

Physical characteristics of the Oporto granite related to stone decay in monuments

Arlindo Begonha^{*}, Daniel Jeannette^{**},
 Claude Hammecker^{**}, Maria Amália Sequeira Braga^{***}
^{*}*Faculdade de Engenharia, 4099 Porto Codex, Portugal*
^{**}*Centre de Géochimie de la Surface, 67084 Strasbourg Cedex, France*
^{***}*Departamento de Ciências da Terra, 4719 Braga Codex, Portugal*

Abstract

Most of the Oporto monuments, were built with the Oporto granite, a two micas, medium-grained leucogranite.

With the purpose of showing that fast imbibitions are responsible for the development of stone deterioration in the monuments, polished thin sections of granite impregnated with coloured resins, and measurements of total porosity, 48 hours porosity, mercury porosimetry, capillarity and permeability to nitrogen were made in unweathered and weathered granites of the Trindade quarry and in granitic stones of the interior walls of the Hospital Santo António. Results show that total porosity and 48 hours porosity are very low in all samples. They are different in the unweathered and weathered granites of the quarry. The stones used in the monument had different degrees of weathering. Most of the porosity is invaded by the solutions. Imbibitions are, indeed, very fast in the weathered granites of the quarry and of the monument.

Keywords

Granite, hydrothermal alteration, weathering, plagioclase, deterioration, porosity, capillarity, permeability.

Introduction

Most of the Oporto monuments, namely the Hospital de Santo António, were built with the Oporto granite, a medium-grained leucogranite, sin-tectonic considering the third phase (F3) of the Hercynic deformation (Pereira et al. 1989) and exhibit severe stone decay features with

different soluble salts and, therefore, in the type of stone deterioration (Arnold and Zehnder 1989; Jeannette and Hammecker 1992).

Begonha and Sequeira Braga (1993) refer that in the Hospital de Santo António, granular disintegration is observed essentially in the lower areas of the façades due to the rising of soluble salt solutions by capillarity from the ground. It is also observed in stones involved by large amounts of recent Portland cement mortars, which are also a source of soluble salts. Basically, plates are formed in stones where the evaporation of soluble salt solutions is not realized on the surface of the stone but in a horizon of accumulation. Black crusts are associated to sheltered areas on walls not exposed to run-off. In these areas there is an accumulation of soluble salt solutions by capillary transfer that evaporate on the surface and there is a deposition of fly ashes and soot related to air pollution.

All these deteriorations result of the concentration of soluble salts (gypsum, halite and nitrates) on the surface or near it after the migration of the solutions across the weathered granite, which proves the existence of an internal porous network in the granitic stones that allows capillary transfer of the solutions.

The petrophysic characteristics are, indeed, the most important factor that enables stone decay. The fastness of capillary transfer of the soluble salt solutions depends on the porous network geometry and on the size of the pores of the rock (Merts 1991; Jeannette and Hammecker 1993).

Since there is a wide range of the size and geometry of the pores and their interconnections, a rock porosimetry study requires several techniques, each one with its precise application field (Meng 1993).

Earlier studies concerning capillary transfer of soluble salt solutions in granites and its influence in stone decay in the monuments have been accomplished by Alves et al. (1992) and by Jeannette et al. (1993).

soluble salt solutions responsible for stone deterioration in the monuments.

Materials

The Oporto granite is a two micas medium grained leucogranite composed by quartz, plagioclase, microcline, muscovite and biotite. The molecular percentages of anorthite in the plagioclases (An_{6.9}-An_{14.3}) have been analysed by a scanning electron microscope (SEM) equipped with a X-ray microprobe (EDS-WDS). Apatite (as an inclusion in plagioclase, microcline and in biotite) and zircon (as an inclusion in biotite) are the accessory minerals.

Samples have been taken in three different areas in the Trindade quarry being two of fresh (unweathered) Oporto granite (F1 and F2) and one of weathered granite (T).

Two samples of stones (H1 and H2), not submitted to any weathering or deterioration process after the building of the monument, have been taken in two interior walls of the Hospital de Santo António.

When unweathered, the Oporto granite is homogeneous light gray but in the weathered rock it is slightly yellow.

The Oporto granite, as well as, all the two micas granites and leucogranites of Northwestern Portugal were affected by tardi-post magmatic alteration phenomena related to the albitization and muscovitization phenomena of these rocks (Dias 1987; Sequeira Braga 1988; Brilha 1992). As a consequence, the most fresh samples collected in the Trindade quarry (F1 and F2) are not really fresh but unweathered. In fact, a hydrothermal alteration was responsible for the sericitization of the plagioclase, as well as, the albitization of the microcline in the fresh granite. Fresh rock is used in this paper in the context of parent rock in a weathering profile model. In this model the unweathered rock (fresh rock) evolves successively to weathered rock, (saprock) saprolite and finally to soil (Bisdom 1967; Meunier 1980; Sequeira Braga and Paquet 1987). Besides, the samples taken in the monument correspond to the weathered granite observed in the weathering profiles in the quarry (sample T).

