

Poultices and mortars for salt contaminated masonry and stone objects

Michael Auras

Institute for the conservation of stone, Mainz, Germany

Abstract

The success of measures to reduce the salt content of contaminated objects by application of poultices depends on several factors: experiences with different poultice materials, with modifications of their application and with the influence of the specific conditions. Some of these critical factors are the admixture of different clay minerals to the poultice, surface sealing and pre-wetting. Hints for an enhancement of the efficiency of desalination are derived from case studies and from laboratory experiments. Tests to achieve further enhancement of desalination efficiency by applying electrical potential or by addition of water from the backside are described. A sensitive treatment of a salt contaminated painting on wooden panel is also presented. The second part of the paper is concerned with the suitability of different mortar systems for repointing or rendering. The pros and cons of cementitious mortars of high porosity and reduced capillarity versus hydraulic lime mortars with high capillarity are discussed in the light of practical experience in building preservation and maintenance. Porous cementitious mortars with waterrepellent admixtures have frequently been used over the last 30 years. If moisture supply from the masonry is low, they can maintain an intact surface for a long time. Several cases are discussed where new damage occurred after a couple of years. An alternative is the use of lime mortar which works as sacrificial mortar or plaster. Due to its high capillarity moisture and salt are soaked into the lime mortar which ultimately deteriorates by salt crystallization. If the strength of the lime mortar is enhanced by natural hydraulic components or by compaction during application the service life time of such a hydraulic lime mortar can reach decades even with extreme salt load. Research on desalination poultices and on lime mortars in the last two decades, as well as practical experience, have led to a wide variety of materials for desalination and building maintenance. A thorough analysis of the specific situation and the careful

selection of the appropriate material and the adequate method of its application remain critical aspects in building preservation.

Keywords

Natural stone, masonry, salt decay, desalination, poultice, lime mortar, natural hydraulic lime, stone conservation, restoration

1. Introduction

Historic buildings and monuments made up of natural stone or brick often show deterioration phenomena caused by soluble salts (Fig. 1). Whenever water penetrates porous building materials the available soluble salts are mobilised. The different salts, their transport mechanism and the deterioration processes caused by them are discussed elsewhere in this volume. Two possibilities to handle salt contaminated objects are discussed. The main topics covered are the application of poultices and the selection of appropriate mortars and renderings.



Figure 1: The metallic sculpture of Joan of Arc resists salt crystallisation while sandstone archery and lime rendering deteriorate at the garden wall of Stolzenfels Castle.

2. Salt reduction by poultices

2.1 Salt transport and salt distribution in porous building materials

For desalination purposes or - more accurately - salt reduction purposes, wet poultices can be applied on surfaces of porous building materials. The purpose of this method is the transport of soluble salts from a substrate into the poultice which is then removed

with its salt content. In contrast to renderings and plasters poultices are applied for some weeks only and have no decorative or protective function.

The transport of salts needs water as solvent and as transport medium. Different transport processes have to be distinguished:

- Ionic diffusion of salt components is driven by the concentration gradient between salt free water in the poultice and a salt solution in the pore space of the substrate. The larger the pores the faster the diffusive salt transport proceeds.
- Salt in aqueous solution can also be moved by capillary transport of the solvent water. Capillary transport is possible in pores with radii between about 50 nm and 100 μm . It depends on the water content and the pore structure of poultice and substrate.
- Convective transport of aqueous salt solutions can be caused by gravity, external pressure or differences in density or temperature. This kind of transport preferentially takes place in large pores, caverns or fissures.

Salt reduction by application of poultices usually affects a subsurface zone of a few centimeters only. A long-lasting effect can only be achieved if most of the salt is concentrated near the surface and if salt supply from adjacent zones is cut off. It is essential to know the salt distribution in an object before taking a decision on the use of poultices. In certain cases a temporary salt reduction is sufficient to carry out conservation measures before the salt content is replenished. For example formation of silica gel can be hampered by high salt contents when stone strengthening by silicic acid ester is carried out (Sattler, 1992).

2.2 Functionality

Considering how poultices work two different principles can be distinguished, i.e. permanently wet poultices versus drying poultices.

Covering a poultice with polyethylene foil after application prevents the loss of water by evaporation. In the first stadium part of the water is sucked off from the poultice into the stone substrate by capillarity. Crystalline salts present in the pore space dissolve in the infiltrating water. In the second stadium the prevention of evaporation keeps the water content in the poultice and in the stone nearly constant. Part of the dissolved salts is transported into the poultice by ionic diffusion (Fig. 2, left side). Ionic diffusion through the pore space of natural stone is very slow and thus salt reduction takes its time. A regular replacement of the poultice every few days is recommended to keep the gradient of salt concentration between masonry and poultice high. An exchange is also necessary to avoid mould. The proportion of salt which can be removed by poultices depends on the ratio of the amounts of water in the poultice and in the stone substrate.

Drying poultices shift the zone of evaporation of water from the stone surface (or subsurface) into the poultice. Thus salts crystallize in the poultice where pore water evaporates. The salts are transported into the poultice by capillarity as well as by ionic diffusion (Fig 2, right side). When the drying process continues, water supply from the stone into the poultice declines and the evaporation front slowly moves from the surface of the poultice into its interior parts and finally back into the stone surface. Then the poultice should be removed, because the salt supply from the substrate into the poultice is finished. Usually the drying of the poultices takes three or four weeks.

Sometimes it can take much longer, especially if the masonry is humid, if the weather is cold and wet and if water retention of the poultice material is high. In most cases two or three repeats of poulticing are necessary to extract a reasonable proportion of salt.

Because water transport driven by capillarity or convection is much faster than ionic diffusion through a narrow pore space, in most cases the desalination effect of drying poultices is higher than that of poultices kept permanently wet (see WTA-Recommendation 3-13-01/E. WTA: German shortcut for the International Association for Science and Technology of Building Maintenance and Monuments Preservation).

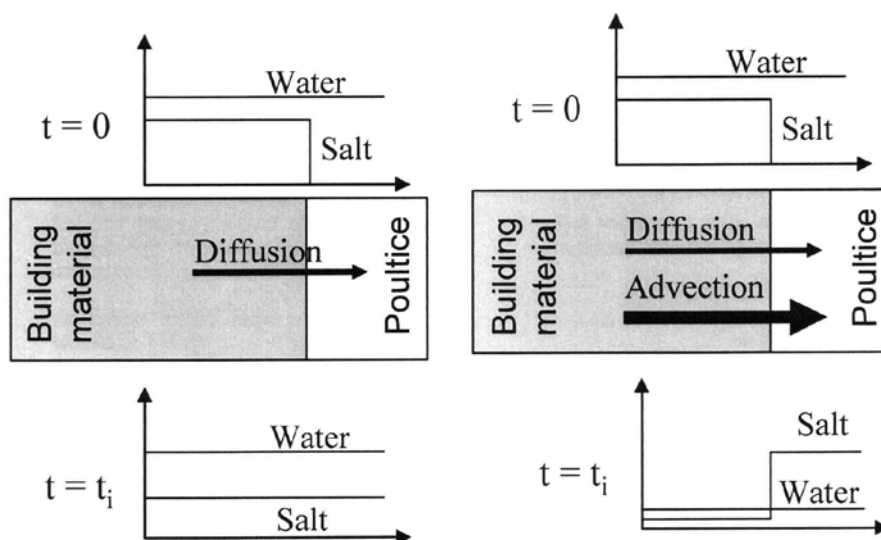


Figure 2: Functional principles of poultices: wet poultice (left), drying poultice (right). From WTA-Recommendation 3-13-01/E.

