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GEOSCIENCES

Study of salt-induced changes in the Leptinito Gneiss of a column from the Mosteiro de São Bento in Rio de Janeiro, Brazil

CARLA C. FELIX, KÁTIA L. MANSUR & ROBERTO CARLOS C. RIBEIRO

Abstract: The object of this study can be found among the various ornamental rocks used in historic buildings in the city of Rio de Janeiro. It is a degraded Leptinito Gneiss that makes up one of the support columns of the kitchen of the Mosteiro de São Bento (Monastery of Saint Benedict) in Rio de Janeiro. The main aim of the present study is to identify the causes of the high degree of degradation of said column. Non-destructive tests were performed, and laboratory evaluation of the disintegrated fragments may help restore and conserve this column in the future. Results obtained from the tests performed on the altered column were compared to those obtained from another column in the monastery, also built in Leptinito, which is more intact and is a sound Leptinito Gneiss. The results showed that degradation of the column is caused by the crystallization of salts (halite) inside the rock, which is reducing its mechanical strength and causing an imminent risk of collapse.

Key words: Efflorescence, Leptinito Gneiss, ornamental rocks, salt-induced changes.

INTRODUCTION

The use of rocks in construction has always been part of history. According to the ABNT (Brazilian Association of Technical Standards) standard NBR 15012:2013 (ABNT 2013), ornamental rock is natural stone material used in internal and external cladding, structures, elements of architectural composition, decoration, furniture and funerary art. Its main fields of application include isolated pieces such as sculptures, table tops and feet, counters, tombstones, and buildings, highlighting the internal and external wall coverings, floors, pillars, columns and thresholds, among others (Chiodi Filho 1995).

In Brazil, ornamental rocks have been used as revetment since the colonial period, their use having increased from the second half of the 20th century (Frascá 2003). In the city of Rio de Janeiro, the use of ornamental rocks in historic buildings is remarkable due to the abundance and availability of such rocks, especially Facoidal and Leptinito Gneisses (Mansur et al. 2008, Oliveira 2019). The geological and geomorphological pattern of Rio de Janeiro, which is surrounded by large rock masses, have caused the city to have a strong relationship of dependence with the quarries, which produce products to be used as construction material, in paving, and in facade ornaments (Almeida & Porto Jr 2012). Among the various ornamental rocks that make up the historic buildings in the city, the object of study of this research is a Leptinito Gneiss column in an evolved state of alteration and degradation inside the Mosteiro de São Bento (Monastery of Saint Benedict).

The Leptinito Gneiss is also known as Leptinito, in Portuguese, is a metamorphic rock and its mineralogy is composed basically of quartz, alkali-feldspar, plagioclase, and small amounts of biotite and garnet, although it may also present apatite, muscovite, zircon, ilmenite and magnetite (Marques et al. 2010). It is a light-colored gneiss with fine to medium grain size, slightly banded, and with little developed foliation due to the orientation of the biotite and the elongated feldspar and quartz grains (Barroso 1993). Its origin is related to the amalgamation of the Gondwana Supercontinent and the area of of Leptinito occurrence restricted to the Serra da Carioca, in the city of Rio de Janeiro (Silva & Mansur 2017, Valeriano et al. 2012).

The Mosteiro de São Bento in Rio de Janeiro was founded in 1586 (IPHAN 2019a) and is located in the center of the city of Rio de Janeiro, near Guanabara Bay. The region is known as Rio Antigo (Old Rio), where the population was concentrated at the time of colonization and, for this reason, there are several buildings that have a high cultural and historical value. The monastery is an important tourist location in the city of Rio; its church is famous for masses accompanied by Gregorian chanting and for its interior beauty that is covered by gilded carving on the walls, ceiling, and pilasters (Oliveira & Justiniano 2008). Since the creation of the Instituto do Patrimônio Histórico e Artístico Nacional (IPHAN) (Institute for National Historical and Artistic Heritage) in 1937, material and immaterial cultural assets have been officialized as valuable records that must be preserved. In 1938, the Mosteiro de São Bento in Rio de Janeiro, was listed as a heritage site by IPHAN (IPHAN 2019b, c).

Some rocks are more easily altered due to their intrinsic characteristics and may also be affected by anthropogenic degradation (Reys et al. 2008). According to Article 3 of the Venice Charter (International Charter on the Conservation and Restoration of Monuments and Sites) "*The conservation and restoration of monuments aim to safeguard both the work of art and the historical testimony*" (ICOMOS 1964). For these reasons, studies are needed to identify the changes that occur in rocks in order to preserve them. In order to conserve public heritage, it is essential to combine technical resources and respect for heritage charts (Reys et al. 2008).

The alteration of the rocks is intensified, in nature, when they come into contact with the atmospheric conditions prevailing on the Earth's surface, through the action of weathering. This degradation includes physical and chemical changes, which result in the reduction of the mechanical strength of the rock and also in changes in the aesthetic appearance (Frascá & Yamamoto 2014). According to these authors, the deterioration of rocks used in buildings and monuments, whether modern or historical, is empirically related to the actions of intrinsic and extrinsic factors, like petrographic, physical, and mechanical characteristics with the agents of the environment and with repair, cleaning, and maintenance procedures. Human action can also accelerate the process of rock alteration and degradation.