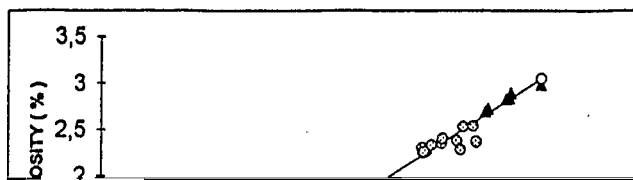
Indeed, kaolinite and gibbsite have been identified by X-ray diffraction (XRD) in the <2µm fraction in samples of weathering profiles (either in the saprock or in the saprolites) and also in stones of the Hospital de Santo António (H1 and H2). Their presence has been corroborated in polished thin sections using a scanning electron microscope. These two secondary minerals are characteristic of a high degree of weathering in the perhumid and temperature climate of Southwestern Atlantic Europe (Sequeira Braga 1988; Sequeira Braga et al. 1990). Granitic stones already weathered by hydrolysis of the parent minerals were, therefore, used as building materials of

SAMPLE	DRILL SAMPLE	NT %	N48 %	S48	A g/cm ² (h1/2)	B cm(h1/2)
T	T1	2,65	2,27	0,86	0,06489	3,319
	T2	3,03	2,55	0,84	0,09481	4,661
	T3	2,61	2,31	0,89	0,07041	3,545
	T4	2,62	2,26	0,86	0,05651	3,069
	T5	2,69	2,34	0,87	0,07565	3,504
	T6	2,9	2,39	0,82	0,06015	2,996
	T7	2,95	2,54	0,86	0,09838	4,604
	T8	2,77	2,36	0,85	0,07248	3,469
	T9	2,93	2,29	0,78	0,06913	3,655
	T10	2,63	2,27	0,86	0,06435	3,384
	T11	3,06	2,38	0,78	0,06986	3,451
	T12	2,78	2,41	0,87	0,07927	3,62
H1	H44	1,93	1,72	0,89	0,04974	3,473
	H45	1,91	1,7	0,89	0,04992	3,546
	H46	2,01	1,78	0,89	0,0589	4,003
	H47	1,82	1,63	0,9	0,03985	2,967
	H48	1,96	1,53	0,78	0,03149	2,361
	H49	1,78	1,6	0,9	0,04183	3,159
H2	H50	3,13	2,71	0,87	0,08095	3,349
	H51	3,15	2,73	0,87	0,08264	3,581
	H52	3,3	2,84	0,86	0,08462	3,502
	H53	3,33	2,85	0,86	0,08635	3,721
	H54	3,59	3	0,84	0,07753	2,746
	H55	3,34	2,91	0,87	0,07258	2,619
F1	F70	0,93	0,64	0,69	0,00958	1,12
	F71	0,93	0,63	0,68	0,00989	0,953
	F72	0,95	0,65	0,68	0,00953	1,24
	F73	0,92	0,68	0,74	0,00776	1,237
	F74	0,81	0,8	0,99	0,00776	0,984
	F75	0,72	0,66	0,92	0,00741	0,862
	F76	0,78	0,75	0,96	0,00869	0,99
F2	F77	0,88	0,77	0,88	0,00996	0,906
	F96	1,14	0,96	0,84	0,02514	1,935
	F97	0,96	0,86	0,9	0,01217	1,218
	F98	0,92	0,84	0,91	0,01168	1,139
	F99	1,09	0,96	0,88	0,02184	1,365
	F100	1,09	0,97	0,89	0,03176	1,823
	F101	1,13	1	0,88	0,03376	1,988
	F102	0,91	0,78	0,86	0,01003	1,107
	F103	0,96	0,87	0,91	0,01118	0,996
	F104	0,88	0,79	0,9	0,01065	0,797
F105	0,87	0,75	0,86	0,00999	0,914	

Table 1 - Results of the petrophysic characteristic of the unweathered samples (F1; F2) and weathered samples (T) of the quarry and of the stones of the Hospital de Santo António (H1; H2).

the monuments (Sequeira Braga et al. 1993).

After impregnation with coloured resins, polished thin sections have been executed in all samples, in order to be studied in the optical microscope and in the scanning



N_T and N_{48} results.

The obtained equation $N_{48}=0.0143+0.846N_T$ with a coefficient of correlation $r=0.995$ has been plotted in fig. 2, allowing a very good adjustment to the results.

The stones of the monument were already weathered and had distinctive degrees of porosity and, conse-

Capillarity - water absorption test

Capillarity - water absorption tests have been carried out in the 42 drilled samples (table D).

