Jadwiga W. Lukaszewicz & Piotr Niemcewicz (eds.) Proceedings of the 11th International Congress on Deterioration and Conservation of Stone. 15 - 20 September 2008. Torún. Poland. Proceedings Volume II, Torún 2008: 339 - 1347.

OBJECT-SPECIFIC DESALINATION OF TOMB MONUMENTS

W. Wedekind[1], J. Ruedrich[2], T. Kracke[2], T. Licha[2] & S. Siegesmund[2]
[1]*Wandwerk GmbH, 10119 Berlin, Germany*
[2] *University of Goettingen GZG-Strukturgeologie, 37077 Goettingen, Germany*

Abstract

In an interdisciplinary project, object-specific desalination methods have been developed and carried out on seven prominent burial monuments and two mausoleums at the Bartholomew Cemetery in Goettingen (Germany). The monuments were constructed from the local sandstone (Buntsandstein). The methods discussed in this study are desalination in a water bath, cyclical sprinkling and capillary flow desalination. To verify the effectiveness of the applied methods, the salt content in the rinse-fluids were measured during the salt reduction process. Furthermore, the salt content was measured on eluted drill cuttings samples before and after the salt lowering procedure. Determination of salt impact was carried out by measurement with an ion chromatograph and by electrical conductivity. The different salt phases were determined by means of x-ray diffractometry analysis. The primary purpose of the project was to optimise the efficiency of the desalination treatments to further a sustainable conservation of the monuments.

Keywords: desalination, sandstone, tomb monuments

1. Introduction

Damages on structures built from natural building stones are in many cases due to the impact of salt crystallisation. The fundamental prerequisite is the reduction of the stresses created by salinisation. The damage processes may be stopped or slowed down by preservation measures, which would guarantee a sustainable protection of the object under consideration.

The transport of salts largely occurs by solution in the pore spaces of natural building stones. This can also be utilised by the measures designed to reduce the presence of salts. Two transport mechanisms are known: capillary transport and ion diffusion. Capillary transport occurs at a relatively high rate. It is dependent upon the pore space properties of the rock, the moisture content, temperature and the pressure gradient. In contrast the diffusion processes operate at very slow rates. They are determined by the saturation in the pore spaces, the mode of pore space interconnectivity and the precipitates in the solution. The only applications that come into question are those which can be easily executed at low costs. The most practical method by far for use in preserving historical monuments is the compression desalination process (Auras & Melisa 2002).

2. The Bartholomew Cemetery and its Tombs

The historical Bartholomew Cemetery is closely connected to the rise of the Georgia-Augusta University of Goettingen, which was one of the most important

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centres of science in Europe during the 19th century. The cemetery is the last resting place for many distinguished German and European personalities involved in the humanities and scientific research.

In this period, thirty professors who taught and became renown at the University of Goettingen found their last resting place at the Bartholomew Cemetery. Examples are the physicist and writer Georg Christoph Lichtenberg, the poet Gottfried August Buerger, the mathematician and philosopher Abraham Gotthelf Kaestner as well as the church-historian Gottlieb Jacob Planck.The number of tombs preserved today comprises a total of 167. Many of the tombs only show fragmentary preservation. The types of graves found at the cemetery consist of simple enclosure graves, tomb slabs, steles, gravestones, stone pillars, gothic pinnacle-pillars, obelisks, cubic-shaped columns and two mausoleums.

3. Preservation and the Causes for Damage

The construction material predominately used for the tombs at the Bartholomew Cemetery is the highly porous Buntsandstein. Different types of damage and stress-strain phenomenon are evident on the stones (Fig. 1). They range from locally-formed holes to finely sanded surfaces, crack formation, flaking and crusts as well as conchoidal fractures leading to material loss. The causes for the damages on the tombs might be due to different reasons. However, the analyses show that in large part the material loss is due to the high salt concentration resulting in crystal salt wedging. The best example of this type of salt weathering can be seen on the Adolf Ellissen obelisk (cf. Kracke et al. 2007).