According to Frascá (2002), the main causes of rock degradation, considering the climatic conditions and construction techniques used in Brazil, are the tropical climate (large variations in temperature and humidity); cleaning agents, which use several chemical substances, whose components can cause changes, especially in the aesthetic aspect of the rocks; environmental pollution, in which the various elements dispersed in the atmosphere have great influence; and crystallization of salts.

One of the main, and most powerful causes of weathering of rocks and other porous materials, such as mortar and even concrete used in constructed heritage is the crystallization of salts. According to Alves et al. (2021), the frequent association of sodium chloride with erosive effects is supported by its abundance in the built environment due to contributions from sea-related sources (sea spray, seawater, which can contaminate, also, neighboring groundwater). The crystallization of salts is a weathering agent responsible for the deterioration of rocks in maritime and humid climate environments and can result both in aesthetic and physical damage (Cardell et al. 2003, Chanvillard & Scherer 2006, Frascá & Yamamoto 2014, Benavente et al. 2015, Ricardo et al. 2017, Alves et al. 2021). In urban settings, salt can have different origins, such as inadequate treatment of rocks and air pollution (Neto et al. 2016). In coastal areas, salt deposition on buildings and monuments occurs mainly through marine aerosol. A typical situation that leads to this problem is the rise of the salt solution through the rock by capillarity (Moropoulou et al. 1995, Rodrigues & Gonçalves 2007, Frascá & Yamamoto 2014, Ricardo et al. 2017). According to Rodrigues and Gonçalves (2007), another possible situation for the occurrence of salt crystallization inside the rock is the direct action of rainwater and infiltration.

The crystallization of salts in the porous system of the rock generates pressure capable of expanding the pores, causing them to break, consequently leading to internal disintegration of the rock, thus initiating its destruction. This internal expansion is also responsible for the change in pore sizes. The degradation mechanism is caused by salt crystallization pressure and depends on the saturation degree and pore size (Winkler & Singer 1972). According to Charola (2000) for damage to occur, salts must move through porous bodies, which is a process that requires the presence of water and/or moisture. Pursuant to Angeli et al. (2006), one type of alteration pattern is the anisotropy, an intrinsic property of the material, which means that alteration has a favourite direction for a stone. Four different origins can be identified: the grains (mineral composition due to sedimentation, shapes and orientation), the pores (shape, orientation), the joints and the fractures.

Efflorescence occurs due to the concentration of salts that crystallize on the rock surface through evaporation. Subflorescence occurs when the salts crystallize through evaporation inside the pores near the rock surface, where the mechanical action of the salt crystallization process can start its destructive work, causing flaking and loss of material due to crystal growth that tends to cause pressure inside the rocks (Rodrigues & Revez 2016, Uchida et al. 2000, Frascá & Yamamoto 2003, La Iglesia et al. 1994, Neto et al. 2016). With crystallization, the pressure exerted on the pores causes micro-cracks to propagate and expand. Consequently, the less hard minerals, such as micas in general and in particular expansive clays, are the first to be purged from the rock, causing mass loss and increased porosity (Ricardo 2015). Saline occurrences can have repercussions of many types, ranging from the merely aesthetic effects that efflorescence can cause to mass loss problems that can destroy the affected surfaces (Rodrigues & Gonçalves 2007).

The main aim of the present study is to identify the causes of the high degree of alteration of one the Leptinito columns that supports the Mosteiro de São Bento in Rio de Janeiro. For this purpose, *in situ,* non-destructive tests and laboratory evaluation of the fragments that disintegrate daily from the column were performed. For comparative purposes, similar non-destructive tests were carried out on another, more intact, column of the monastery. Some results obtained from the tests performed on the altered column were also compared to those of a Leptinito studied by Ferreira et al (2020).

All these tests were performed in the laboratory or *in situ*, using portable equipment belonging to the Centro de Tecnologia Mineral (CETEM) (Center for Mineral Technology) in Rio de Janeiro. CETEM has been working since 2008 in the characterization and conservation of stone heritage and is considered a reference in this area. It has been working in partnership with IPHAN since 2009.

MATERIALS AND METHODS

The study material is a column in Leptinito found in a storeroom immediately below the monastery kitchen (Figure 1a). This gneiss is composed mainly of quartz, feldspar, biotite, and garnet and is fine grained. The rock presents well-marked foliation which, in this piece, was in a vertical position, that is, perpendicular to the ground. The column is undergoing an accelerated degradation process, and the tests performed on its structure were also performed, for comparison purposes, on another column carved from intact Leptinito (Figure 1b).

The intact column is located in the cloister reading room, outside the area of influence of the kitchen. The distance between the two columns is less than 5 meters apart.

The kitchen has been in operation for years and it was reported that, due to its constant washing, there have already been several leaks from the kitchen that have infiltrated the storeroom. The kitchen floor was only renovated in 2016 with the application of waterproofing. Previously, the floor was made of standard ceramic tiles. After the renovation, an asphalt blanket was applied, and the floor was covered with high-quality ceramic tiles appropriate for the type of use.

The initial procedure adopted for the acquisition of data from non-destructive testing was to divide the whole column into four parts of equal size with the help of cotton lines and name them top “A”, middle “B”, middle “C”, and base “D” (Figure 2). Subsequently the points to be measured in the columns were selected and the analyses were performed at these same points.

