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Surface modification of a granite building stone in central Rio de Janeiro

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ABSTRACT

In order to evaluate environmental controls on the soiling formation and decay of building stones a set of mapping and physical and chemical analyses were carried out on granite from a historical church in the polluted centre of Rio de Janeiro. These techniques highlight the increasing of threatening damage on generally perceived as a durable building material, caused by granular disaggregation and contour scaling in areas close to ground level. Mapping also indicated the formation of black crusts over entire building façades, concentrated on areas sheltered from rain-wash. Analyses demonstrated the influence of marine aerosols, rock and mortar composition and mostly of the atmospheric pollutants on the decay and soiling of the granite. Much of the decay is associated specifically with the presence of halite (NaCl) and gypsum ($CaS0_4.2H_2O$). The fact that black, gypsum crusts are able to develop over entire façades in a humid subtropical environment is testimony to the high levels of local pollution, especially particulate deposition. Reduced rainwash, in sheltered micro-environments of narrow, canyon-like streets, overcomes the gypsum tendency to be washed away from buildings façades. These observations further highlight that decay processes are primarily controlled by microclimatic conditions.

Key words: weathering, granite, air pollution, marine aerosols, gypsum crusts.

INTRODUCTION

Interactions between the atmosphere and stone used in monuments and buildings invariably lead to the formation of altered surface layers, producing damage to the original stone (Sabbioni 1995). According to Fassina (1991) all rocks and material exposed to a weathering environment deteriorate continually as a result of physical, chemical and biological processes. In turn, the degree and distribution of the main types of observable stone deterioration in urban environments are often related to different patterns of wetting and drying and particularly to the exposure of the stone surface to driven rain (Camuffo et al. 1983). This is particularly the case for so called "grey and black crusts" that are frequently observed on stone surfaces in polluted environments. These can also be associated with extensive deterioration, if crusts are breached, for example, in the course of over-energetic stone

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cleaning, or where crusted surfaces eventually delaminate through contour scaling in response to subsurface salt accumulation (Smith et al. 1994). According to Whalley et al. (1992) black crust are retained preferentially on parts of buildings that are sheltered from direct rainwash and also exposed to more concentrated pollution attack in the form of "occult" (e.g. dew and frost) and dry gaseous and particulate deposition. Crusts typically comprise interlocking tabular crystals of gypsum that entrap atmospheric particulates (Saiz-Jimenez 1993) and form a reactive surface on which other precipitates can form. These ancillary components include inorganic airborne particulates (e.g. soil particles, dust, fly ash), organic airborne particulates (e.g. plant remain, pollen), inorganic precipitates and organic growth in or on the crust surface (e.g. bacteria, fungi) (Whalley et al. 1992). Carbonaceous particles (such as flyash) originated from oil and coal combustion (e.g. power plants, industry) are also frequently present and these can act as active catalysts for the transformation of calcium carbonate to gypsum (Del Monte et al. 1984).

It is the inclusion of particulates that is primarily responsible for the characteristic grey/black appearance of gypsum crusts. On non-calcareous stone, particulate deposition may also provide a direct source of gypsum (e.g. within flyash particles derived from the combustion of fossil fuels) or of calcium carbonate (e.g. within street dusts and debris from the weathering of building materials) that can be converted into gypsum in a sulphur rich atmospheric environment. More typically, however, gypsum is derived from the *in situ* alteration of calcareous building – mainly limestones – and, for example, lime rich mortars. Thus, even on non-calcareous stonework, it is common to see crusts in areas where moisture has seeped from mortar joints and washed over the stonework below (Smith et al. 2002), or below areas where limestone has been used for architectural detail such as string courses and window frames.

The absence of gypsum crusts on areas of buildings subject to rainwash does not, however, necessarily mean that gypsum is not forming. Instead, it could be that any gypsum that does form is removed in solution at a rate and a frequency that prevents its accumulation into a coherent and extensive crust. The importance of this balance between formation and removal (input Vs output) was recently illustrated in a study of limestones in the polluted environment of central Budapest (Hungary), where it was shown that the combination of low rainfall and high rates of dust deposition enhanced rapid regrowth of gypsum crusts on spalled areas, even where they were exposed to rainwash (Smith et al. 2003). Further evidence of the importance of the balance between gypsum input and output as a control of crust formation is provided by the work of Tang et al. (2003). They used archive photographs of buildings in the northeast American city of Pittsburgh to show how patterns of soiling have changed over time. In the mid twentieth century, when pollutant deposition dominated, many façades exhibited a complete cover of black crusts. However, by the late twentieth century, reductions in the airborne concentrations of sulphur dioxide and particulates meant that many façades that were soiled in the late 1930s had become white because the rate of removal of soiled material by rainwash now exceeded the rate of soiling by pollutant deposition and chemical reaction. The retention of crusts in areas sheltered from rainwash and/or driven rain results in a patchy, yet predictable pattern of partial soiling.

