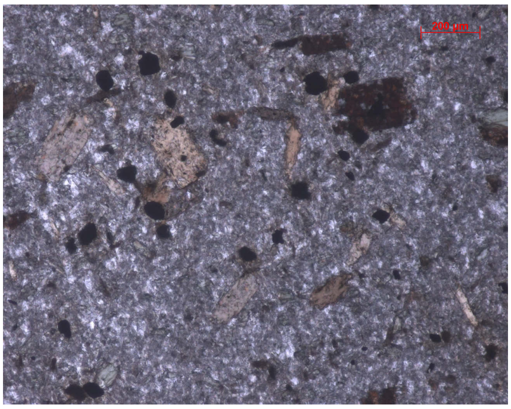

Figure 3: Quartz-phyllite sample (optical microscope; plane-polarized light).

4.2 Chemical and physical-mechanical characterization

Chemical features

The results obtained for major elements contents of “Tanha” schist are presented in the following table (Table 1).

Table 1: Major elements contents of “Tanha” schist.

Major Elements (%)	
SiO_2	60.78
Al_2O_3	18.50
Fe_2O_3	7.55
MnO	0.07
CaO	0.36
MgO	2.78
Na_2O	1.51
K_2O	3.82
TiO_2	0.95
P_2O_5	0.15
Loss On Ignition	3.44

Physical-mechanical properties

The following table (Table 2) contains the average results obtained for “Tanha” schist on the identification properties.

Table 2: “Tanha” schist identification properties.

Compressive strength	110 MPa
Flexural strength under concentrated load	42.9 MPa
Apparent density	2760 kg/m^3
Open porosity	1.2 %
Water absorption at atmospheric pressure	0.4 %

The following table (Table 3) contains the average results obtained for “Tanha” schist on some durability properties.

Table 3: “Tanha” schist durability properties.

Abrasion resistance	26.5 mm
Resistance to ageing by thermal shock – mass variation	- 0.01 %

Visual appearance of “Tanha” schist specimens before testing and after 20 cycles of thermal shock can be seen on the following Figures 4 and 5.

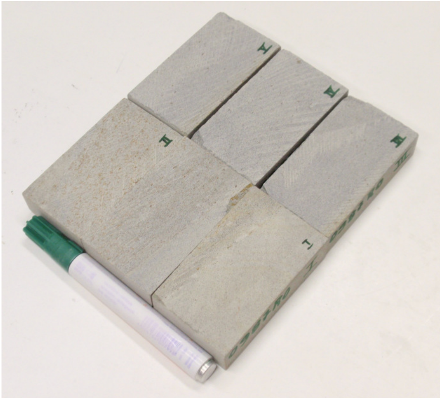

Figure 4: Resistance to ageing by thermal shock. Specimens’ appearance before testing. The specimen placed in the middle left position is the control specimen, which is not submitted to test.

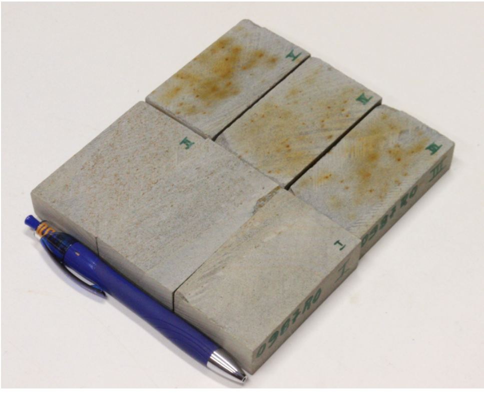

Figure 5: Resistance to ageing by thermal shock. Specimens’ appearance after 20 cycles of thermal shock. In three of the five tested specimens spots and stains of iron oxide occurred. These features covered about 50-60% of the total surface area of the specimens.

5. Conclusion

In this contribution we present as a “Case study” the “Tanha quarry” where a lithology of “Complexo Xisto-Grauváquico” is presently exploited for industrial purposes. In spite of the absence of granite outcrops, the schist is affected by thermal metamorphism that is responsible for a latter biotite. The presence of this late biotite can justify the occurrence of the brownish stain appearance after thermal essays.

Acknowledgements

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