To assist in the monthly collection of the material that disaggregates daily from the altered column, a 40 kg Kraft Paper was

Figure 1. a: Column with accelerated alteration located in the deposit. b: More intact column located in the cloister.

arranged around the column. After collecting the disintegrated fragments each month, this material was separated, weighed to quantify the loss of material from the column, and chemically and mineralogically characterized using of X-ray fluorescence and X-ray diffraction, respectively. Also, the circumference of each portion of the altered column (“A”, “B”, “C”, and “D”) was measured.

The Illustrated Glossary on Stone Deterioration (Vergès-Belmin et al. 2008), published by the ICOMOS - International Council on Monuments and Sites was used to identify and describe the alteration morphologies present in the altered column

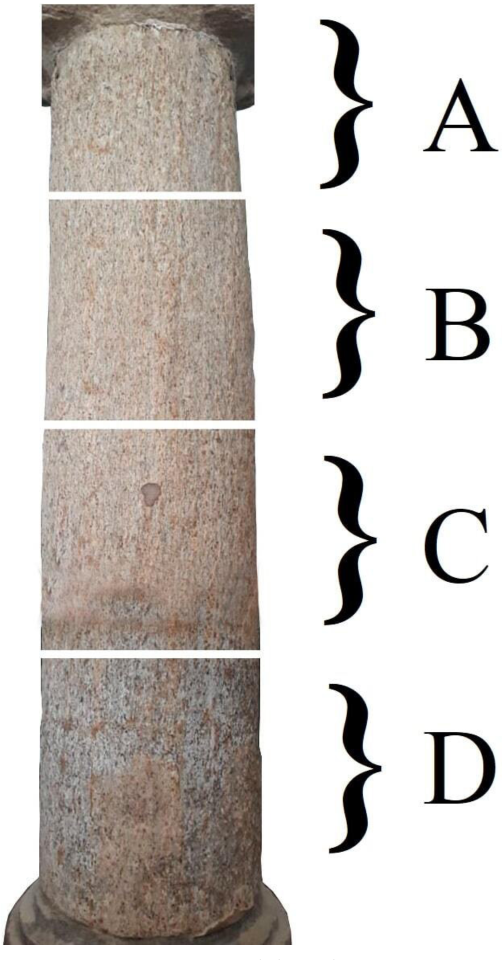

Figure 2. Altered column divided into four equal parts (“A”, “B”, “C”, and “D”).

The hardness test, which is non-destructive and *in situ*, allows the superficial resistance of the rock to be evaluated. A Proceq Equotip 550 portable hardness tester was used to measure the hardness. This measurement is based on the rebound method, in which an impact device is positioned at 90° to the surface of the material, and then a button is pushed to release a tungsten ball, located inside the device, which hits the surface of the object under study and calculates the hardness of the material at the point that suffered the impact of the ball. The ratio of the rebound velocity to the impact velocity multiplied by 1,000 results in the HL hardness value (Leeb hardness). HL is a direct measure of strength, the third letter of the HL unit refers to impact device D, with hardness unit HLD (PROCEQ 2017).

The test ultrasonic wave propagation velocity, which is non-destructive and performed *in situ*, allows indirect evaluation of the degree of cohesion of the rocks. The device used was the PUNDIT- PL-200 (Portable Ultrasonic Non-Destructive Digital Indicating Test) from the manufacturer PROCEQ. The PUNDIT is equipped with two transducers, one emitting and the other receiving ultrasonic waves, its speed is measured according to the transit time between the transducers over a known distance. Before starting the test it is necessary to apply a thin layer of couplant gel on the faces of the transducers to ensure their acoustic coupling to the rock surface; failure to use this gel can result in a loss of signal (PROCEQ 2017).

In both columns, only the indirect method was used, which is particularly useful for determining the depth of cracks or the quality of the stone surface (PROCEQ 2017), because no wave propagation was obtained, due to the level of alteration of the rock that makes up the altered column and added to the fact that its diameter is large, the PUNDIT being unable to take a reading from this method. To perform this test, the transducers were initially positioned 10 centimeters apart. The transmitting transducer remained in the same initial position while the receiver was always 10 centimeters further away from its initial position. The indirect measurements were performed for as as long the device captured the waves and the signal was accurately read.

The water absorption test with Karsten tube, which is non-destructive and performed *in situ*, aims to assess the strength of a material by measuring the amount of water absorbed by the surface of this material over a given period of time. The format of the Karsten tube resembles that of a pipe, its vertical portion is graduated from 0 to 4.5 millimeters and it has a flat, circular edge at the bottom, which was attached to the rock surface with the help of dental sodium alginate (a moldable, sealing material that is appropriate for this type of test because it does not stain the rock and is easy to remove).

The methodology used was based on the RILEM - II standard. 4 Water Absorption Tube Test (2006). At the beginning of the test, it was necessary to fill the tube with distilled water up to the zero reference level, the time was marked with the help of a stopwatch, and the decrease in the height of the water over time was interpreted as an indication of the permeability of the rock (the greater the absorption, the greater the permeability). The RILEM standard measures time intervals of 5, 10, 15, 20, 30, and 60 minutes, but absorption occurred in less than 5 minutes, so the time interval were adapted to 0.13; 0.25; 0.5; 1.00; 1.50; 2.00; 3.00; 4.00 and 5.00 minutes.