2.3 Poultice materials

2.3.1 Field experiments

A variety of materials has been used to prepare poultices. In most cases cellulose fibres or mixtures of clay minerals and aggregates with or without addition of cellulose fibres are used (Ettl & Schuh, 1992; Klenz Larsen 2001). Frequently used clay minerals are montmorillonite (smectite, bentonite) or kaolinite, but also attapulgite, sepiolite and others are reported. Sometimes paper pulp, cellulose tissues or textiles are used.

Poultices must be very water absorbent. They have to retain water to a certain extent to regulate the evaporation velocity. They should also have high specific surfaces and a high ion exchange capacity to adsorb salts. In most cases effectiveness of salt extraction is higher for poultices containing clay minerals than for those containing only cellulose fibres (Fig. 3).

Poultices based on clay minerals are advantageous because they don't need a daily check, which is necessary for cellulose containing poultices to prevent mouldiness. On the other hand, poultices made up of cellulose fibres have advantages: on fragile surfaces they are the first choice because they are soft, easy to handle and because they can be removed from most surfaces without residue.

Hopp & Zier (2005) report interesting results from tests with textile poultices which were used to extract salts from mortars of brick masonry. The extent of salt extraction was quite similar whether textile strings or bentonite poultices had been applied in the joints. The advantages of the textile strings were their simple use, their residue free removal and the possibility to re-use them after washing out the salt content.

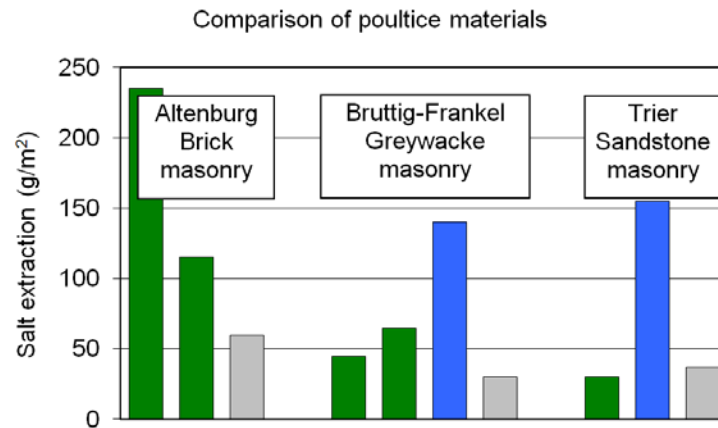


Figure 3: Comparison of salt extraction by different poultice materials: bentonite (green), kaolinite (blue), cellulose fibres (grey). Results of field experiments on masonry made of brick (Altenburg, sum of 2 poultice cycles), greywacke (Bruttig-Frankel, 1 cycle, data from Egloffstein & Auras, 2000) and sandstone (Trier, 2 cycles, data from Auras & Melisa, 2002).

2.3.1 Laboratory tests

Figure 3 shows the results of three field tests with different poultice materials. The diagram shows that kaolinite seems to work somewhat better than bentonite. To confirm this, laboratory tests have been carried out in a cooperative project with the University of Weimar (Goretzki & Terheiden, 2003). Sandstone prisms were first immersed in saturated solutions of different salts. The prisms were then sealed on five sides and on the sixth side they were covered by a poultice. Evaporation could only take place from the side with the poultice. After several weeks the weight of the samples remained nearly constant. The poultices were then taken off and their salt content was analysed. The sandstone prisms were cut into slides and their salt content was analysed at different depths. The results showed that the difference between kaolinite and bentonite depended on the kind of salt used. Figure 4 shows two exemplary diagrams.

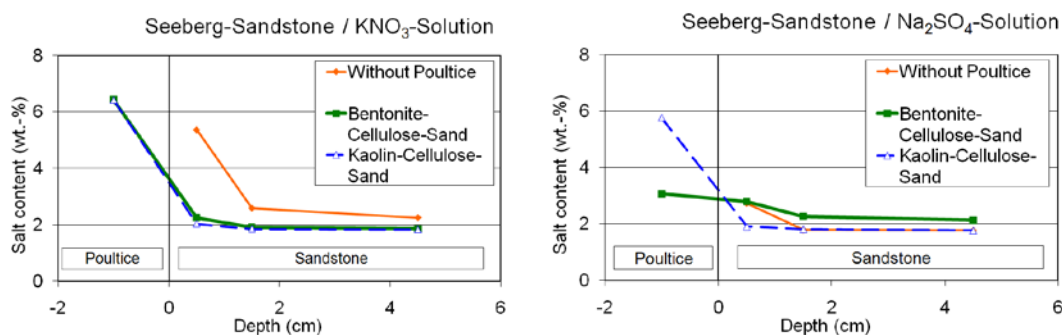


Figure 4: Extraction of different salts from sandstone prisms by kaolinite and bentonite poultices (data from Goretzki & Terheiden, 2003).

In the next step, with a similar test set-up as described for figure 4 some variations of the mixture of kaolinite poultices were tested. Two commercial poultices on base of bentonite (Nr. 2) and kaolinite (Nr. 3) were included. For the other poultices the proportions of kaolinite, cellulose and sand were varied systematically (table 1). In two poultices quartz sand was replaced by pumice. Also two types of cellulose fibres have been compared: According to the manufacturer's indication, Arbocel BC 1000 has an average fibre length of 700 μm and a water absorption of 990 wt.-%. For Arbocel BWW 40 the fibre length is 200 μm and the water absorption is 580 wt.-%. After 6 weeks of evaporation, the salt content of the poultices was determined by electrical conductivity of aqueous eluates. Additionally tests on leaching and washing out pumice have been carried out to exclude an influence of soluble ions set free from pumice. Figure 5 shows minor variations of the poultice mixture having minor influence on the result of salt extraction. The replacement of sand by pumice, however, has a significant effect.

Nr.	Kaolin	Arbocel BC 1000	Arbocel BWW 40	Quartz sand 0-2 mm	Pumice 1-2 mm
4	1	1		6	
5	1		1	6	
6	1		1	5	
7	1		1	4	
8	1		2	6	
9	2		1	6	
10	1			3	
11	1				3
12	1		1		6

Table 1: Composition of poultices shown in figure 5.

