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https://doi.org/10.3390/IECG2019-06198
Proceedings 2019, 24(1), 5.

Approaches to the Study of Salt Weathering of Geological Materials †

Carlos Alves 1,* and Carlos Figueiredo 2

1 LandS/Lab2PT (FCT-AUR/04509) & Earth Sciences Department, School of Sciences, University of Minho, 4710-057 Braga, Portugal

2 CERENA—Centro de Recursos Naturais e Ambiente, UID/ECI/04028/2019, DEcivil,
Instituto Superior Técnico, University of Lisbon, 1049-001 Lisbon, Portugal; carlos.m.figueiredo@ist.utl.pt

* Correspondence: casaix@dct.uminho.pt

† Presented at the 2nd International Electronic Conference on Geosciences, 8–15 June 2019. Available online: https://iecg2019.sciforum.net/.

Published: 4 June 2019

Abstract: Salt weathering is the main erosive process affecting diverse geological materials in historical and contemporary structures and can also contribute to visual changes by surface crystallization. The main goal of the present paper is to assess publications concerning the study of salt weathering of natural stone considering the main approaches (laboratory tests and field observations). Our focus will be on rock types other than sedimentary carbonate rocks and sandstones (which are the most studied rocks both in laboratory and field studies). Granite and pyroclastic rocks are dominant in the studied set. Also deserves highlighting (for scientific reasons) the scarcity of studies regarding foliated rocks and marble.

Keywords: cultural heritage; built environment; laboratory tests; fieldwork

1. Introduction

Soluble salts can contribute to visual alteration of surfaces of diverse types of rocks used as stones due to surface crystallization and they are the main erosive agent of these materials.

Salt weathering can affect stone elements on diverse locations, not being limited to coastal areas given that there are diverse other sources besides seawater (for a classical review see Arnold and Zehnder [1]). It can affect historical heritage and recent structures (as in Alves et al. [2]).

In this paper we will attempt to assess the situation in terms of approaches to salt weathering of stones, considering simulation studies (by exposition and laboratory tests) and field studies. In order to have a manageable set of works to analyze in the framework of the present work, we will analyze publications on this theme published in or after 2010 (focusing on studies of the present decade) found in the Scopus database (this will leave out many publications, including several of our own!). Only cases with actual natural stone will be considered.

2. Analysis of Publications

We found few studies concerning controlled exposition to environmental conditions:
one with volcanic rocks in Japan (Seiki et al. [3]) and another one regarding dolostones in Spain (Cámara et al. [4]).

A large majority of the studies found concerned limestones (we will also include dolostones here) and sandstones and there are many publications that will not be discussed specifically here, besides those that are referred to in the context of methodological issues (laboratory studies with these rocks alone amounted to around fifty).

Laboratory studies are, in general, more frequent than field studies (around 50% more), with diverse types of salts and weathering conditions (for recent reviews on laboratory salt weathering testing see Alves et al. [5], Lubelli et al. [6]). In the selected set, the main rock types are volcanic rocks (Seiki et al. [3]; Yu & Oguchi [7]; Yavuz [8]; López-Doncel et al. [9]; Germinario et al. [10]; Özşen et al. [11]; Çelik & Aygün [12]; Martínez-Martínez et al. [13]; Pötzl et al. [14]; Sato & Hattanji [15]; Zalooli et al. [16]), being dominated by studies of pyroclastic rocks, and plutonic rocks
(Cámara et al. [4]; Yu & Oguchi [7]; López-Arce et al. [17]; Silva et al. [18]; Vázquez et al. [19]; Cerrillo et al. [20]; Martins et al. [21]; Sousa et al. [22]; Vázquez-Nion et al. [23]; Graus et al. [24]) with granite being dominant in this subset. In our present review we found fewer publications concerning laboratory testing of metamorphic rocks; most of them studying marbles (Vázquez et al. [19]; Martínez-Martínez et al. [25]; Navarro et al. [26];

Vazquez et al. [27]) with one studying gneiss (Ricardo et al. [28]) but none in slates or schists. There are several questions connected with these laboratory studies in terms of relations to real conditions, namely in terms of scale (which might affect their potential for assessing the effects of rock heterogeneity). The diversity of testing conditions also hinders meta-analysis of results, tending to create a certain "case study" framework.

Under field studies we will consider works dedicated to the study of human objects that have been subjected to actual weathering conditions (not laboratory simulations). These studies have focused, in general, on the distribution of salt occurrences and associated decay forms, which can include 2D/3D documentation of the structure using laser scanning and photogrammetry (Bala'awi et al. [29]). These assessments can contribute to the evaluation of the effect of time by comparison of stone decay with age of emplacement (Přikryl et al. [30]).

