



Mineralogical study of the deterioration of granite stones of two Portuguese churches and characterization of the salt solutions in the porous network by the presence of diatoms

Arlindo Begonha*

Faculdade de Engenharia, Universidade do Porto, Rua Dr. Roberto Frias, s/n, 4200-465 Porto, Portugal

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ABSTRACT

Two Portuguese churches were built with stones of different types of two-mica fine to coarse grained granites. The stones in both monuments were previously submitted to a natural weathering process in the quarries leading to a homogeneous and very well interconnected porous network composed of very thin fissures, allowing a fast capillary transfer of rain water and salt solutions. Therefore, the stones presently exhibit several types of stone decay. A mineralogical study of the deteriorations was carried out in the two churches that permitted the identification of several minerals of soluble salts responsible for stone decay. Some forms of diatoms have been identified in samples of deteriorated stones in both monuments. Several ions in the salt solutions present in the porous networks of the granites, which are in conformity with the minerals of soluble salts associated with the deterioration of the granite, permit the development of several forms of diatoms.

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1. Introduction

The S. Pedro de Rates Church was built in the 12th century in the Romanesque style (Fig. 1a) and was submitted to several transformations in the 13th, 17th and 18th centuries. In order to re-establish the original features of the Romanesque style, the monument was subjected to a profound and controversial intervention by the Direcção Geral dos Edifícios e Monumentos Nacionais (DGEMN) [1] in the thirties and forties in the 20th century (Fig. 1b).

In 1984, the DGEMN applied a silicone consolidating in the Western and Southern portals with the purpose of stopping the strong loss of material due to granular disintegration [2]. A chemical reaction between the consolidating and the UV rays changed to orange the original gray colour of the stones.

The monument is located in an open valley with an intense agriculture activity, 9.5 km East of the Atlantic Ocean and

about 30 km North of Porto. The phreatic level is about 2.5 m deep. The church and the area outside were used as a cemetery during several hundred years.

The S. Gonçalo Church in Amarante is situated in the steep right bank of the Tâmega River valley (Fig. 2a), 40 km East of the Atlantic Ocean and of Porto and was essentially built between 1540 and 1620. The Southern façade is the most important one, exhibiting a three floor portal in the Renaissance, Mannerist and Baroque styles (Fig. 2b). Two wide cornices separate the three floors of the portal. The church and the adjoining cloister were used as a graveyard for several hundred years.

The monuments were built with two different two-mica fine or medium to fine and medium to coarse grained granites. Stones of the fine or medium to fine granites were employed in the portals and in the architectonic details in both churches. These four granites are composed of quartz, microcline, sodium plagioclase, muscovite and biotite.

* Tel.: +351 225081881; fax: +351 225081446.

E-mail address: abegonha@fe.up.pt.