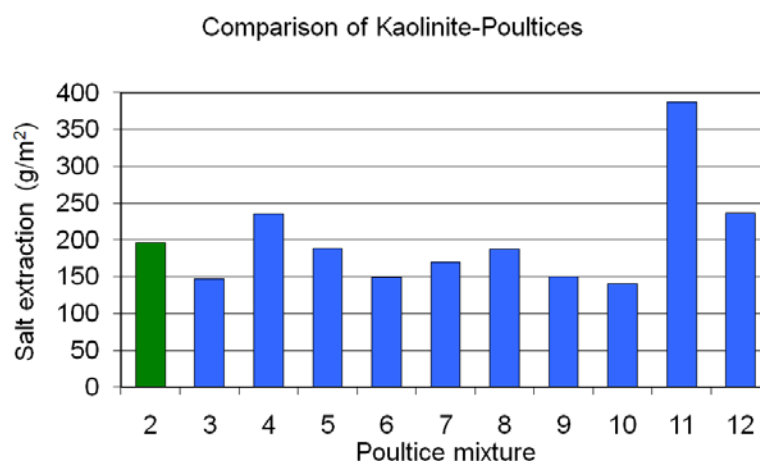


Figure 5: KNO_3 content in kaolinite poultices of different compositions after drying of salt contaminated sandstone prisms in laboratory tests. Number 2 and 3 are commercial bentonite and kaolinite poultices. The composition of the other poultices is given in table 1.

In the same project some measurements of pore size distributions of bentonite and kaolinite poultices at various water contents have been carried out at the Geological

Institute of the University of Karlsruhe. Both poultices had been composed of similar proportions of quartz sand, cellulose fibres and bentonite or kaolinite. In Figure 6 for each material and water content two curves are drawn to show the scatter of single measurements. Despite this variation some observations are possible. The main difference between the two poultices seems to be a distinct change of total porosity and pore radius distribution of the bentonite poultice during drying. Especially the pores of micrometer size vanish. The pore radius distribution of the kaolinite poultice in the wet state is similar to the bentonite poultice but total porosity is lower. Unlike bentonite the pore size distribution of the kaolinite poultice remains nearly constant during drying and the pores of micrometer size remain stable. Because the small pores exert high capillary pressure it is expected that the soaking of moisture from the stone into the kaolinite poultice remains active at low moisture content during drying.

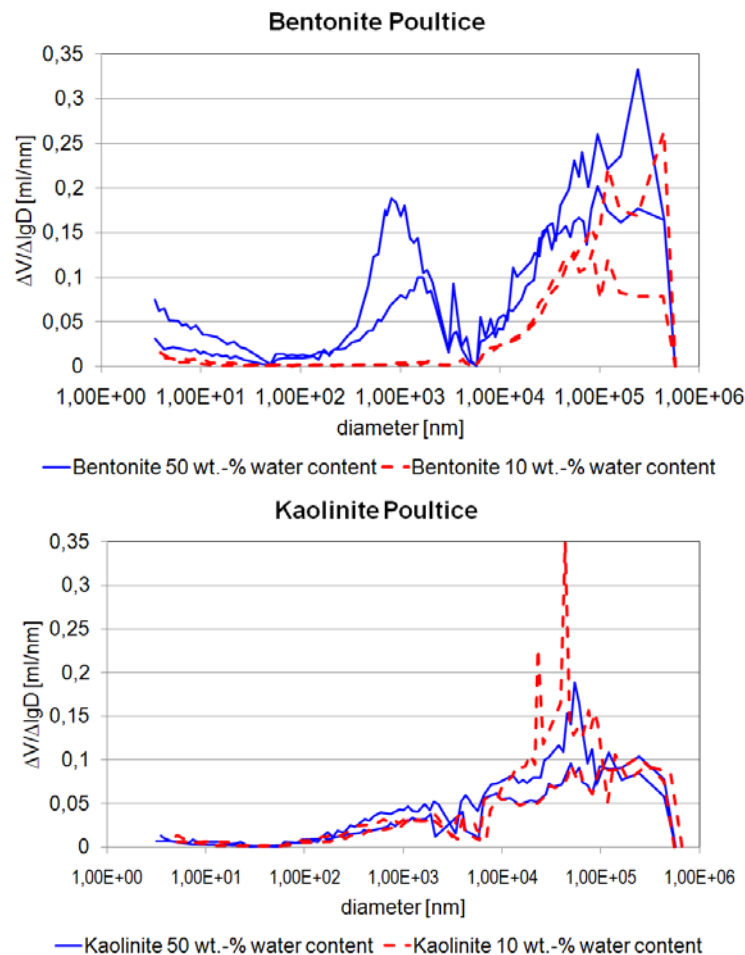


Figure 6: Pore size distributions of bentonite (upper) and kaolinite poultices (lower diagram) of different moisture content. Two of four measurements for each material and moisture content are shown. Data: Geological Institute of the University of Karlsruhe.

The role of different mineral compounds in desalination poultices was examined in a qualitative mineralogical approach by Richardt (2002). She tested poultices of cellulose fibres mixed with kaolin, bentonite, allophane, sepiolite, zeolite and hydrotalcite treated with solutions of sodium chloride and nitrates of potassium, sodium and calcium, respectively. While zeolite, hydrotalcite, bentonite and sepiolite are able to bind salts by intracrystalline bonding, kaolin and allophane adsorb salts on their mineral surfaces. In the case of intracrystalline bonding, various mechanisms can

be distinguished: Bentonite and sepiolite bind ions and neutral molecules by adsorption between crystalline layers. Zeolite is able to integrate certain ions or molecules in its cage-like crystalline structure. Hydrotalcite exchanges carbonate from its crystalline interlayers for nitrate. Based on her experiments Richardt (2002) concludes that the effectiveness of hydrotalcite and zeolite is better than that of allophane, bentonite, kaoline or sepiolite. When salts or certain anions get fixed in the crystalline structures of zeolite or hydrotalcite they are eliminated from the continuous aqueous salt solution. So the concentration gradient between stone and poultice remains high and desalination can proceed. Further research on this topic would be appreciated. Richardt (2002) also points out the influence of the pH value in the poultice material on adsorption of ions by clay minerals. With sinking pH values adsorption of anions increases while the adsorption of cations declines.

2.4 Other factors influencing salt extraction

Porosity and pore size distribution of the substrate also have a great influence on the salt content of the stone and on the effectiveness of desalination. This can be shown at the crypt of the church of Saint Goar, where salt loaded columns built of different stone types were treated with bentonite poultices (Fig. 7). Wendler (2007) points out that salt gets extracted much better from substrates with large pores compared to materials with fine pores.

Other important factors influencing salt extraction by poultices are climatic conditions and surface properties of the substrate (pollution, coatings, stone conservation agents).



Figure 7 (left): Salt reduction at a column in the crypt of the church of St. Goar. Numbers show the amount of salts extracted by the first two cycles of bentonite poultices.

Figure 8 (middle): Application of different types of poultices with a plastering machine (from Egloffstein & Auras, 2000).

Figure 9 (right): Desalination of joints with bentonite poultice.

2.5 Application

Some experiments have been made with the application of poultices by plastering machines (Egloffstein & Auras, 2000; Auras & Melisa, 2002; see also Fig 8). While manual application is preferred for sculptures and other pieces of art, application by plastering machines allows the treatment of larger parts of a building.