In their study, Tang et al. (2003) are careful to point out that over the intervening period annual rainfall totals in Pittsburgh had not increased. This reflects the understanding that high rainfall, especially associated with low levels of atmospheric pollution, generally negates the formation of gypsum crusts. In turn, this reasoning has underlain an assumption that buildings within the humid Tropics are not at risk from soiling by gypsum crusts. In this paper we present evidence that questions this assumption. The examination of superficial crusts formed on a major historic building in the centre of Rio de Janeiro point towards the irrefutable neoformation of gypsum in the crust.

BACKGROUND TO CASE STUDY

Rio de Janeiro contains some of the most important colonial architectural buildings in Brazil. However, due to climatic conditions, high levels of pollution and lack of resources, some of these buildings are poorly conserved and are beginning to show symptoms of severe stone decay (Smith and Magee 1990). Granite and granitic gneiss (augen gneiss) – generally regarded as being durable when used in construction – are the main stones used for prominent buildings in the city. Because of their widespread natural occurrence, information on the long-term, natural weathering of granite rocks is widely available. For example, Power and Smith (1994) have documented the deep and thorough chemical weathering of the local gneiss over a geological timescale in the Rio de Janeiro area under a stable soil and vegetation cover. Most commonly this is through the hydrolysis of weatherable constituent such as biotite micas and feldspars. However, whilst this demonstrates the eventual susceptibility of these rocks to chemical alteration, the comparatively short timespan over which the same rocks have been exposed within buildings works against the easy identification of any post-emplacement alteration. This same constraint may be applied to granites used for construction elsewhere in the world. There is very limited information with respect to the weathering of historic granite buildings compared to those constructed from limestone and sandstone. Previous research tends to concentrate on monitoring changes in physical and mechanical properties during the course of limited mechanical disaggregation (Sweevers et al. 1995). Most commonly this is attributed to the action of salts derived either directly from atmospheric pollutants (Smith et al. 1993) or from the alteration of mortars and adjacent limestones (Cooper et al. 1991). Previous research on the formation of black crusts on buildings and monuments and their influence on stone decay has similarly been restricted largely to sandstones, limestones and also to Europe and North America. Studies that have examined crust development on granites have associated them with high levels of atmospheric pollution in urban environments and have stressed the importance of particulates as sources for both the mineral and organic components of the crusts (Schiavon 1996, Schiavon et al. 1996). As with other substrate, the spatial distribution of crusts on granite buildings appears to be strongly influenced by architectural detail and exposure to the environment. For example, Begonha and Sequeira Braga (1996) working in Oporto, identified thin black crusts over complete façades that were subject to wetting by rain, except for those areas strongly affected by surface runoff (rainwash). A similar, façade-wide distribution of thin black crusts is evident in the centre of Rio de Janeiro on one of the city's most prominent churches – the Church of Ordem Terceira de Nossa Senhora do Monte do Carmo situated on Praça XV de Novembro (Figure 1). This church was constructed over two hundred years ago, principally of medium grained, garnet-rich granite, and is one of the most important historic buildings in Rio de Janeiro. It is located on one of the main roads within the city centre and experiences intense traffic conditions, the pollution effects of which are accentuated by the large number of surrounding tall buildings that create a canyon-like urban landscape. In addition, the church is located close to the harbour side of Guanabara Bay and it is to be expected that the façade be subject to the deposition of salt-rich marine aerosols. Decay on this church was first described by Smith and Magee (1990), who emphasised the early signs of physical breakdown near ground level through blistering and scaling. In an attempt to extend this work, the current study examines in detail the distribution and composition of the black crusts and their possible impact on the degradation of underlying and adjacent stones.

ENVIRONMENTAL CONDITIONS

The metropolitan area of Rio de Janeiro (6500 km^2) is the second most populated and one of the most prosperous areas in Brazil. A population of almost