The disaggregated material collected from the column was analyzed by means of X-Ray diffraction with the main objective of identifying the types of salts that were efflorescing in the column (mineralogical characterization). First, the samples were ground until they reached a diameter smaller than 106 μm, using a Pulverisette 6 benchtop pulverizer, then they were subjected to the quartering process, using Quantachrome Instruments Rotary Micro Riffler equipment, so that the samples could be homogenized and the analysis result could be representative. Finally, with the samples at the correct size and homogenized, they were sent to the Coordenação de Análises Minerais (COAMI) (Coordination of Mineralogical Analyses) at CETEM to be analyzed in a Bruker-AXS D8 Advance Ec diffractometer.

The X-Ray fluorescence assay was performed in order to identify the chemical composition of the salt found efflorescing in the column (chemical characterization). For the test, pellets containing 2.0 g of sample (grains disaggregated from the column) and 0.6 g of boric acid, binder, were prepared and dried in an air recirculation at 105°C for 12 hours. The pellets were prepared in FLUXANA's VENOX automatic press and boric acid was used as binder at a 1:0.3 ratio. The semiquantitative analysis was performed in an X-ray fluorescence spectrometer, AXIOS MAX model from PANALYTICAL, equipped with a rhodium tube.

RESULTS

A considerable amount of rock grains have disaggregated over the months, ranging from 119.56 to 246.19 grams per month. It is strong evidence that the Leptinito composing the column is in an advanced state of alteration, with the loss of approximately 2 kilograms in 12 months, indicating that in a few years it may disintegrate completely.

Using a tape measure, the circumference of each part of the altered column was measured. At its top, part "A", a circumference of 1.51 meters was obtained. The middle parts, "B" and "C", had circumferences of 1.67 and 1.73 meters, respectively, while at its base, “D”, the circumference was 1.58 meters. This result confirms that the middle portion of the column is more altered than the others, with crystallization of the halite causing internal expansion of the rock structure and, thus, a larger circumference in this part than in the top and bottom sections of the column.

The alteration morphologies present in the altered column were identified and described based on the Illustrated Glossary on Stone Deterioration published by ICOMOS. Efflorescence can be observed on the entire surface of the rock (Figure 3).

The gneiss presents granular disaggregation, which happens when the grains detach from the rock matrix, and this is confirmed through collection of the disaggregated material. It is also possible to observe the blistering that is occurring around the entire column along with the granular disaggregation (Figure 4). Both morphologies are consequences of saline efflorescence.

The fragility of the column is observed in the values of surface hardness found. The average hardness value of the altered column was 287.56 ± 22.98 HLD, which is very low compared to that of the sound leptinito gneiss which is 632.1 ± 23.84 HLD. As for a healthy leptinito gneiss, according to Ferreira et al. (2020), the hardness value is 634.10 ± 23.84 HLD.

According to these results, it can be stated that the altered column has a very low surface hardness due to the action of the salt that has degraded it over the years, directly affecting the mechanical strength of the column. The fragility of the Leptinito is verified by the analysis of the results for the ultrasonic waves propagation velocity, shown in Table I, which presented values around 1,862 m.s^{-1} and 1,881 m.s^{-1} at the top, 1,489 m.s^{-1} and 2,110 m.s^{-1} the base, and values of around 436 m.s^{-1} and 597 m.s^{-1} in the middle portion. This is very low when compared to the values obtained in the cloister column, where the test was performed only in the middle portion and showed values ranging from 4,280 m.s^{-1} to 5,291 m.s^{-1} as shown in Table II. The top (A2) and bottom (D2) of the column have higher values than the middle of the column (intersection B2-C2), which means that in the middle of the altered column, the rock surface is less cohesive and more degraded than the other parts (top and bottom).

Water absorption on the surface of the altered column occurred in a very short time interval (Table III). Both the top and the bottom had an absorption time of 5 minutes. In the middle sections of the column, absorption occurred in a shorter time, after 3 minutes and 30 seconds, respectively. This means that the middle

Figure 3. Occurrence of efflorescence. Accumulation of poorly coherent salt crystals on the gneiss surface.

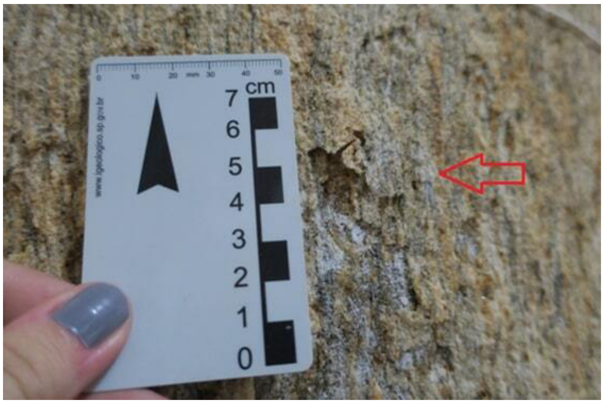

Figure 4. Millimeter-order blistering indicated by the red arrow.

part of the column presents higher permeability and porosity than the top and bottom, indicating a higher state of degradation.

Figures 5 and 6 present the diffractograms (the result of the mineralogical characterization) of fragments from the altered column, with and without the presence of efflorescence, respectively.

The results obtained in the chemical characterization test, Table IV, corroborate the presence of halite, as there is a high percentage of chloride and sodium of 15.4% and 27.8%, respectively. Comparing these results with those obtained in a fragment without efflorescence, much lower levels of around 3.5% and 8.4% are observed. There is a high percentage of silicon in the fragment without efflorescence (60.1%), which is compatible with this type of rock because it comes from quartz and feldspar, minerals that are found in higher levels in gneisses.