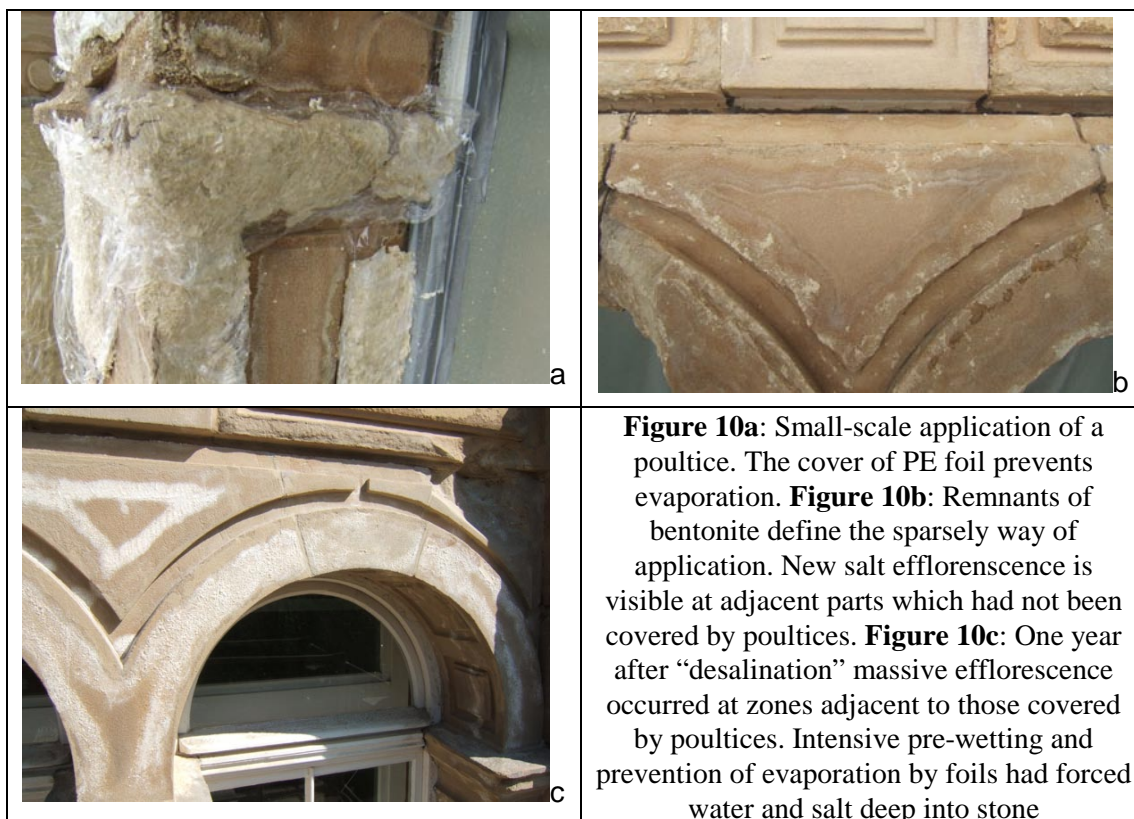
Sometimes residues of clay minerals remain on the stone surface when the poultices are removed. Especially particles of kaolin can adhere persistently to the substrate and hamper cleaning. An intermediate layer of Japanese paper or cellulose fibres can be applied between stone and clay poultice to prevent remnants of clay minerals adhering to the surface of the treated stone.

Special care must be given to the contact between poultice and substrate. If the poultice detaches from its substrate the capillary contact is interrupted and the salt transport into the poultice is stopped. Admixtures of methyl cellulose can enhance the adhesion on the substrate but also increase the risk of mould.

If the building stone is quite dense and the mortar has a high capillarity, salt will be predominantly accumulated in the mortar. In these cases it might be adequate to extract salt from the mortar joints only. Such an approach was tested successfully at the Rentamt of Worbis, where masonry made up of dense limestone had been built with gypsum mortar. This mortar was contaminated with up to 4.1 wt.-% of nitrates and up to 0.5 wt.-% of chlorides. Joints were desalinated by bentonite poultices as shown in figure 9. Poultice samples have been eluted with water and the electrical conductivity of the solutions was measured by Hinrich Rademacher (Rademacher, pers. comm.). The results of these measurements were recalculated to salt contents of the poultice samples and to the amounts of salts extracted by the poultices. Depending on the varying salt loads of the different parts of the building, salt extraction rates between 100 and 1000 g salt per square meter of joint were measured. After salt extraction the repointing and rendering was carried out with a renovation mortar according to WTA (see below). After 6 years, a visual inspection was carried out. The facades were found in a very good state with a little loss of paint at a few spots where salts had migrated to the surface again.

Application of poultices should not be too small-scale. A zone of some decimetres around a visible salt contamination should be covered by poultices. Otherwise a lateral transport of the salts in adjacent regions can take place (Fig. 10a, b).

It is important to prevent very intensive pre-wetting: In several cases too much water was brought into the stone by pre-wetting and by wet poultices. Water as well as salts dissolved in the water can be transported deep into the interior of the stone by capillarity. It can take several months until this salt is transported back to the surface. Usually at this time restoration work has finished, scaffolding is removed and the shock about the “new” salt efflorescence is big (Fig. 10c).



A critical check on the amount of removed salt is necessary. If only samples of the treated stone are taken, very low salt contents might be measured near the surface because the salt has soaked deep into the stone rather than been removed by the poultice. Therefore analyses of poultice samples are essential. The recalculation of the amount of extracted salts from poultice analysis allows a better evaluation of results. Before salt extraction, appropriate building operations must be carried out to stop the supply of water and salt. Otherwise, a short time the salt content might have returned to the same level as before.

It is strongly recommended to respect the advices given by the WTA-Recommendation 3-13-01/E, which is available in German and English language.

2.5 Modifications

Venzmer (2005) reports on microbial denitrification of masonry contaminated by nitrates. Denitrifying bacteria are able to reduce nitrates to nitrogen or nitrogen oxides which escape as gases. These bacteria are brought into the surface of porous stone or brick with the help of textile poultices. Anaerobic conditions are necessary. Up to now this interesting approach still seems to be in an experimental stage.

The combination of poultices with electrokinetic methods was tested in two field experiments (Auras & Melisa, 2002). Sandstone masonry was treated at Trier and brick masonry at Weilerbach. Titanium mesh was used as electrodes which were embedded into poultices of bentonite-cellulose-sand. A DC field was applied for about four weeks, voltage and current were measured every hour. Evaporation of water was prevented by PE foils. After four weeks the DC field was switched off and the PE foil was removed. The poultices remained on the walls for three more weeks to allow advection of salt solution and salt crystallisation in the poultices during drying.

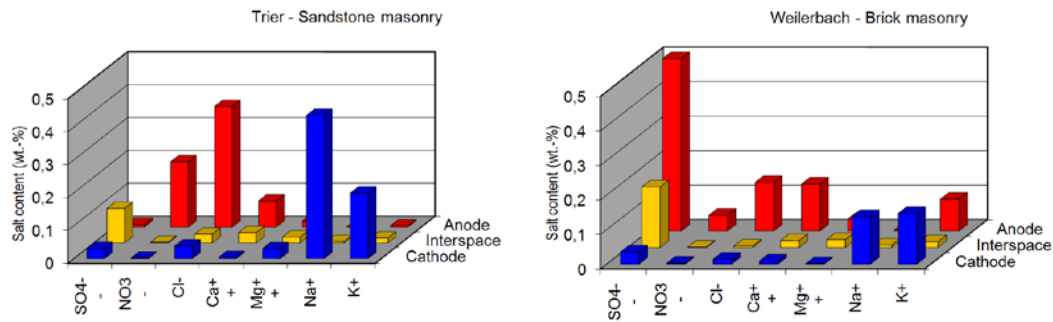


Figure 11: Salt content of bentonite poultices after electrokinetic supported desalination at the church of St. Augustine at Trier (left) and a chimney of Weilerbach Castle (right; data from Auras & Melisa, 2002).