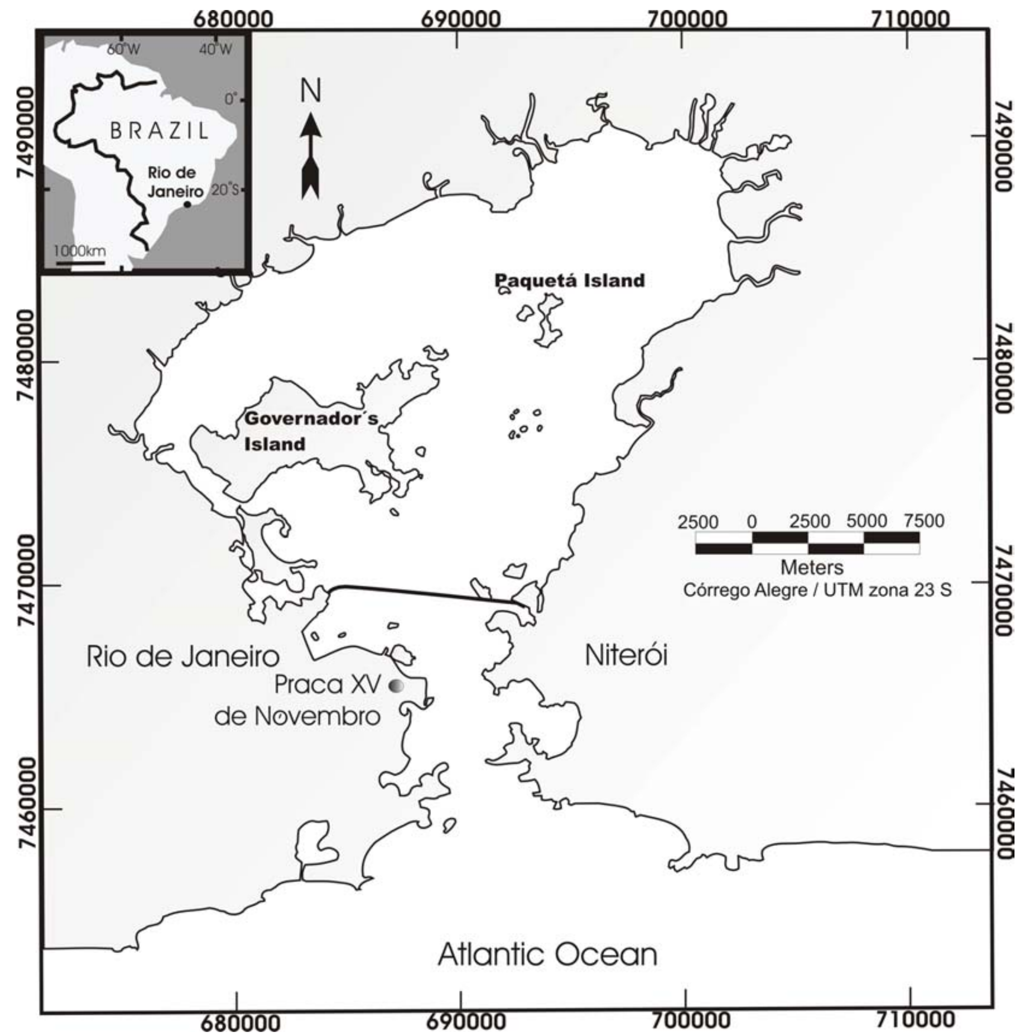

Fig. 1 – Location map of the studied site.

10 million and a projected annual growth of 1.4% were recorded in a 1990 census. This area experiences a humid sub-tropical climate, an average annual temperature of 22°C with summer temperatures ranging from 30-32°C and an average rainfall of 1200-1800 mm. Although rainfall is concentrated between November and March, it can rain during any month and relative humidity, especially in littoral locations remains high throughout the year together with high concentrations of marine aerosols. A significant decline in air quality over recent decades due to increased vehicle emissions has occurred. It is now common under still-air conditions for much of the area, including Niterói, to be blanketed by a photochemical smog (Smith et al. 2004). This smog contains high concentrations of carbonaceous and sulphate rich particles that originate from industrial emissions, construction sites, soil disturbance and stone masonry activities (Daisey et al. 1987, Miguel 1991, Azevedo et al. 1999). Marine aerosols can also be added since sodium and chlorine deposition rates of 2.2

and 4.2 t/Km^2/annum respectively, have been estimated (Moreira-Nordemann et al. 1988). Extractable organic matter in urban aerosols has been used as a marker for fossil fuels amongst the aliphatic hydrocarbons monitored in low level sites within Rio de Janeiro (Azevedo et al. 1999). Elsewhere in Rio de Janeiro State, Quiterio et al. (2004) have identified, in the absence of strictly enforced emission controls, concentrations of heavy and trace metals in airborne particulates in industrial and urbanised environments that reach levels significantly in excess of those generally recorded for similar areas around the world. The presence of these metals in any deposited particulates could catalyse the formation of gypsum on stone surfaces (Camuffo et al. 1983).

According to Smith and Magee (1990), high levels of vehicle emissions are reflected in the physical appearance and soiling of many buildings within the city centre where high densities of private and commercial traffic are frequently channelled along streets flanked by high-rise buildings. Pollution tends to concentrate and persist within these corridors and its most obvious long-term effect is the black staining of many buildings near to street level.