There is a significant percentage of aluminum (15.2%) that comes from the feldspars that compose the rock. Note that these elements are significantly reduced in the rock efflorescence due to the presence of NaCl. It is also observed that the sample of the fragment containing efflorescence presents extremely high loss by calcination (LbC), 24.7%, which is related to the presence of carbonates associated with calcium

Table I. Ultrasonic velocity values obtained from the modified column.

Distance between transducers (m)	Ultrasonic velocity (m.s-¹)	Location of the column where it was measured
0,1	1.862	A (top)
0,2	1.881	A (top)
0,1	597	B-C (middle)
0,2	436	B-C (middle)
0,1	2.110	D (bottom)
0,2	1.489	D (bottom)

Table II. Ultrasonic velocity values obtained from the column in the cloister reading room.

Distance between transducers (m)	Ultrasonic velocity (m.s-¹)	Location of the column where it was measured
0,1	5.291	B-C (middle)
0,2	4.435	B-C (middle)
0,3	4.280	B-C (middle)
0,4	4.556	B-C (middle)
0,5	4.604	B2-C2 (middle)
0,6	4.648	B-C (middle)

Table III. Water absorption results with the Karsten tube.

	Column location			
	A	B	C	D
Time (m)	Water level (ml)	Water level (ml)	Water level (ml)	Water level (ml)
0,13	0,4	0,5	1,8	1,3
0,25	0,6	0,8	2,9	1,5
0,3	0,7	1	3,4	1,6
1	1,1	1,7		2
1,5	1,5	2,9		2,4
2	1,8	3		2,7
3	2,5	3,9		3,2
4	3			3,7
5	3,6			4,1

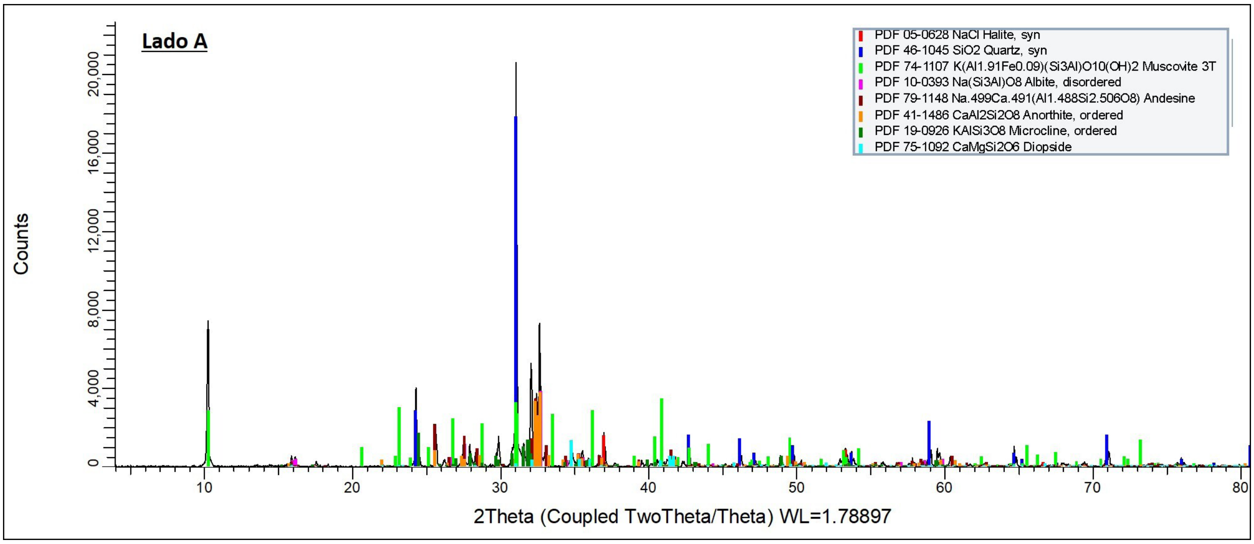

Figure 5. Diffractogram of a point in the gneiss where efflorescence is present.