Salt extraction showed quite encouraging results but the ionic distribution in the poultices was somewhat surprising (Fig. 11). Both objects, sandstone and brick, contained complex salt mixtures which can be described as mixtures of magnesium sulphate, potassium nitrate, sodium chloride and minor gypsum. The proportions of ions varied locally. At Trier the best extraction results were achieved for sodium, chloride, potassium and nitrate ions while only minor parts of the calcium, magnesium and sulphate ions could be removed. Part of the nitrate was reduced to nitrite. At Weilerbach, however, mainly sulphate, followed by potassium, sodium, chloride and calcium were extracted, but only minor amounts of magnesium and nitrates. The method seems to work ion-selectively with best results for chloride and alkaline ions while only a minor part of magnesium ions could be extracted. Ultimately serious disadvantages prevented further research:

- The method requires intensive wetting and moisture penetration deep into stone.
- The voltage used was very high and discolouration by oxidation of ferrous materials in the masonry occurred.
- The titanium electrodes were partially oxidized to TiO₂ which led to tenacious white stains on the stone surface.
- The high voltage caused hydrolysis and extreme pH values between 3 and 10 in the surrounding of the electrodes. Especially the very low pH values near the cathode gave rise to concern about further deterioration of the stone surfaces.

Further tests with lower voltage under laboratory conditions would be necessary to enable a detailed evaluation of the method.

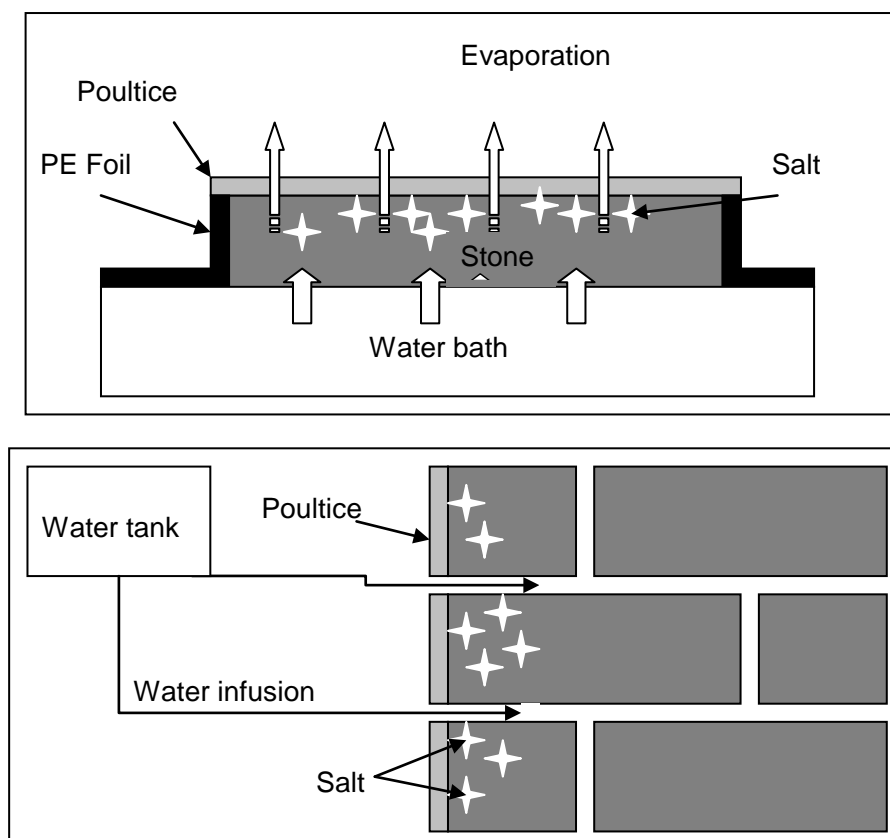


Figure 12: Pictorial schematics of unidirectional water transport through stone objects into a poultice from water bath (upper picture) and by water infusion (lower picture).

The most effective enhancement of salt extraction by poultices seems to be the installation of unidirectional water transport through the stone into the poultice. Figure 12 shows pictorial schematics of some possible variations. Examples have been published by Ettl & Schuh (1992), Friese & Hermoneit (1993) and Siedel (2005). Also, if salt is extracted by immersion in a water bath it is recommended to apply poultices during evaporation.

3. Mortars and renderings for salt contaminated masonry

3.1 Soluble salts in new mortars

Often salt extraction by poultices or other methods is impossible. Especially in the case of salt contaminated masonry the replacement of mortars and renderings is one of the frequently used methods to minimise deterioration by salts.

In building preservation, the alkali and sulphate contents of new mortars should always be checked to minimize the input of new soluble salts into a historic building or monument. Cementitious mortars always contain soluble sulphate ions. Gypsum or anhydrite is added during the cement production to slow down the setting of the cement. Also alkali and calcium ions are soluble compounds of cementitious materials. The alkali content of cement can vary over a wide range. Addition of certain pozzolanic compounds like trass can increase the content of soluble alkalis

considerably. On the other hand, high calcium lime contains only traces of alkalis and sulphates. Examples of representative analyses are given in table 2.

Binder (Euronorm label)	Na ⁺	K ⁺	SO ₄ ²⁻
High calcium lime (CL 90)	n.d.	n.d.	26
High calcium lime with low hydraulic compounds (CL 80)	9	62	35
Natural hydraulic lime (NHL 2)	9	233	106
Natural high hydraulic lime (NHL 5)	15	302	188
Mixture of lime (CL 90) and low alkali Portland cement (CEM I 42,5 HS-NA) in the ratio 1:1	28	113	300
Mixture of lime (CL 80) and Portland cement (CEM I 42,5) = 1:1	56	173	791
Portland cement (CEM I)	53	136	1230
Cement-bearing hydraulic lime (HL 5) with rhenish trass	203	346	767

Table 2. Proportions of soluble alkali and sulphate ions in new mortars (in mg/kg; n.d.: not detected; data from Kraus, 2002).

3.2 Cementitious renovation mortars

For about 30 years, cementitious renderings designed especially for masonry contaminated by salts have been available. In Germany they are called renovation mortars according to WTA because their properties and application are defined in the WTA-Recommendation 2-9-04/D and many of these products are certified by WTA (www.wta.de). According to WTA, renovation mortars and renderings have got a very high porosity of about 50 vol.-% and most of this porosity consists of very large pores. Usually a system of two layers of rendering are combined, the upper one with water repellent admixtures. The functional principle is that a salt solution slowly enters the interior layer of the rendering and is stopped at the contact to the upper layer. Water evaporates and escapes by water vapour diffusion while the salts crystallise in the large pores. The surface of the rendering remains dry and free of salt efflorescence or new damage. The cementitious binding material makes these mortars and renderings insensitive to salt crystallisation.