SAMPLING AND ANALYTICAL METHODS

Surface samples were collected from those areas of the church that exhibited well-developed black crusts and showed serious symptoms of stone decay. Because of the sensitivity of sampling historic buildings, it was only possible to obtain small, usually $< 2 \times 2$ cm chips from surface crusts. Small chips of weathered stone and black crust were mounted separately onto aluminium stubs, gold coated and their surface analysed using a Scanning Electron Microscope (SEM) (Jeol Winsen JSM 6400). Water-soluble salts were extracted from the $< 63\mu$m fractions by shaking 2gm of sample in 10ml of deionised water for two hours and allowing them to stand overnight at room temperature prior to centrifuging and filtration through a 0.2μm membrane filter for analyses. Cations, Ca, Mg, Na, K, Fe, Cu, Fe, Mn, Ni, Pb and Zn were analysed using a Perkin Elmer Model 3100 atomic absorption spectrometer. An air/acetylene flame was employed to atomise the sample solutions. Water soluble ions were extracted using a technique of extracting 0.5 gm of sample in 2.5 cm^3 of 0.2μm membrane filtered deionised water. Sample extracts were also membrane filtered (0.2μm) prior to IC analysis. Water-soluble anions, F, Cl, NO_3, PO_4 and SO_4 were analysed using a Dionex Model DX 500 ion chromatograph. An Ion-Pac AG4A-SC (4 mm) guard column and an AS4A-Sc (4m) anion exchange column were used and the injection loop was 25μL volume. A 1.8m M Na_2CO_3/1.7mM $NaHCO_3$ mixed solution at a flow rate of 2 ml per minute was used as elutant and a conductivity detector plus an Anion Self-Regenerating Suppresser (ASRSTM) was employed. Detection limits for all anions was 1 ppm.

RESULTS AND DISCUSSION

To highlight the degree of stone weathering in the church façade, those areas most affected by black crusts and weathering were mapped (Figure 2). Black crusts occur over most of the façade, but are more concentrated in areas sheltered from direct rain-wash, and those close to street level where granular disintegration, blistering and contour scaling of stonework were observed (Figure 3).

SEM analyses of the black crusts showed high concentrations of gypsum, which occur as a needle-like crystals plus a lower concentration of halite. Gypsum crystals have accumulated in the inter- and intra-crystalline fractures of quartz and feldspar crystals and bridge gaps between open cleavage planes in micas causing deformation and breaking (Figure 4a, b, c and d). Gypsum ($CaSO_4.2H_2O$) crystallise in the monoclinic system. The external morphology of gypsum varies considerably depending on temperature and impurities in the water, but commonly it appears as prismatic, twinned, or as clusters and crusts. One well known variety appears as blades with curved faces (Figures 4A,

Fig. 2 – Distribution of black crust on the church of Ordem Terceira de Nossa Senhora do Monte do Carmo façade.

B, C and D) or lenticular forms comprised of two curved faces, the most famous of this type being the desert rose (Schreiber 1988). According to Neill and Smith (1996) micas are the main avenues of entry for agents of decay, since once their structure has been deformed, they can either form potential fluid pathways into the rock substrate, or undergo volumetric change to induce mechanical decay.

The occurrence of gypsum crystals is widespread on non-calcareous surfaces in urban environments and this has led researchers to postulate on intrinsic and extrinsic sources of calcium (Cooper 1989, Sabbioni and Zappia 1992, Whalley et al. 1992, Halsey et al. 1995, O'Brien et al. 1995, McKinley et al. 2001). These authors have attributed the formation of gypsum to the sulpha-