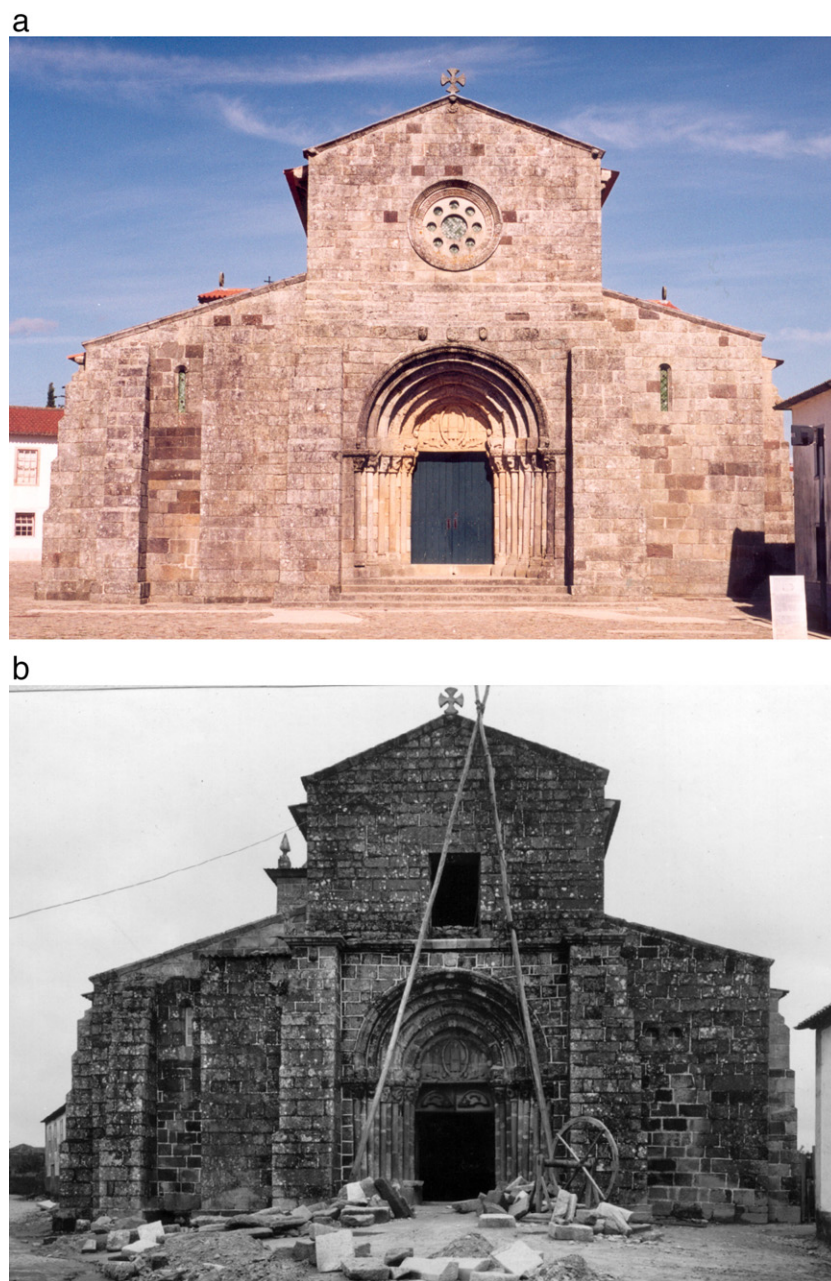


Fig. 1—S. Pedro de Rates Church. **a:** October 2001. **b:** Intervention in the thirties and forties of the 20th century [1].

The mineralogical composition and the petrophysical characteristics of the stones show that all types of granite were already weathered before they were used in the construction of both monuments.

Gibbsite ($\text{Al}(\text{OH})_3$) and kaolinite ($\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$) were identified by means of X-ray diffraction (XRD) of the $<2\ \mu\text{m}$ fraction in samples of stones of both churches [3,4a]. These two secondary minerals were inherited from the weathering process of the granites in the quarries. They show a high degree of mineralogical evolution and are the final weathering products in the weathering profiles of the granite rocks in the Northwest region of Portugal [5,6a,7,8].

The results of dry bulk density (d), 48 h free porosity (N_{48}), mercury porosimetry (total porosity by mercury intrusion (N_{Hg}), microporosity (N_{μ}), diameters of the family pores (d_a)

and type of porous network) and coefficient of capillary rise by water absorption (B) obtained in samples of stones of S. Pedro de Rates and S. Gonalo de Amarante are shown in Table 1.

According to Table 1 [4b,9], in each monument the stones have different weathering degrees. Besides this, the weathering process of all types of granite applied in the two monuments led to homogeneous porous networks essentially composed of very thin and very well interconnected fissures, allowing a fast and effective capillary transfer of rain water and salt solutions. These results are in accordance with those referred in other Portuguese granite monuments [6b,10–16].

As a result, the weathered granite stones of S. Pedro de Rates and S. Gonalo de Amarante presently exhibit several types of stone decay.

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