Field studies can include the performance of diverse tests on site such as the use of Drilling Resistance Measurement System (Modestou et al. [31]), and many generally non-destructive procedures such as measurements of moisture content and water absorption (Zoghlami et al. [32]), the Schmidt rebound test (Boumezbeur et al. [33]), ultrasonic velocity propagation (Zoghlami et al. [32]; Zezza [34]), rock surface micro-topography (Kamh & Koltuk [35]), image analyses (Zezza [34]; Ruiz-Agudo et al. [36]), and colorimetric studies (Columbu et al. [37]).

Field studies also frequently include the characterization of the salts, namely in terms of types, amounts, and sources, using diverse mineralogical and chemical techniques, including advanced analytical techniques such as isotopic analyses in the search for the sources of the salts (Hosono et al. [38]; Siedel et al. [39]; Rivas et al. [40]; Kloppmann et al. [41]). The involved sampling mostly consisted of collecting salt concentrations (efflorescences) and loose stone portions (which are considered as already compromised by the action of the soluble salts) but could include contact by extraction by paper pulp poultices (Egartner & Sass [42]) and more invasive procedures such as microdrilling (Ruiz-Agudo et al. [36]; Siedel et al. [39]). There are some cases where it was possible to collect laboratory specimens from discarded blocks (but these are rare situations that generally cannot be replicated for other study places so they will not be specifically considered here).

In the case of field studies we found some more balance between the studied rocks (of course excluding limestones and sandstones). Nonetheless, there is some predominance of igneous rocks, clearly dominated by granites (Sousa et al. [22]; Rivas et al. [40]; Silva Hermo et al. [43]; Warke et al. [44]; Costa [45]; Pozo-Antonio et al. [46]), followed by volcanic rocks (Seiki et al. [3]; Columbu et al. [37]; Antonelli et al. [47]). However, we also found studies of gabbros (Matović et al. [48]) and diorites (Bader et al. [49]).

In terms of metamorphic rocks we found studies of slates (Cann [50]), schists (Peñas Castejón et al. [51]), marbles (Zezza [34]; Antonelli et al. [47]) and gneiss (Küng & Zehnder [52]; da Conceição Ribeiro et al. [53]; Gaylarde et al. [54]).

These field studies focused on real anthropogenic objects of stone, but they suffer from the "case study" stigma (they concern a limited set of rocks under conditions of a given place) and furthermore, there is, usually, insufficient historical information in terms of these materials and conditions in this kind of study.

Some papers include field and laboratory studies. We can highlight in relation to this the publication by Martínez-Martínez et al. [55] concerning a study of limestones in Spain, which based in the comparison of laboratory and field studies presents a proposal of equivalence in terms of time.

3. Final Considerations

This review highlights the predominance of limestones and sandstones in terms of studies of salt weathering, while in a kind of second level were studies concerning plutonic and pyroclastic rocks. The incidence of laboratory studies of salt weathering concerning rock types seems to be in part related to the relevance of those rock types in terms of cultural heritage, which might explain the scarcity of studies including slates and schist but certainly will not explain the few studies with marbles. Hence, the perceived susceptibility of stone types also seems to influence the selection of stones for these studies (this seems a more likely explanation for the relative scarcity of studies considering marbles).

However, this situation can leave out some issues with scientific relevance in terms of understanding the relation between petrographic features and salt weathering processes such as the influence of anisotropy planes (which can be specially marked in some metapelitic rocks, depending on their characteristics) and heterogeneity, which can be significant in marbles. One can question the usefulness of laboratory testing of marble heterogeneity without previous indication from field studies. This indicates a particular interesting case in terms of the problem-situation concerning salt weathering of stones: the special value of field observations that show the effects of salts in heterogeneous marble stones.

The diversity of procedures for laboratory salt weathering constitutes an obstacle to the metaanalysis of results and the definition of universal trends for salt weathering susceptibility.

Author Contributions: Both authors contributed to the present paper.

Funding: The Lab2PT—Landscapes, Heritage and Territory laboratory—AUR/04509 is supported by the Portuguese FCT—"Fundação para a Ciência e a Tecnologia" (Portuguese funds and where applicable the FEDER co-financing, in the aim of the new partnership agreement PT2020 and COMPETE2020—POCI 010145 FEDER 007528). The authors also gratefully acknowledge the support of the CERENA (funded by a strategic project of the FCT-UID/ECI/04028/2019) and the LAMPIST of the Instituto Superior Técnico, University of Lisbon.

Conflicts of Interest: The authors declare no conflict of interest.

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