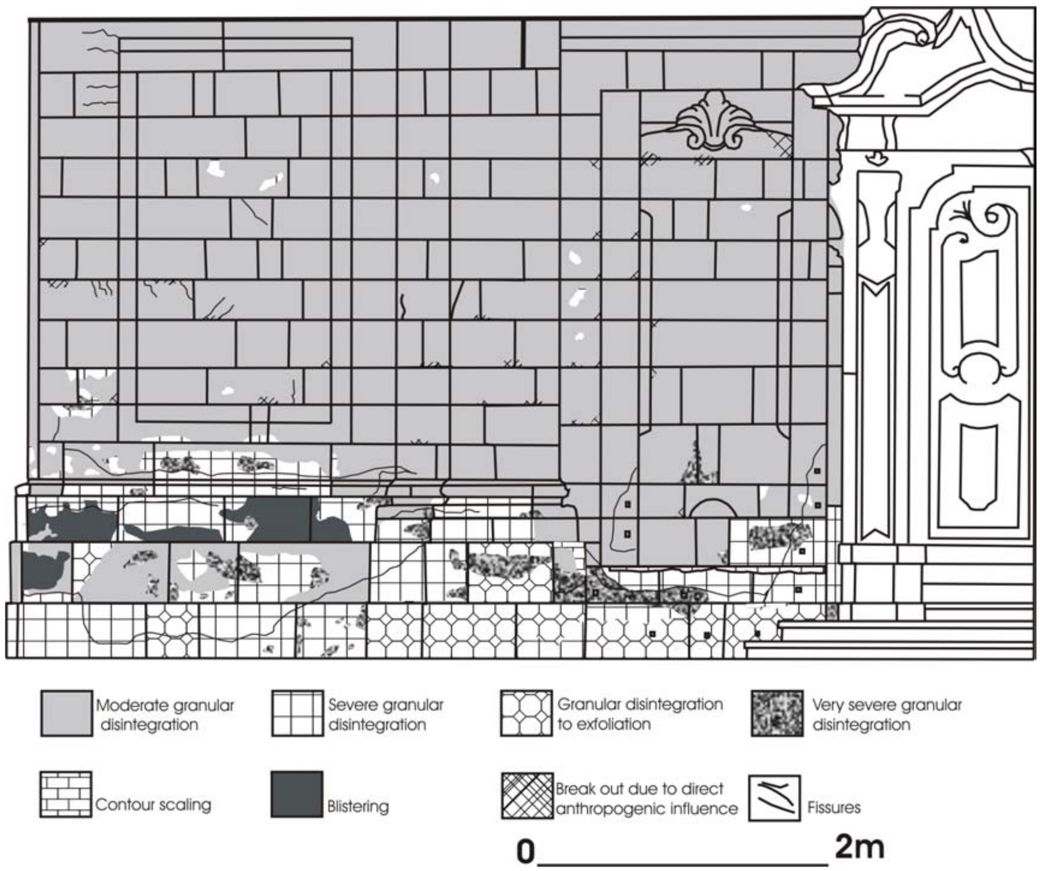

Fig. 3 – Examples of the weathering forms mapped on the façade of the church.

tion of calcium derived from external sources, such as the mortar surrounding the stone, adjacent carbonate stone or an atmospheric source. In this study an obvious source of calcium is from the mortar, present between the granite blocks, which is also used to "protect" the areas already affected by weathering. Calcium can also originate from flyash and SEM analyses revels its presence in all the samples analysed (Figure 4E, F, G and H). Flyash particles are spherical in shape, have irregular porous surfaces containing high concentrations of carbon, silicon, surphur, aluminium, and calcium and originate mostly from oil-fired combustion plants and vehicular emissions (Del Monte et al. 1981). These carbonaceous particles act as a catalyst during the oxidation of SO_2 to SO_3 where H_2SO_4 is ultimately formed and acid rain is produced (Blokker 1978). This process is also accelerated in the presence of some transition and other elements (e.g. Fe, V, Cr, Ni, Pb) and also as a result of their high specific surface area (Urone et al. 1968, Benner et al. 1982). These particles have the ability to anucleate in a humid environment and precipitate $CaSO_4$, that can hydrate/dehydrate depending upon fluctuations in environmental temperature and relative humidity (see Goudie and Viles 1997, chapter 3, for a discussion) (Del Monte et al. 1984, Del Monte and Lefevre 1998). Pye and Schiavon (1989) demonstrated by means of S isotope ratios that the S present in gypsum crusts on building stones originates from atmospheric sources. Hildemann et al. (1994) identified the origin of carbonaceous particulate matter in the urban environment as coming from motor vehicle emissions, especially diesel, using C isotope analysis. Laboratory simulation experiments have also confirmed the interaction between carbonaceous particles and stone (Sabbioni et al. 1996). Several authors have supported the role played by fly ash deposition in the formation of black crusts, (Smith and Magee 1990, Whalley et al. 1992, Sweevers et al. 1995, Rodriguez-Navarro and Sebastian 1996, Ghedini et al. 2000, McKinley et al. 2001).

Results for IC and AAS analyses presented in Table I highlights the high concentrations of the Ca, Na, Cl and SO_4 in the samples. A significant correlation between Ca and SO_4 is shown in Figure 5 and demonstrates the importance of gypsum formation and how it contributes to weathering on the church façade. The presence of gypsum was previously confirmed by a preliminary study of the church by Smith and Magee (1990), who used X-ray diffraction to identify multiple peaks for the mineral. Sodium and chloride are also present but do not correlate as well as Ca and SO_4 and may suggest that that salt (NaCl) weathering plays a lesser role in the weathering process, there are, also more correlation between the elements, which suggest different salts, and it will be better examined in the future research. Previous studies on precipitation chemistry in the metropolitan area of Rio de Janeiro (Mello 2001) demonstrated how precipitation was greatly affected by marine aerosols, as indicated by their high Cl^- and Na^+ concentrations. However, according to Moropoulou et al. (1998) only one third of the Cl originates from marine spray and the remainder originates from anthropogenic sources. In this study area, Ca and K are primarily of Terrestrial origin; such as soil dust, vegetation exudates and biomass burning and on this church another important source of Ca is from the mortar used for building (Smith et al. 2004). Sulphate and NO_3 are released to the atmosphere mainly by human activities, especially as a result of fossil fuel combustion (Fassina 1991). Significant correlations between SO_4 and Ca, and to a lesser extent Na and Cl, and K. F may show the importance of atmospheric deposition (wet and Dry) rather than to material lost by the stone. Normally NaCl concentration is strongly influenced by marine aerosols and the high concentration of $CaSO_4$ can be explained by the presence of gypsum ($CaSO_4.2H_2O$) observed by SEM (Figure 4). Zn, Cu, Pb, Cr, Ni and Mn concentrations in the black crusts come from urban pollution produced within the city itself by industrial combustion processes, road traffic and the wearing down of mechanical parts (Bolbély-Kiss et al. 1999, Silk et al. 1986).