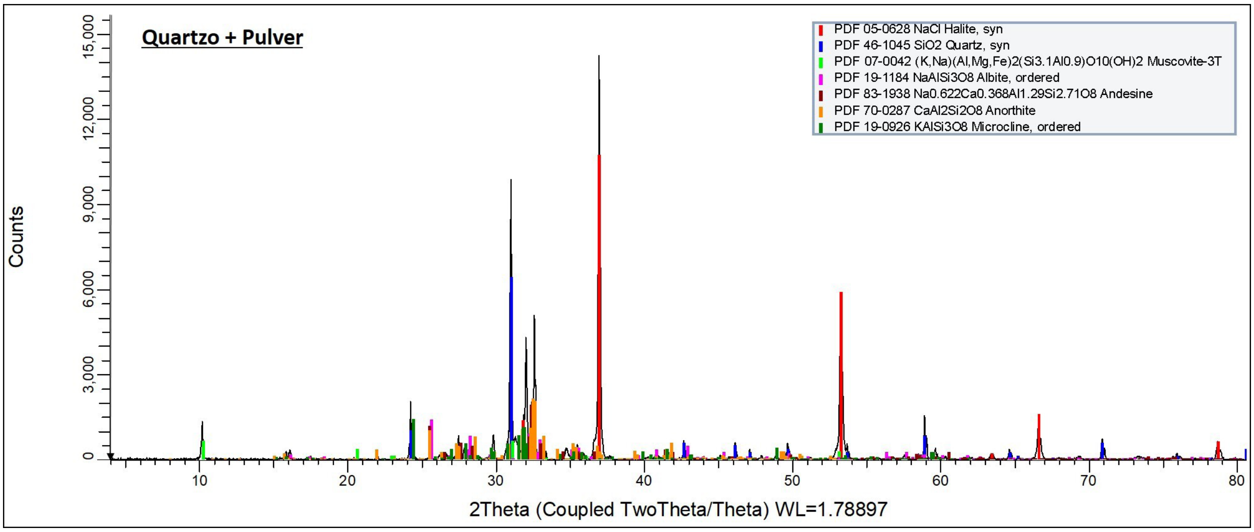

Figure 6. Diffractogram of a point of the gneiss without the presence of efflorescence.

or sodium, originating from the mortars covering the roof and top of the column.

DISCUSSION AND CONCLUSION

It is possible to conclude that the Leptinito that composes the structural column that supports the kitchen of the Mosteiro de São Bento in Rio de Janeiro is undergoing an accelerated process of degradation. The alteration relates to the percolation of water solution with halite, which effloresces at various points, reducing mechanical strength and causing an imminent risk of collapse.

The Leptinito alterations indicate an association between its construction and the direction of the foliation plane of the rock, which is positioned perpendicular to the ground. This provides a preferential path for the percolation of saline solution and, consequently, for the generation of the most critical alteration morphologies identified.

The percolation of the saline solution from the liquid waste of the kitchen through the foliation degrades the rock and generates the mosrt critical efflorescence effects and consequently the greater fragility in the column. This percolation of salt over many years and its accumulation inside the column could lead to the collapse of the column in a few years.

A predominance of halite can be seen on both diffractograms, indicating that this is the salt responsible for the efflorescence in the column, generating rock disaggregation and decreasing its mechanical resistance.

The presence of halite generates efflorescence and defragmentation in column rock. The origin of this salt is possibly related to the products used for cleaning the kitchen on the upper floor; it may also be associated with atmospheric salt (geographical position with the sea in front of the building).

Table IV. Chemical analysis (%) - Sample of the gneiss removed from the efflorescence and Sample of the gneiss without efflorescence.

Oxides Evaluated	Sample of gneiss removed from efflorescence (%)	Gneiss sample without efflorescence (%)
Na_2O	**27.8**	**8.4**
MgO	0.1	0.59
Al_2O_3	5.6	15.2
SiO_2	**24.2**	**60.1**
SO_3	0.11	0.41
K_2O	1.4	3.8
CaO	0.48	1.5
TiO_2	*ND	0.2
Fe_2O_3	0.28	1.8
WO_3	*ND	0.15
*LbC	**24.7**	**4.2**
Cl	**15.4**	**3.5**

(*LbC): Loss by Calcination.
(*ND): element not detected by XRF in the analyzed sample.

According to the results obtained from the test for ultrasonic wave propagation velocity (performed on four parts of the column, top "A", middle "B" and "C" and bottom "D"), when comparing those of both columns, it can be stated that the surface of the gneiss of the altered column presents much lower quality and low cohesion, in relation to that of the column in the cloister, which is more intact. It is also possible to conclude that some parts of the altered column are more cohesive than others.

The results obtained from the Water Absorption test corroborates with that obtained in the ultrasonic wave propagation velocity test, confirming that although the entire column is very degraded and not very cohesive, its central portion is more altered than the top and bottom.

It is the middle portion of the column that is suffering greater consequences from compression stresses, and is more altered than its top and bottom. As it is already weakened by fracturing, it is also the area with the highest salt concentration and its where the column is more degraded. The stress is being applied due to the weight that the already severely damaged column supports from two floors above. In contrast, there is strees resistance from the storeroom floor to the column, subject to equal concentrated forces, but in opposite directions.

The areas in which the stresses are applied on the column are parallel to the foliation of the rock and this ends up generating a decrease in the strength of the material and, for this reason, the column is more susceptible to degradation (Proença 2018, Beer & Johnston 1995). Thus, it is the middle section that is suffering greater consequences from compression stresses. As it is already weakened by fracturing, it is also the area with the highest salt concentration. The cloister column is more intact, but it can be seen that it has lower mechanical strength when compared to a healthy rock, since over time it has also suffered from mass loss and cracks that have directly affected its hardness.

From the study of alterability of the Leptinito that makes up the column, it is possible to provide information that will contribute to the future restoration and conservation of this rock that is part of the support structure of the Mosteiro de São Bento in Rio de Janeiro, which is classified by IPHAN as historic heritage.

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REFERENCES

ABNT - ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. 2013. NBR 15012: rochas para revestimentos de edificações-Terminologia. Rio de Janeiro. 2013.

ALMEIDA S & PORTO JR. 2012. Cantarias e pedreiras históricas do Rio de Janeiro: instrumentos potenciais de divulgação das Ciências Geológicas. Terra e didática 8(1): 3-23.

ALVES C, FIGUEIREDO CA, SANJURJO-SÁNCHEZ J & HERNÁNDEZ AC. 2021. Salt Weathering of Natural Stone: A Review of Comparative Laboratory Studies. Heritage 4(3): 1554-1565. https://doi.org/10.3390/heritage4030086.