In the fresh samples, capillarity rise reached the top only in the most porous F2 samples (F96, F99, F100 and F101). The capillarity coefficient B is much lower in the unweathered F1 and F2 samples of the quarry (1.04 cm/ h and 1.33 cm respectively) than in the weathered samples of the quarry (3.61 cm/ h) and of the monument (3.25 cm/ h for both H1 and H2 samples) (fig. 4). This shows that imbibitions are very fast in the weathered granites (fig. 5). These results are similar to those presented by Alves et al. (1993) in the weathered Braga granite (2.69 cm / \sqrt{h} and 4.58 cm / \sqrt{h}).

The fastness of capillary transfer justifies the important deteriorations in the Oporto monuments built with this quite low porous weathered granite.

In the F1, F2, H1, T and H2 samples, water absorption coefficient A is respectively equal to 0.009, 0.018, 0.045, 0.073 and 0.081 g/cm². The results confirm the different degrees of weathering of the H1 and H2 samples and characterize the weathering degree of the Oporto granite.

Permeability to nitrogen test

Permeability to nitrogen has been measured in 16 fresh and weathered samples under several different confinement and fluid pressures.

The differences between the confinement pressure and the fluid pressure have been always equal to 0.2 bar. All samples present low permeability. Permeability results of six samples representative of unweathered and weathered granite have been plotted in fig. 6.

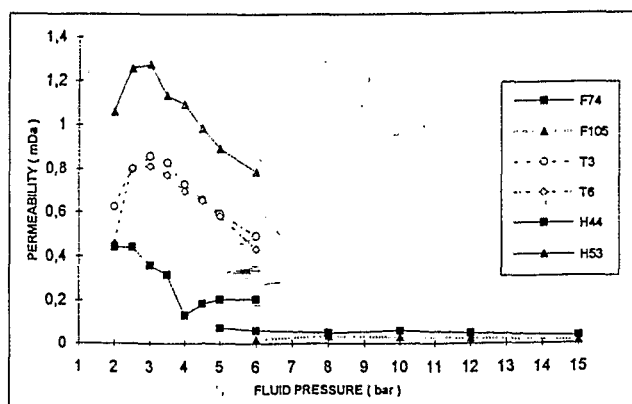


fig 6. Permeability results of the unweathered granite (F74; F105) and weathered granite (T3; T6) of the quarry and of the stones of the monument (H44; H53).

The weathered samples of the Trindade quarry (T3 and T6) are in an intermediate position relatively to the H1 and H2 samples (H44 and H53). The permeabilities of the fresh granite of the quarry (F74 and F105) are lower than those of the weathered samples of the quarry and of the monument. The H2 samples are more permeable to the nitrogen than the H1 samples.

These results corroborate the previous results concerning porosity and capillarity-water absorption tests.

Mercury porosimetry

Mercury porosimetry results show that the most frequent access radii to the pores are 0.20 μ m in two fresh samples of the quarry, 0.65 μ m in one weathered sample of the quarry, and 0.40 μ m in two weathered samples of the monument.

There is a great homogeneity of the access radii to the pores in the weathered samples. Indeed, all free porosity of these granites is invaded by the interconnections between 0.40 μ m and 0.65 μ m. The fastness of capillary transfer of the solutions is a consequence of the homogeneity of the access radii to the pores in the weathered granites.

In spite of the small number of the studied samples it seems that the access radii to the pores (0.20 μ m to 0.65 μ m) depend on the weathering degree of the granite.

Conclusions

The deterioration of the Oporto granite in the monuments is observed in stones previously involved in a hydrothermal alteration (muscovitization of the plagioclase) and later submitted to weathering, being these two processes responsible for the internal microporosity of the plagioclase.

The physical characteristics of the Oporto granite allowed the following conclusions:

- the weathering degree of the granitic stones can be characterized by porosity, capillarity, permeability and mercury porosimetry;
- microporosity of the plagioclase is responsible for most of the total porosity and free porosity accessible to water by capillarity almost corresponds to total porosity;
- in spite of the low porosity, the porous network is very homogeneous, allowing a fast capillary transfer of the solutions, which favours salt concentrations and, therefore, stone decay.

Acknowledgements

The authors would like to thank to Mrs. G. Schram of the Centre de Géochimie de la Surface de Strasbourg for her help in the petrophysic tests and to Mr. J. Dias of the Universidade do Minho for the performance of the polished thin sections. This paper has been supported by the STEP-CT-90-0101 project and by the Programa de Cooperação Científica e Técnica - JNICT - Embaixada de França em Portugal.