SYNTHESIS AND CONCLUSIONS

Although the granite used in the construction of the Church of Ordem Terceira de Nossa Senhora do Monte do Carmo has largely remained intact after c. 200 years of exposure, it has not remained in pristine condition and there is evidence that its structural integrity is beginning to be compromised near to ground level. These changes are most obviously a response to the surface accumulation of anthropogenic aerosols, together with the extensive development of a thin, black crust over most of the front façade of the church that is best developed in areas sheltered from rainwash. The black crust is apparently composed of gypsum and takes the form of either needle-like crystals or a thin surface crystalline patina. Chemical analyses also demonstrate the presence of marine aerosols, such as NaCl and, as for similar black crusts found on granites (Sequeira Braga et al. 1996), their composition is strongly influenced by the surface deposition of street dusts and combustion particles from fossil fuels and reactions with both wet and dry (gaseous) air pollution. The association of these elements have resulted in the formation of salts such as halite (NaCl) and gypsum ($CaSO_4.2H_2O$), which, when found in combination are potentially very effective agents of salt weathering once they find their way into stonework (Smith et al. 2002).

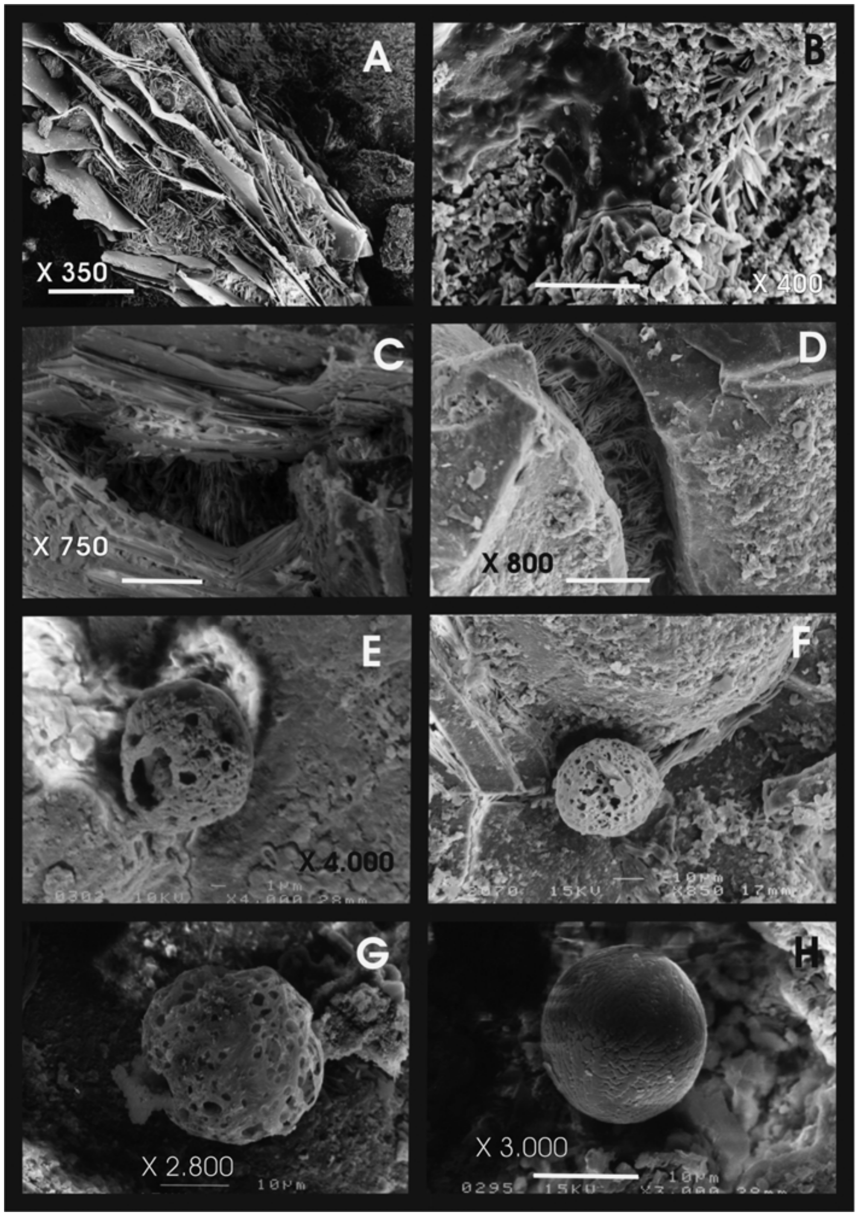

Fig. 4 – SEM micrographs of black crusts showing (A and B) needle-like crystals of gypsum accumulated in the inter- and intra-crystalline fractures of quartz and feldspar crystals and bridge gaps between open cleavage planes in micas causing deformation and breaking (C and D), rounded fly ash particles from combustion of oil-based fuels (E, F, G and H).