ANGELI M, BIGA, J-P, BENAVENTE D, MENÉNDEZ B, HÉBERT R & DAVID C. 2006. Salt crystallization in pores: quantification and estimation of damage. Environ Geol 52(2): 205-213. doi:10.1007/s00254-006-0474-z.

BARROSO EV. 1993. Estudo das características geológicas e do comportamento geotécnico de um perfil de intemperismo em leptinito. Dissertação de mestrado em Geologia - Universidade Federal do Rio de Janeiro – Departamento de Geologia. Rio de Janeiro. (Unpublished).

BEER FP & JOHNSTON JR ER. 1995. Resistência dos Materiais. 3° Ed. Editora McGraw-Hill Ltda. Available at: http://www.joinville.ifsc.edu.br/~rubens.hesse/resistencia/Bibliografia/resistc3aancia-dos-materiais-ferdinand-p-beer-russell-jonhnsion-jr-3-edic3a7c3a3o.pdf. Accessed on: 03 Jul. 2021.

BENAVENTE D, BRIMBLECOMBE P & GROSSI CM. 2015. Thermodynamic calculations for the salt crystallisation damage in porous built heritage using PHREEQC. Environ Earth Sci 74(3): 2297-2313. doi:10.1007/s12665-015-4221-1.

CARDELL CDF, ROUMPOPOULOS K, MOROPOULOU A, AUGER F & VAN GRIEKEN R. 2003. Salt-induced decay in calcareous stone monuments and buildings in a marine environment in SW France. Constr Build Mater 17(3): 165-179.

CHANVILLARD G & SCHERER GW. 2006. Effect of the pore size distribution on crystallization pressure. In Measuring, Monitoring and Modeling Concrete Properties. Springer, Dordrecht, p. 669-673.

CHAROLA AE. 2000. Salts in the deterioration of porous materials: an overview. J Am Inst Conserv (39): 327-343.

CHIODI FILHO C. 1995. Aspectos técnicos e econômicos do setor de rochas ornamentais. Rio de Janeiro. CNPq/CETEM (51): 84-139.

FERREIRA JLM, CASTRO NFE & RIBEIRO RCC. 2020. Relações de medições com ensaios não destrutivos e propriedades tecnológicas de rochas ornamentais" . In: XXVIII Jornada de Iniciação Científica e IV Jornada de Iniciação em Desenvolvimento Tecnológico e Inovação, p. 1-6.

FRASCÁ MHBO. 2002. Qualificação de rochas ornamentais e para revestimento de edificações: caracterização tecnológica e ensaios de alterabilidade. In: Simpósio Brasileiro de Rochas Ornamentais, Salvador. CETEM/MCTI, p. 148-154.

FRASCÁ MHBO. 2003. Estudos experimentais de alteração acelerada em rochas graníticas para revestimento. Tese de doutoramento.- Universidade de São Paulo- Instituto de Geociências. São Paulo.

FRASCÁ MHBO & YAMAMOTO JK. 2003. Ensaios de alteração acelerada em rochas para revestimento – estudos experimentais em rochas graníticas. In: IV Simpósio de Rochas Ornamentais, Fortaleza, p. 165-172.

FRASCÁ MHBO & YAMAMOTO JK. 2014. Deterioração de rochas graníticas em edificações e monumentos. Investigação por ensaios de alteração acelerada. Revista Brasileira de Geologia de Engenharia e Ambiental 4: 23-32.

ICOMOS. 1964. Carta de Veneza. Carta Internacional sobre a Conservação e o Restauro de Monumentos e Sítios. In: II Congresso Internacional de arquitectos e técnicos dos monumentos históricos. ICOMOS (International Council on Monuments and Sites). Veneza.

IPHAN. 2019a. Arquivo Noronha Santos. Available at: http://portal.iphan.gov.br/ans/. Accessed on: 06 Jul. 2021.

IPHAN. 2019b. O Iphan. Available at: http://portal.iphan.gov.br/pagina/detalhes/872. Accessed on: 08 Jul. 2021.

IPHAN. 2019c. Bens tombados. Available at: http://portal.iphan.gov.br/uploads/ckfinder/arquivos/BENS%20TOMBADOS%20E%20PROCESSOS%2 0EM%20 ANDAMENTO%202019%20MAIO.pdf. Accessed on: 23 Jul. 2021.

LA IGLESIA A, DEL CURA MAG & ORDOÑEZ S. 1994. The physicochemical weathering of monumental dolostones, granites and limestones; dimension stones of the Cathedral of Toledo (Spain). Sci Total Environ 152(2): 179-188.

MANSUR KL, CARVALHO IS, DELPHIM CFME & BARROSO EV. 2008. O gnaisse facoidal: a mais carioca das rochas. Anuário do Instituto de Geologia, UFRJ, Rio de Janeiro 3(2): 1-14.

MARQUES EAG, BARROSO EV, MENEZES FILHO AP & VARGAS JR EDA. 2010. Weathering zones on metamorphic rocks from Rio de Janeiro-Physical, mineralogical and geomechanical characterization. Eng Geol 111(1-4): 1-18.

MOROPOULOU A, THEOULAKIS P & CHRYSOPHAKIS T. 1995. Correlation between stone weathering and environmental factors in marine atmosphere. Atmos Environ 29(8): 895-903.