References

1. Alves, C.; Jeannette, D. and Sequeira Braga, M.A. (1993) Origin of porosity in the Braga granite and implications in Braga (NW Portugal) monuments degradation. *Terra Abstracts*, 1, 5, 621.
2. Arnold, A. and Zehnder, K. (1989) Salt weathering on monuments. in *Atti del 1° Simposio la conservazione dei monumenti nel bacino del Mediterraneo-Bari 1989* (ed. F. Zezza), Grafo, Brescia, pp. 31-58.
3. Begonha, A. and Sequeira Braga, M.A. (1993) Stone weathering and deterioration in a granitic monument. in *Eurock'93-Lisboa 1993* (eds. Ribeiro e Sousa and Grossmann), Balkema, Rotterdam, pp. 267-274.
4. Bisdom, E.B.A. (1967) Micromorphology of a weathered granite near the Ria de Arosa (NW Spain). *Leidse Geologische Mededelingen*, 37, 33-67.
5. Brilha, J.B.R. (1992) Estudo da tipologia das alterações do leucogranito no jazigo de caulino de Campados (Esposende): a meteorização responsável pela caulinição. Univ. do Minho, Braga.
6. Dias, G.T. (1987) Mineralogia e petrologia de granitos Hercínicos associados a mineralizações filonianas de Sn - W (Minho, Portugal). Univ. do Minho, Braga.
7. Jeannette, D. and Hammecker, C. (1992) Facteurs et mécanismes des altérations. in *La Conservation de la Pierre Monumentale en France*. (eds. Philippon, Jeannette, Lefèvre). Presses du CNRS, Paris, pp. 73-81.
8. Jeannette, D. and Hammecker, C. (1993) Importance des structures de porosité dans les altérations des pierres des monuments. in *Colloque Sédimentologie et Géochimie de la Surface à la mémoire de Georges Millot. Les colloques de l'Académie des Sciences et du Cadas*, Paris, pp. 307-319.
9. Kobranova, V.N. (1989) *Petrophysics*. Mir Publishers, Moscow.
10. Meng, B. (1993) Characterization of pore structure for the interpretation of moisture transport. in *Int. RILEM/UNESCO Congress Conservation of Stone and other Materials-Paris 1993* (ed. M.J. Thiel). E & FN Spon, London, pp. 155-162.
11. Mertz, J.D. (1991) Structures de Porosité et propriétés de transport dans les grès. *Sciences Géologiques*, 90, 1-149.
12. Meunier, A. (1980) Les mécanismes de l'altération des granites et le rôle des microsystemes. Étude des arènes du massif granitique de Parthenay (Deux-Sèvres). *Mémoires de la Société Géologique de France*, 140, 1-80.
13. Pereira, E.; Carvalho, G.S.; Ferreira, N.; Monteiro, J.H.; Noronha, F. and Ribeiro, A. (1989) Carta geológica de Portugal na escala 1:200000 - folha 1. *Serviços Geológicos de Portugal*.
14. Sequeira Braga, M.A. and Paquet, H. (1987) Gibbsite as a biotite weathering product in a granitic saprolite from Cávado River basin Northwest Portugal, in *Proceedings of the Int. Meeting Geochemistry of the Earth Surface and processes of mineral formation-Granada 1986* (eds. R. Rodríguez-Clemente and Y. Tardy), C.S.I.C./C.N.R.S., Madrid, pp. 175-186.
15. Sequeira Braga, M.A. (1988) Arenas e depósitos associados da bacia de drenagem do rio Cávado (Portugal) - contribuição para o estudo da arenização. Univ. do Minho, Braga.
16. Sequeira Braga, M.A.; Lopes Nunes, J.E.; Paquet, H. and Millot, G. (1990) Climatic zonality of coarse granitic saprolites ("arènes") in Atlantic Europe from Scandinavia to Portugal. *Sciences Géologiques*, 85, 99-108.
17. Sequeira Braga, M.A.; Simões Alves, C.A. and Begonha, A. (1993) Weathering of the Oporto granite and the deterioration of the Hospital de Santo António: historical monument built with granitic materials, in *Alteración de Granitos y rocas afines-Ávila 1991* (eds. Vicente Hernández, Molina Ballesteros and Rives Arnau), C.S.I.C., Madrid, pp. 153-154.
18. Vicente, M.A.; García-Talegón, J. and Iñigo, A.C. (1993) Weathering mechanisms of silicated rocks in continental environments. in *Int. RILEM/UNESCO Congress Conservation of Stone and other Materials-Paris 1993* (ed. M.J. Thiel). E & FN Spon, London, pp. 320-327.

Atti del 3° Simposio Internazionale
Proceedings of the 3rd International Symposium
Venezia 1994

La conservazione dei monumenti nel bacino del Mediterraneo

The conservation of monuments
in the Mediterranean Basin

editori scientifici/scientific editors

Vasco Fassina, Heinrich Ott, Fulvio Zezza