The widespread development of a gypsum-rich black crust questions the assumption, that gypsum accumulation is inhibited in regions of high rainfall.

Two factors appear to explain this anomaly. The first is the high level of atmospheric pollution currently experienced in the centre of Rio de Janeiro. Prior to the banning in 1995 of lead additives to petrol, Smith and Magee (1990) used high lev-

TABLE I

Concentrations (ppm) of the main elements detected in the black crusts sampled on the church façade.

Sample	F ppm	Cl ppm	NO_3 ppm	PO_4 ppm	SO_4 ppm	Fe ppm	Mn ppm	Zn ppm	Cu ppm	Pb ppm	Ni ppm	Ca ppm	Mg ppm	Na ppm	K ppm
1	1.71	33.26	70.00	8.39	131.50	0.9	0.25	0.3	2.85	0.1	–	56	4	20	50
2	2.23	24.30	51.48	9.11	143.08	2.05	0.15	0.2	1.95	0.1	–	57.5	3.5	20	50
3	2.85	55.50	160.92	26.38	303.20	0.65	0.15	0.25	0.9	0.1	–	109.5	6	35	65
4	–	405.40	142.31	–	6730.78	0.2	0.95	0.85	3.9	0.45	–	2750	20.5	150	180
5	–	227.32	373.19	–	7079.05	0.15	1.25	1.15	2.8	0.4	0.65	2850	43	150	130
6	–	223.12	97.28	94.74	1239.47	0.25	0.45	0.1	3.2	–	–	450	24.5	185	160
Detection limits						0.04	0.03	0.01	0.03	0.10	0.04	0.09	0.01	0.01	0.03

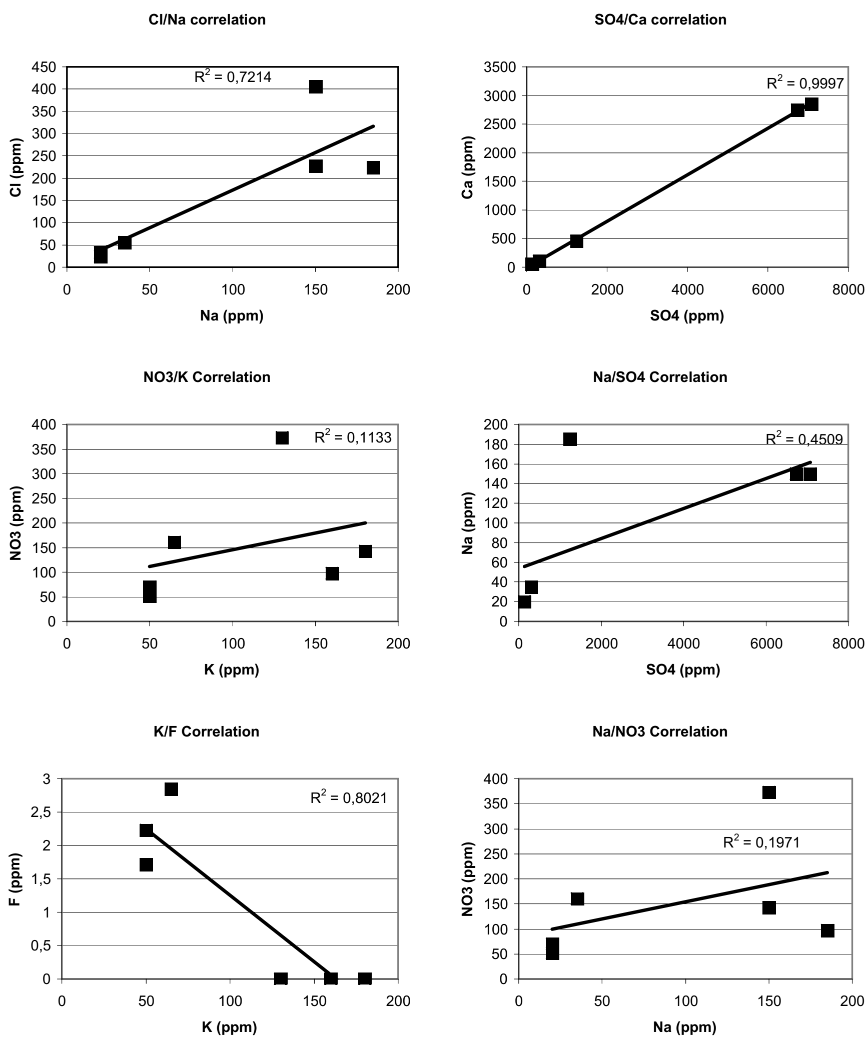

Fig. 5 – Correlation between some chemical elements.