So far the theory. In practice, these renderings often work successfully for a long time if the supply of water and salt is low. But if water availability remains high, evaporation in the pore space and water vapour diffusion through the pore space is not able to remove all the water. In this case, the water content in the masonry can increase slowly until humidity rises over the zone rendered with these materials. Then humidity, salt solutions and damage reach zones further up in the facade which had often been intact before (fig. 13). The newly added material, i.e. the renovation mortar remains intact while the historic and often original materials get destroyed. Furthermore, if water supply is rather low but salt content is very high, new damage can occur in the form of spalling or flaking of the new rendering (fig. 14).



Figure 13 (left): Humidity and salts ascend behind a cementitious renovation rendering and now have reached the zone above the newly rendered basal zone.

Figure 14: Porous renovation rendering spalled off the wall by efflorescence of mirabilite.



Figure 15 (left): The wall is covered with a water-repellent rendering, deteriorated parts of the sandstone elements had been replaced by dense cementitious mortar. The sandstone frame is the only place where water can evaporate, so transport of water and salt is redirected into the sandstone. Severe damage is the result of the high concentration of salt in the sandstone.

Figure 16 (right): Deterioration of sandstone in contact with cementitious repointing mortar.

Another problem arises on facades where rendered areas are combined with unrendered parts like ashlar or door frames of sandstone or other materials of high capillarity. On surfaces covered by hydrophobic plaster the evaporation of moisture can only proceed slowly by water vapour diffusion through the pore space of the plaster. In sandstone, moisture is transported much faster to the surface by capillary forces and evaporation takes place at the surface. As a consequence the transport of water and salt in the masonry is redirected into the zones with high evaporation rates. After a while salts get enriched in these uncovered sandstone elements, and deterioration proceeds in an accelerated way (Fig. 15).

3.3 Lime mortar

Many historic monuments are built with lime mortar. Characteristics of lime mortars are their high capillarity and limited strength. In comparison, cementitious mortars

usually are denser and stronger. Repointing often is carried out with dense and hard cementitious mortars. In many cases they are put on the surface of joints filled with porous, weak and capillary active lime mortars which were used as original building material. Water transport from the interior parts of a wall to the surface is reduced. In such cases water and salt usually find a way through the stone alongside the joint if the stone is porous. This can lead to severe damage of the stone in contact to the joints (Fig. 16).

On the other hand, mortars and renders made up of non-hydraulic lime are easily susceptible to deterioration processes caused by salts. This can be seen at many historic buildings. Lime renderings on wet and salt contaminated walls can show discolouration, moisture stains, salt efflorescence and strong sanding. Especially renderings made of high calcium lime often show accelerated weathering after a short time. Sometimes they are used as sacrificial layers. Various types of sacrificial layers designed to buffer different kinds of deterioration or damage are defined in the WTA-Recommendation 2-10-06/D.

In the last 15 years, natural hydraulic limes (NHL) experienced a certain renaissance in building preservation. Their high capillarity can also lead to water stains or discolorations if they are applied on masonry with elevated moisture content. Nevertheless, in many cases they showed very good results, some of which are reported in the following paragraphs. Sometimes water stains and discolorations might be accepted if only basal zones are affected, because these zones can be repaired easily. This aesthetic problem is less pronounced if lime mortar is not used for rendering but for repointing, because most historic facades made up of natural stone or brick show a broad variety of colour nuances.

At Hardenburg Castle, large areas of sandstone masonry had to be repointed in the 1990s. Most of the masonry was contaminated by salts, predominantly nitrates (Fig. 17). Because very large areas had to be treated, repointing by machine was preferred to manual application. In many similar cases where mortars based on cement and trass had been used, severe damage of sandstone blocks had been observed after years because these mortars had been very dense and strong. Therefore it was decided to work with lime mortar.

Repointing was carried out as shotcrete, but for the first time – at least in our region - a NHL mortar instead of cementitious mortar was used in this way. Brick-dust was added to obtain a reddish colour correspondingly to the sandstone. Samples taken from a test area were examined. The high pressure application led to an intensive compression of the mortar which in turn gave rise to an increase of compression strength up to about 5 MPa after 28 days of curing. After more than 10 years a detailed inspection was carried out. Some problems had occurred at the wall crest. These seem to be caused by thermal effects and the absence of expansion joints. On the whole the mortar and the masonry was in a good condition. In salt loaded areas salt efflorescence occurred predominantly on the surface of mortars but only to a minor extent on sandstone surface (Fig. 18). It is evident that porosity and capillarity of the lime mortar is still there despite the high pressure application. But due to this application the strength of the mortar is high enough to withstand salt crystallisation until now.



Figure 17 (left): Sandstone wall from Hardenburg Castle with salt efflorescences and hygroscopic moisture stains.

Figure 18: Salt efflorescence occurs predominantly on the surface of repointing mortar.

As another example, Stolzenfels Castle should be mentioned. On the ruins of a mediaeval castle a summer residence for the later King of Prussia, Friedrich Wilhelm IV, was built in the years 1832 – 1842. Mortars used both in the Middle Ages and in the 19th century are mixtures of hydraulic lime with an aggregate of sand, greywacke fragments and large amounts of pumice. The latter gives rise to nearly omnipresent efflorescence of sodium sulphate, since sodium is extracted from pumice wherever water penetrates the masonry. Most of sulphate probably was deposited as air pollutant as the Rhine valley in which Stolzenfels is situated was an important travel way for cars, trains and ships and correspondingly air pollution was quite high in the 19th and 20th century. Part of the sulphate even might originate from the oxidation of pyrite which is an accessory mineral in the greywacke used as building stone. In the garden wall, which is focussed here, additionally high amounts of nitrates are present. The garden wall is several meters high and about 2 m thick. Its crest had been leaking for many years. Water penetrated the wall and led to salt efflorescence and severe damage on renderings and sandstone elements (fig. 1).

Because actual reinstatement work outside the garden will take about a year, the salt contaminated render from the 19th century was taken off to enhance drying of the wall and the wall crest was protected against rain by a tentlike roof. While drying, the wall is covered by a NHL render which was applied as a sacrificial layer (Fig. 19). Parts of the medieval plaster are preserved under the NHL plaster. Between historic and sacrificial rendering a paint of slaked lime was applied to allow easy removal of the sacrificial layer. After seven months some samples were taken from the sacrificial layer to check salt ingress. Figure 20 shows that at different parts of the wall various proportions of alkaline nitrates, sulphates and chlorides had migrated into the sacrificial layer.

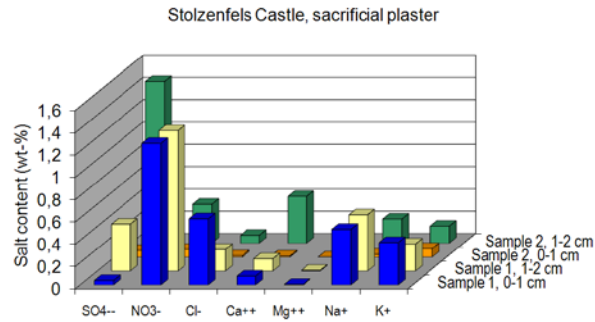


Figure 19 (left): Garden wall of Stolzenfels Garden protected by a sacrificial rendering of NHL mortar.