NETO JAB, SMITH BJ, MCALISTER JJ, DA SILVA MAM & DA SILVA ALC. 2016. Intemperismo de sal em rochas ornamentais em um prédio histórico na cidade do Rio de Janeiro: implicações geomorfológicas. Terra Livre 2(41): 169-190.

RILEM II.4: Water absorption tube test. 2006. RILEM - International Meeting of Testing and Research Laboratories on Materials and Constructions, 4 p. Available at: http://www.amt-labs.com/docs/RILEM%20II.4%20Test%20Method.pdf Accessed on: 15 Jul. 2021.

OLIVEIRA LFBD. 2019. Influência da cristalização de sal solúvel na degradação de propriedades petrofísicas de granitóide. Trabalho de conclusão de curso-Universidade Federal do Rio de Janeiro- Departamento de Geologia. Rio de Janeiro.

OLIVEIRA MAR & JUSTINIANO F. 2008. Barroco e Rococó nas igrejas do Rio de Janeiro. Brasília/DF Monumenta/IPHAN.

PROCEQ. 2017. Operating Instructions Equotip 550. Proceq S.A. Available at: https://www.proceq.com/products/list/Category/equotip/ Accessed on: 13 Jul. 2020.

PROENÇA SPB. 2018. Curso de resistência dos materiais. Available at: http://www.livrosabertos.sibi.usp.br/portaldelivrosUSP/catalog/book/194. Accessed on: 17 Jul. 2021. DOI: 10.11606/9788580230635.

REYS AC, DEL LAMA EA & DEHIRA LK. 2008. Monumentos da cidade de São Paulo: formas de alteração e conservação. Revista CPC (5): 93-122.

RICARDO AM. 2015. Uma rocha e um palácio: características e alterabilidade do gnaisse facoidal no Paço Imperial do Rio de Janeiro. Dissertação de mestrado em Geologia - Universidade Federal do Rio de Janeiro – Departamento de Geologia. Rio de Janeiro. (Unpublished).

RICARDO AM, MANSUR KL, BARROSO EV, SENRA F, AVELLAR G & RIBEIRO RC. 2017. Mapeamento das morfologias de alteração das rochas do Paço Imperial, Rio de Janeiro. Geologia USP, Série científica 17: 45-58.

RODRIGUES JD & GONÇALVES TD. 2007. Sais solúveis nas construções históricas: introdução e relato sumário. Sais solúveis em argamassas de edifícios antigos. Lisboa, LNEC Laboratório Nacional de Engenharia Civil, p. 1-14.

RODRIGUES JD & REVEZ MJ. 2016. Glossário ilustrado das formas de deterioração da pedra, tradução da versão inglês-francês, Vol. 15, Série Monumentos e Sítios do ICOMOS, Portugal. Disponível em: http://www.icomos.pt/images/pdfs/Glossario_Pedra_Icomos.pdf Accessed on: 25 Oct. 2021.

SILVA RGP & MANSUR KL. 2017. Proposta de roteiro para a prática de geoturismo urbano e para a geoeducação no centro da cidade do Rio de Janeiro. Anais do IV Simpósio Brasileiro de Patrimônio Geológico e II Encontro Luso-Brasileiro de Patrimônio Geomorfológico e Geoconservação, Ponta Grossa, Brasil, p. 482-486.

UCHIDA E, OGAWA Y, MAEDA N & NAKAGAWA T. 2000. Deterioration of stone materials in the Angkor monuments, Cambodia. Eng Geol 55(1-2): 101-112.

VALERIANO CM ET AL. 2012. Geologia e recursos minerais da folha Baía de Guanabara SF.23-Z-B-IV, estado do Rio de Janeiro, escala 1:100.000. Available at: http://www.cprm.gov.br/publique/media/geologia_basica/pgb/rel_baia_guanabara.pdf Accessed on: 05 Jul. 2021.

VERGÈS-BELMIN V ET AL. 2008. Illustrated glossary on stone deterioration patterns. ICOMOS (International Council on Monuments and Sites), p. 86.

WINKLER EM & SINGER PC. 1972. Crystallization pressure of salts in stone and concrete. Geol Soc Am Bull 83(11): 3509-3514.

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CARLA C. FELIX[1]
https://orcid.org/0000-0002-5396-7958

KÁTIA L. MANSUR[1]
https://orcid.org/0000-0003-4151-7463

ROBERTO CARLOS C. RIBEIRO[2]
https://orcid.org/0000-0002-5600-7290

[1]Programa de Pós-Graduação em Geologia, Universidade Federal do Rio de Janeiro/UFRJ, Departamento de Geologia, Av. Athos da Silveira Ramos, 274, Cidade Universitária, 21941-916 Rio de Janeiro, RJ, Brazil

[2]Centro de Tecnologia Mineral/CETEM, Av. Pedro Calmon, 900, Cidade Universitária, 21941-908 Rio de Janeiro, RJ, Brazil

Correspondence to: **Carla Corrêa Felix**
E-mail: carlacfelix8@gmail.com, katia@geologia.ufrj.br

Author contributions

Carla Corrêa Felix: Conception of the work, data collection, data analysis, and interpretation and drafting of the article. Kátia Leite Mansur and Roberto Carlos da Conceição Ribeiro: Conception of the work, data collection, data analysis, and interpretation and critical revision of the article.