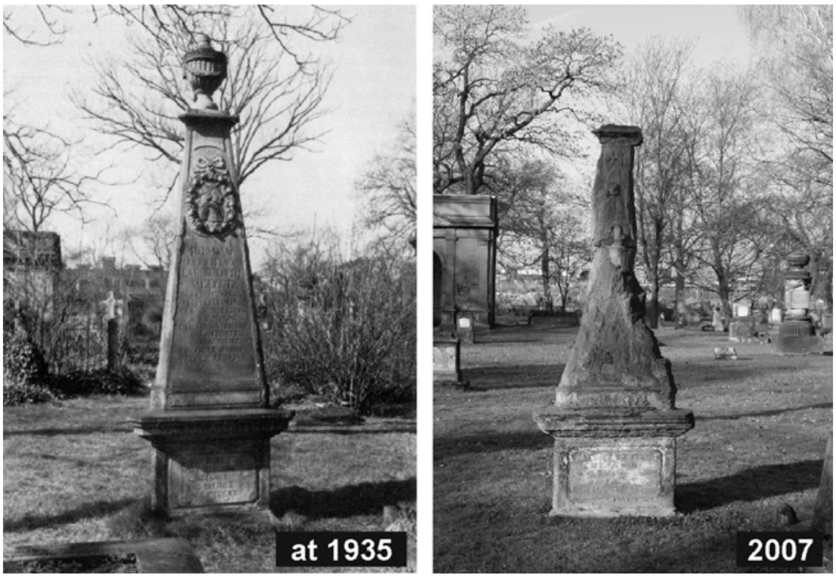

Figure 1: Historical and present-day photo showing the condition of the Sielentz obelisk exhibits strong weathering and a loss of ornamental designs.

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The salt-induced weathering of the monuments was determined using eluates from drill cuttings. The samples were retrieved at different heights on the structure and at depth. The analyses were done using an ion chromatograph (IC) and by measuring the electrical conductivity (EC). An x-ray diffraction investigation was also performed on the salt efflorescence's on the obelisk's surface.

The analyses reveal that the main weathering stress of the sandstone is due to sulphates and a subordinate amount of nitrates. Chlorides are verifiable in only small amounts in the lower part of the gravestone. In general the salt-induced weathering decreases from the lower to the upper part of the obelisk (cf. Arnold & Zehnder 1990). This shows that the salt crystallisation can be directly related to capillary rise. Likewise the front part of the obelisk also exhibits a high salt-induced degradation.