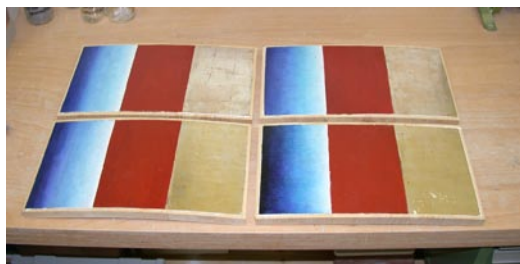
Figure 20 (right): Salt content of sacrificial lime rendering after seven months.

In zones with new efflorescence or hygroscopic moisture, amounts of salts between 80 and 800 g/m² are found in the upper centimetre of the lime render up to now. After removal of the sacrificial layer the walls will be repointed and rendered either with modified kinds of renovation mortar according to WTA or with NHL mortar, depending on their specific salt and moisture content. The final layer will be NHL renderings whose colour, grain size and surface structure is adapted to the different kinds of historic renderings. In many zones with less pronounced moisture and salt load, historic renderings will be preserved and complemented with NHL mortar.

4. A look into another field of conservation: Salt extraction from a mediaeval painting

The painting “Crucifixion of Christ” from the church of Falken was painted about the year 1420. The substrate of the painting is a panel of spruce wood on which a canvas lining is mounted. The canvas is coated with a glue bonded chalk ground on which the paint layer is applied. Efflorescence of magnesium and calcium sulphates had been observed in the 1970s. The salts were supposed to have migrated onto the wooden panel from the damp wall on which the painting was fixed. During a first restoration in the 1970s a gypsum coating was applied on the back side of the panel (Wehrsig, pers. comm.). In 1999 new damage of the paint layer and water stains were observed. Additional to gypsum, significant amounts of nitrates were detected in the back side coating. Crystallisation of salts had caused the separation of parts of the paint layer from the grounding. On the back side the gypsum coating had detached from the wood in big flakes (Wehrsig, pers. comm.).

During the recent restoration the future of the painting had to be considered. Stabilisation of the indoor climate was impossible for financial reasons. So methods to reduce the salt content of the painting and its wooden panel had to be taken into consideration. The gypsum coating had to be removed to prevent further migration of salts through the wooden panel into the paint. The idea came up to use a new coating on the back side as poultice to extract salts from the wooden panel. The exchange material should have small pores (high capillary pressure) and low strength. Some research was done to find a material suitable as a coating. Details about the painting and its restoration will be published elsewhere (Wehrsig et al., in prep).



Kaolin-Cellulose-Pumice	20.5 g Cellulose fibres
	45 g Kaolin
	240 g Pumice
	274 ml H ₂ O
Kaolin-Tylose	40 g Kaolin
	50 ml Tylose solution (0.5 wt.-% in H ₂ O)

Figure 21: Dummies for desalination tests.

Table 3. Composition of the coatings tested on dummies.

Various materials were tested as back side coating suitable for salt extraction. Finally test specimen of wooden panels with canvas, chalk grounding and different paint layers were prepared by Wehrsig (Fig. 21). Silver gilding was selected as the material with lowest permeability, red egg tempera correlated best with the original paint and a blue and white field of tempera and watercolour simulated the retouching of the 1970s. These dummies were contaminated with a saturated salt solution which contained a mixture of ions similar to the one found in the old coating. After drying two materials which had performed best in the pre-tests were applied on the back side of the dummies. The compositions of the two coatings are given in table 3.

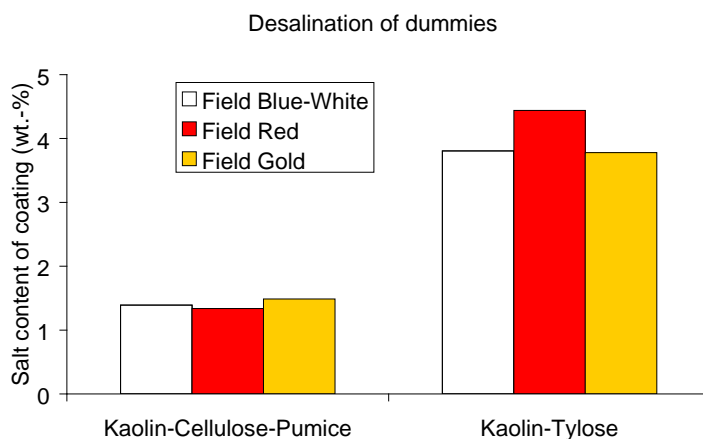


Figure 22: Salt content in the coating of dummies.

After a drying phase of several weeks under laboratory conditions (23°C / 65 % rh) the coatings were removed from the dummies and their salt content was analysed. From the results shown in figures 22 and 23 it becomes evident that kaolin with tylose worked better than the coating composed of kaolin, cellulose fibres and pumice. About 60 wt.-% of the extracted salt was nitrate. The sort of paint layer on the front had a minor influence on the salt reduction.

Based on these results a new kaolinite-tylose back side coating was applied in 2005 when the painting returned to the church after restoration. In 2006 and 2007 samples of the coating were analysed (Fig. 23). A continuous migration of salts from the wood into the coating was observed, and so the coating was exchanged again in 2007. The state of the painting and the progress of desalination have to be controlled thoroughly for the next years.

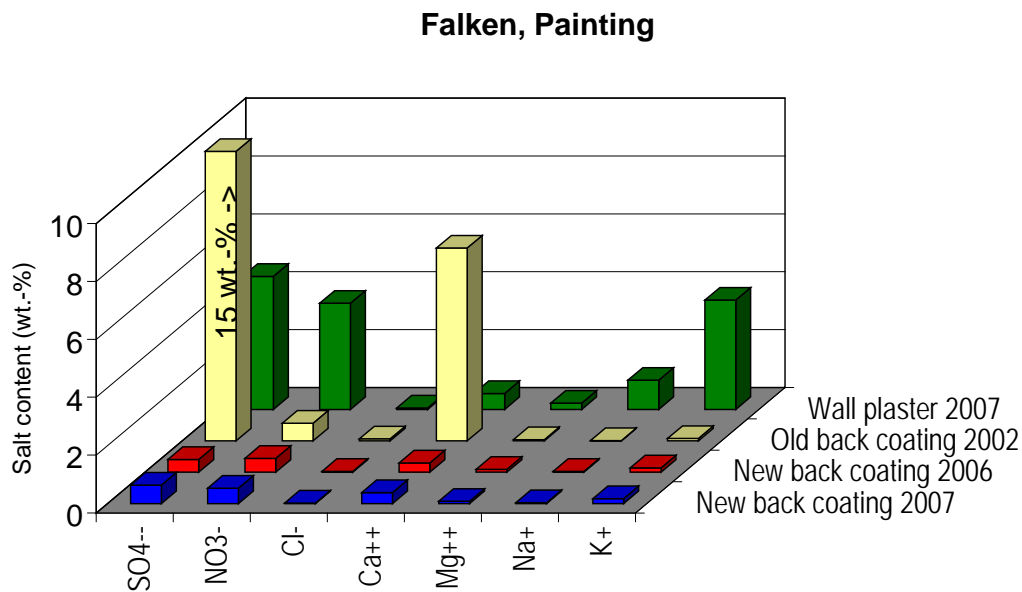


Figure 23: Salt content in the wall plaster and in the old and new backside coatings of the painting.