els of lead in the crusts of the church to identify vehicle emissions as a major contributor to at least the near-ground soiling of this and other buildings in the area. However, recent literature has identified a wide range of additional industrial, commercial and domestic sources of atmospheric pollution within Rio de Janeiro including high concentrations of air borne particulates. The rapid deposition of these particulates as dust accumulations on the surface of stonework has been identified elsewhere (Smith et al. 2003) as a key factor in promoting the rapid growth of black crusts. The second factor may relate to a possible reduction in the incidence and effectiveness of rainwash over the stonework of the church compared to that expected within a humid sub-tropical environment. There is no quantitative evidence to support this contention, but it is a reasonable proposition that the canyon-like topography of narrow streets and tall buildings could shelter large areas, especially at and near street level, from incident rainfall depending upon local wind conditions, building orientation, the degree of shelter afforded by adjacent buildings and any shelter provided by overhanging architectural detail on higher storeys. However, even if rainfall were evenly distributed over the city, its high specific surface (the ratio of the total building and street surfaces to the land area that they occupy) must mean that the average rainfall per unit area of stonework is much less than that indicated by standard meteorological observations. Moreover, the funnelling of wind along the confined streets should also permit increased evaporation of any moisture precipitated onto and within stonework. Ultimately the migration of moisture and salts into the stonework – possibly through micro-fractures explained by salt crystallisation (Figure 4) – could promote the chemical decay of the underlying granite. This could include the hydrolysis and complete breakup of the garnet, the weathering of mica and the feldspars. We intend to investigate this possibility in a future detailed study of the substrate. In doing so, the incidence and effectiveness of surface runoff in dissolving any gypsum from building façades should be curtailed. Whilst at the same time, the surface precipitation of gypsum and other salts could be facilitated. It could be, therefore, that the key to explaining gypsum crust formation lies in understanding the microclimatic conditions that prevail at the stone/atmosphere interface, rather than regional values of mean annual rainfall. These microclimatic conditions are in turn determined by factors such as the detailed geometry of the building and its local setting. By controlling airflow patterns of over and around building surfaces, these same factors also are likely to play a significant influence on particulate deposition patterns.

Finally, since the study church was first examined in the late 1980s by Smith and Magee (1990), it is noticeable that, although gypsum crust have grown steadily in terms of extent and thickness, recent years have seen a marked increase in the incidence of contour scaling and granular disaggregation near the base of the front façade. As both Smith and Magee (1990) and Neill and Smith (1996) have noted, this breakdown is linked to the opening up and subsequent exploitation of near-surface micro-fracture networks in association with the penetration of both halite and gypsum. Undoubtedly, the surface accumulation of these salts as open-textured surface crust provides a readily available store that can potentially be mobilised into the stonework whenever it is wetted. The precise role of surface crusts in providing the salts that may ultimately trigger effects such as contour scaling is still poorly understood and is the focus of ongoing research at the church. However, the possibility that gypsum crusts could, and the strong circumstantial evidence that they do, contribute to mechanical breakdown is a cogent argument in favour of their removal. Provided that this is carried out sympathetically and in a manner that neither abrades or washes salts into the underlying stone.

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RESUMO

Com o objetivo de se avaliar os controles ambientais na formação de crostas e deterioração de rochas ornamentais em fachadas de prédios históricos, uma série de mapeamentos e análises fisicas e químicas foram realizados em granitos da fachada de uma igreja histórica numa área poluída no centro da cidade do Rio de Janeiro. Estas técnicas destacam a ameaça crescente dos danos causados pela desagregação granular e esfoliação da rocha que é fortemente percebido por se tratar de um material de alta durabilidade usado na fachada do prédio em áreas localizadas ao nível do chão. O exercício de mapeamento possibilitou a demarcação e observação das áreas afetadas pela formação de crosta negra sobre toda a fachada do prédio, principalmente concentradas em áreas abrigadas da ação da chuva. As análises demonstraram a influência de aerosóis marinhos, composição das rochas e argamassas e dos poluentes atmosféricos na deterioração e formação de crostas no granito. Muito da deterioração é associado especificamente a presença de sais, tais como halita (NaCl) e gipsita ($CaS0_4.2H_2O$). O fato da crosta negra de gipsita ser capaz de se desenvolver sobre toda a fachada do prédio, em um ambiente sub-tropical úmido é testemunha da eficácia dos altos níveis de poluição local, especialmente da deposição de particulados, e da reduzida lavagem pela chuva em um micro-ambiente protegido, em ruas estreitas, que funcionam como corredores de poluição, impedindo a tendência da gipsita ser lavada das fachadas dos prédios históricos. Essa observação destaca que os processos de intemperismo operante, são principalmente controlados por condições microclimáticas.

Palavras-chave: intemperismo, granito, poluição do ar, aerossóis marinho, crosta de gipsita.

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