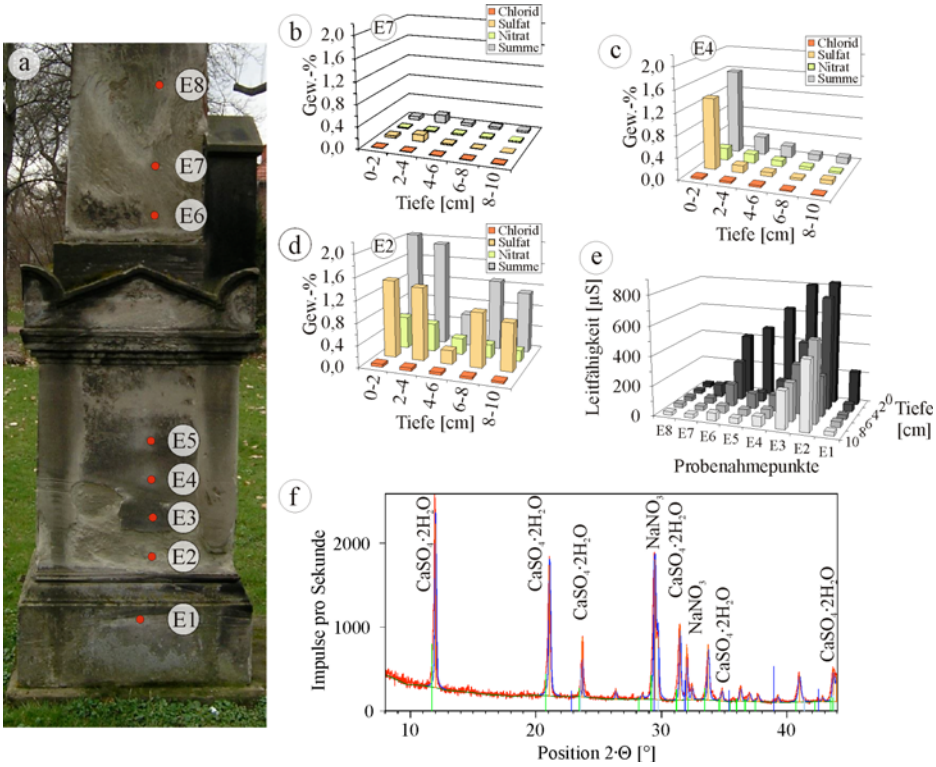

Figure 2: Salt-induced weathering on the Adolf Ellissen Tomb: a) sample points; b-d) ion chromatograph analyses; e) conductivity analyses and f) x-ray diffractometer analyses.

The salt contamination decreases with depth in the monument. X-ray diffraction measurements of the solids from the eluate solution not only revealed gypsum ($Ca[SO_4]\cdot 2H_2O$) enrichment, but also a contamination by $NaNO_3$ (nitratine, Fig. 2f). The analyses on the other tomb monuments also exhibit comparative degradation, as well as salt phases showing a similar distribution and concentration as in the Ellissen Tomb.

4. Applied Salt Reduction Methods

4.1. Salt Reduction Bath (Lejeune Dirichlet Tomb)

The balustrade tomb had to be dismantled because of difficulties with the foundation. The quadratic enclosure comprises 13 building stones which form an ornamental balustrade. Placed on every corner is a pillar. The open spaces in the balustrade are covered with panels. Because the construction has a symmetrical shape, four stones in the complex can be compared with each other. This concerns not only the outer shape and dimensioning, but the type of stone variety. The greatest damage to the stone can be seen on the eastern and southern areas of the balustrade. Damages to the west side of the tomb are the lowest, followed by the north side. These sides are exposed to the rain. Efflorescence of lightly coloured salt precipitates and gypsum crusts attest to the high salt-induced weathering of the tomb.

The principle behind the applied salt reduction bath is based on the diffusive equilibrium in solutions and the presence of precipitates. For this process a complete wetting of the stone is necessary. The ion concentration in the stone is high and in the surrounding solution low. The four pillars and the chosen areas in the four balustrades were desalinated in static water baths. A basin was constructed for every stone object which would hold sufficient water to cover the objects. For every stone five immersion baths were performed with the same volume of water, so that the results could be compared with each other. The stones were kept in the basin for a period of five days per bath. The increase in the electrical conductivity in the desalination solution was measured, which is dependent on time and various depths. Daily measurements were made at different levels in the bath. The depth dependency results from the higher density of the salt solution, which becomes enriched through time in the lower part of the solution due to gravity. Thus, a higher salt density is measured at the bottom of the basin.

The electrical conductivity showed a strong increase after four days of water immersion. On the fifth day the values stabilised and only an insignificant increase was measurable (Fig. 3b). The conductivity values decreased with the increasing number of salt reduction baths. This suggests that the concentration of salts were reduced in the stone tomb objects. Between the fourth and fifth immersion bath only a small difference in the conductivity could be measured. The method shows that a far-reaching salt reduction can be attained. Salt contamination is reduced by half even after the first desalination bath. Afterwards the desalination process progressed in much smaller steps. The approximate amount of the extracted solids could be calculated from the steamed samples. For the eight stone samples treated, a sum of ca. 1500 g could be withdraw.

4.2 Cyclical Sprinkling (Strohmeyer Stele)

The main weathering form visible on the Strohmeyer Stele is a peeling formation, which is directly related to salt crystallisation stress. Damages are concentrated on the lower half of the inscription zone (east side). In these areas the surface shows total damage by weathering. and salt efflorescence’s could be found. Chemical testing done with test strips show that nitrate compounds can be detected in situ on the gravestone.

The goal of the sprinkling method is to target the strongly stressed zones and to keep moisture movement at a minimum. Salts become concentrated on the stone surface by capillary transport, diffusion and the subsequent drying regimen. In the following description, the step-by-step procedure (Wedekind & Rüdrich 2006) for the ensuing treatment is given in reduced form. The untreated portions of the gravestone (73 cm in width) are covered in plastic, so that the drying process can concentrate on the badly weathered area (ca. 750 cm^2). At the lower end of the treated area a drain gutter was constructed from clay, so that the eluate can be funnelled into a sample bottle (Fig. 4). The wetting of the stone surface was done by spraying the material with a fine mist.

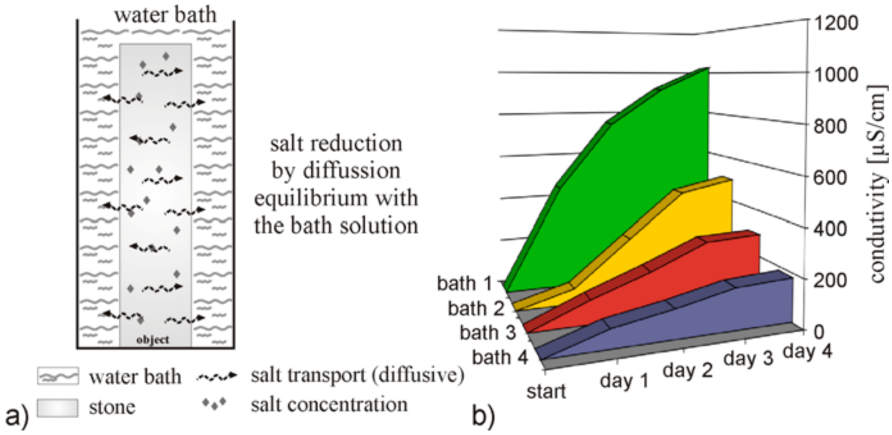

Figure 3: Salt reduction bath: a) schematically sketches of the applied measures and b) electrical conductivity of the bath solution.

At the beginning of the procedure the water is predominantly absorbed by the porous stone surface through capillary forces. Water absorption is dependent upon the transport properties of the material. They are controlled by the pore space properties, like porosity and pore radii distribution and are a time-dependent process (Wittmann 1996). In the case of the treated gravestone stele, salt contamination was analysed from drill cuttings obtained in the first two centimetres of the stone.

Sprinkling and drying time was investigated on reference samples before the actual treatment. The reference sandstone material is the variety Reinhausen, which is found in the region of Goettingen and shows a porosity of 21.6 vol.-% (Kracke et al. 2007). The w-value varies between 15.08 $kg/m_2*\sqrt{h}$ and 17.66 $kg/m_2*\sqrt{h}$ in the different petrophysical directions. The contamination zone was sprinkled for moisture penetration during a period of five minutes, in accordance with the determined infiltration rates for the Buntsandstein variety. Excess water not absorbed by the stone was collected in 0.5 litre amounts and checked for electrical conductivity. After every sprinkling cycle, a break of ca. 24 hours was observed in order to initiate the drying procedure, which leads to the concentration of salts in the near-surface area of the stone. A volume of 10 x 0.5 litres of eluate was collected and analysed after each sprinkling cycle. Over a period of 14 days, a total of nine treatment cycles were completed.

The highest values of electrical conductivity could be determined by the first measurement in the course of a respective sprinkling treatment. In comparison to the first dataset, the second values showed a decrease ranging between 30-50% after sprinkling. A continual decrease in the electrical conductivity occurred in the other eight measurements. The last conductivity value was measured at around one-fourth of the initial sprinkling cycle value.

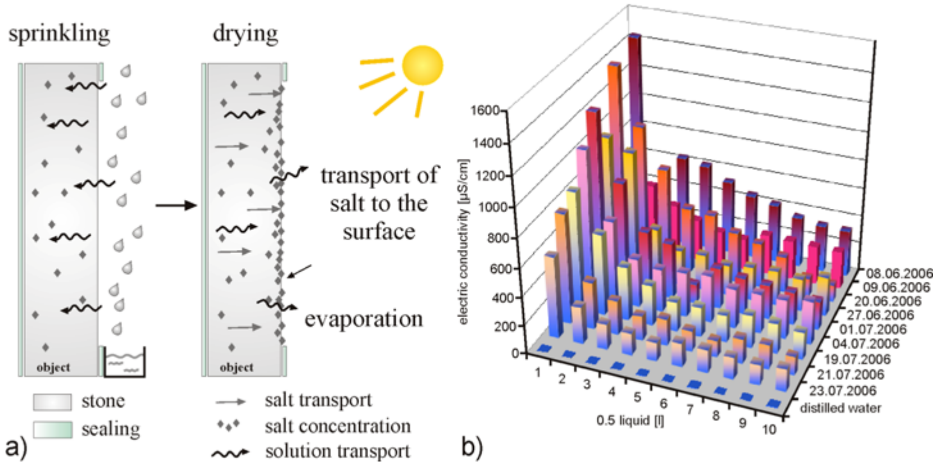

Figure 4: Cyclical sprinkling: a) schematically sketch of the applied measures and b) electric conductivity of the sprinkling solution.

In comparing the treatment cycles, a reduction of the electrical conductivity between the first and second measurement was around 50%. By the third and fourth determination the values showed a 10% reduction. Following the fourth, fifth and sixth cycle, the conductivity showed a verifiable reduction of around five percent. Further measurements produced comparable reductions below one percent.

In order to quantify the amount of salt reduction from the damage zone, solutions from a number of samples were dried and the amount of precipitate was determined. Thus, the salt content can be extrapolated for all other electrical conductivity measurements. In total 12 g of dissolved solids were extracted by using the sprinkling method. This is equivalent to working an area of around 16 g per square metre. When comparing the drill flour samples before and after the treatment, a significant desalination effect could be confirmed. Even the follow-up examination by salt check tests (cf. Weiss & Ungerer 2001) attest to the large-scale desalination on the stone’s surface.

4.3. Capillary Flow (Ellissen Tomb)

The most pronounced damages on the Ellissen obelisk monument were located on the lower part on the south side of the cubic-shaped base. The south side is also the preferential drying side. The northwest side of the monument is exposed to a higher degree of precipitation, whereby the drying gradient is directed toward the south. Sunlight on the exposed south side speeds up the drying process.

Drilling resistance measurements showed massive gypsum enrichment had developed at a depth of 10-20 mm in the damage area of the Ellissen Tomb. The salt crystallisation is not just a general surface area phenomenon, like the electrical conductivity measurements reveal, but can be categorised as more or less a structural problem.

In order to reduce the enrichment at depth, emphasis was placed on using drop impregnation and the generation of moisture flow. Drill openings from the preliminary investigation and additional holes were drilled for this procedure. Distilled water was continually transmitted into the drill holes by means of a drop system to a depth of about 10 cm into the stone (Fig. 5). On the south side of the cubic base, compresses made from washed sand and cellulose fibres were placed in the evaporation and damage zone. To increase the drying in the compresses, the whole cubic obelisk base (except for the compress area) was sealed in flexible plastic. Over a period of four weeks five litres of distilled water was continually added to the rock by the drop system procedure. This was done by capillary moisture movement, which is favoured by the high porosity of the damage zone, directly into the compresses undergoing drying. The compresses were changed a total of four times after every infusion. After the compresses were dried, the material was analysed in regards to precipitated solids.

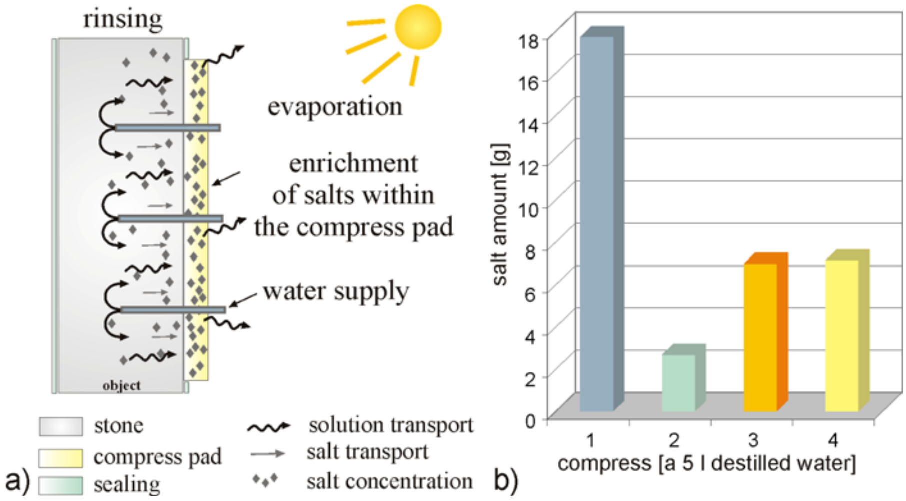

Figure 5: Capillary flow: a) schematically sketch of the applied measures and b) extracted salt amount from the compresses.

In four compress cycles a total of about 38 g of precipitated solids could be extracted. The first compress contained about 18 g of extracted solids from the rock, which is half the amount retrieved from all four treatments. The amount in the second compress weighed in at merely 2.5 g of solids, whereas in the third and four treatments about 7 g was extracted. Follow-up investigations confirm the successful salt extraction. The hardening zone in the inner part of the rock could be removed, which was verified by drilling resistance measurements.

5. Conclusions

The salt reduction measures applied to the tombs at the Bartholomew Cemetery differ considerably in regards to their application, depth impact, salt reduction efficiency and time expenditure. Water immersion desalination clearly seems to be the most efficient method. The purging method by using a capillary flow also shows the ability to reduce the salt content significantly. Both methods are characterised by a long-term impact that leads to sustainable salt reduction. For the sprinkling method, the decisive factor is the duration and the interval between the cyclical effects. When the effective reaction period is too short, the mobilisation of the salts at depth is insufficient. Therefore, it is of critical importance to know the depth of the enrichment horizon, the salt phases and the water absorption properties and drying behaviour of the rock.

No universal procedure exists for dealing with salt-induced weathering. However, there are many methods for mobilizing salts in porous natural building stones, transporting the salt to the surface and reducing their impact by different approaches. Most methods use the capillary solution transport process in combination with diffusive ion transport (e.g. water immersion bath). This is very suitable because of its relatively high rate, especially when in situ measures are called for. The application of the different methods are restricted by numerous circumstances and constraints, e.g. the property of the natural stone, depth-dependent enrichment and the type of salt phases as well as the geometry of the monument and its degree of degradation. According to the conditions of the object and its boundary parameters, the right method must be chosen. Hence, it is necessary and imperative that corresponding desalination measures be scientifically monitored.

6. Acknowledgements

We would like to thank the University of Goettingen construction office, the State Office for Preservation of Historical Monuments (Lower Saxony) and the Department for Green Spaces and Environment Goettingen. This study was financed by the Deutsche Bundesstiftung Umwelt and the German Research Foundation (Si 438/17-1).

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