4. Conclusions

Salt reduction by application of poultices needs careful application and regular control. Waiting time is long. Because the method is time-consuming and not easy to handle it should be used preferentially in restoration of sculptures or high-value objects by conservators. Even if the application by plastering machines allows a treatment of large areas, working with poultices often conflicts with the pressure of time and costs which is typical for building operations.

Functional principles of poultices and the relevant conditions of their application are outlined in the WTA guideline 3-13-01/D. Fragile surfaces should be treated with poultices of pure cellulose fibres only.

The role of mineral compounds in poultices needs further research. The different minerals are able to bind salts in various ways as shown by Richardt (2002). Only poor data exist on the influence of these compounds on the efficiency of salt extraction. Also more information is needed on pore size distribution of poultices and its change during drying. Both factors, mode of salt binding as well as pore space characteristics, are suggested as playing key roles regarding the efficiency of salt extraction. Most of the mineral compounds seem to act more or less ion-selectively, suggesting case-related choice of poultices.

The best way to enhance the efficiency of salt extraction is the combination of poultices with water advection from the rear side through stone into poultice (fig. 12).

The method of salt extraction by poultices can be transferred into other fields of conservation as shown by the example of the painting from Falken.

If mortars with cementitious or pozzolanic compounds are used in conservation, their content of soluble alkali and sulphate ions has to be considered.

Cementitious renderings with high porosity and water repellent admixtures can provide sound surfaces for many years if the supply of water and salt is cut off by appropriate measures. The effect of salt extraction is less pronounced for these

materials, their primary function is covering those problems. Severe damage can occur if rendered zones are combined with uncovered elements of porous building stones within a facade. Transport of moisture and salt then is redirected into the zones where evaporation is less hampered.

Mortars and renderings made up of air-lime are not resistant against salt crystallisation. They can be used as sacrificial layers protecting surfaces of high value from deterioration by salt crystallisation for a limited time.

If moisture and salt loads are confined to small basal zones of a building and if a possible repair is accepted by the client, lime mortars can be used. Lime mortars can extract salts from the masonry. Compared to cementitious materials they can be removed easily from masonry without remnants.

Especially NHL mortars should be considered as an alternative to cementitious mortars. They do not reduce evaporation significantly and are able to incorporate salts in their pore space. Replacing the mortars from time to time extracts part of the salt from the masonry. Depending on the composition and the kind of application they can get strong enough to withstand salt crystallisation for a long time.

Acknowledgement

Thanks to Algis Wehrsig, Ortrud Wagner, Gabriela Melisa, Petra Egloffstein, Karin Kraus, Holger Reinhardt, Reinhold Elenz, Lothar Goretzki and Hinrich Rademacher for confidential cooperation. Many thanks to Christiane Auras, Claudia Gerner-Beuerle and Tim Padfield for their help with the manuscript. Part of the work was supported by funding from the Deutsche Bundesstiftung Umwelt, which is thankfully acknowledged.

References

- Auras, M. & Melisa, G. (2002): Kompressenentsalzung – Wirkungsprinzip, Materialien, Anwendung, Fallbeispiele. In: Salze im historischen Natursteinmauerwerk. Institut für Steinkonservierung e.V., Mainz, IFS-Bericht Nr. 14, p. 41 – 52.
- Egloffstein, P. & Auras, M. (2000): Kompressenentsalzung – Ein Materialvergleich. Institut für Steinkonservierung e.V., Mainz, IFS-Bericht Nr. 10, 63 – 74.
- Ettl, H. & Schuh, H. (1992): Entsalzungsversuche an Sandsteinen - Umweltbedingte Gebäudeschäden am Zisterzienserkloster Eberbach. Die Geowissenschaften, 10., Heft Nr. 9/10, 1992, 285-287.
- Friese, P. & Hermoneit, B. (1993): Entsalzung von Ziegelmauerwerk mit dem Injektionskompressenverfahren. Bautenschutz + Bausanierung, 16, 2/93, 26-27.
- Goretzki L. & Terheiden, C. (2003): Vergleichende Untersuchungen zur Wirksamkeit von Bentonit- und Kaolinitkompressen. Bauhaus-Universität Weimar, 8 pp., unpubl.
- Hopp, H. & Zier, H.-W. (2005): Abschlussbericht zum DBU-Projekt „Modellhafte Entwicklung einer innovativen Technologie zur komplexen Salzreduktion und zur Konsolidierung dieser Bereiche an stark umweltgeschädigtem Ziegelmauerwerk am

Beispiel der Stadtkirche St. Johannis in Gera (Thüringen).“ (AZ: 18427-45). Ingenieurbüro für Steinsanierung, Erfurt, 82 pp, unpubl.

Klenz Larsen, P. (2001): The Development and Testing of a Salt Extracting Mortar. Internationale Zeitschrift für Bauinstandsetzen und Baudenkmalpflege, 7, 79-90.

Kraus, K. (2002): Lösliche Alkalisalze in neuen Mörteln. In: Salze im historischen Natursteinmauerwerk. Institut für Steinkonservierung e.V., Mainz, IFS-Bericht Nr. 14, 11 – 18.

Richardt, K. (2002): Kompressenentsalzung - Mechanismen der Salzbindung an mineralische Zusätze. Diploma thesis, Institut für Mineralogie, Universität Hannover.

Sattler, L. (1992): Untersuchungen zu Wirkung und Dauerhaftigkeit von Sandsteinfestigungen mit Kieselsäureester. Dissertation, Universität München und Forschungsbericht 9/1992 des Bayer. Landesamtes für Denkmalpflege / Zentrallabor.

Siedel, H. (2005): Entsalzung von Naturstein - Methoden und Probleme. In: Siegesmund, S.; Auras, M. & Snethlage, R. (eds.): Stein / Zerfall und Konservierung. Edition Leipzig, 102-108.

Venzmer, H. (2005): Biokompresse. Huss-Medien, Berlin, Schriftenreihe Altbausanierung 9/10, 170pp.

Wehrsig, A., Wagner, O., Reinhardt, H. & Auras, M. (in prep.): Entsalzung des Tafelbildes „Kreuzigung Christi“ aus Falken mittels Rückseitenstrich. Arbeitsblätter des Thüringischen Landesamts für Archäologie und Denkmalpflege, Erfurt.

Wendler, E. (2007): Möglichkeiten und Grenzen einer Salzreduzierung durch Kompressen: Materialoptimierung und aktuelle Fallstudien an Naturstein, Ziegel, Putz und Wandmalerei. In: Grassegger, G., Patitz, G. & Wölbart, O. (eds.): Natursteinsanierung Stuttgart 2007. Fraunhofer IRB Verlag, Stuttgart, 29-37.

WTA-Recommendation 2-9-04/D (2004): Sanierputzsysteme. Wissenschaftlich-Technische Arbeitsgemeinschaft für Bauwerkserhaltung und Denkmalpflege e.V., München, 24 pp.

WTA-Recommendation 2-10-06/D (2006): Opferputze. Wissenschaftlich-Technische Arbeitsgemeinschaft für Bauwerkserhaltung und Denkmalpflege e.V., München, 18p.

WTA-Recommendation 3-13-01/E (2001): Non-destructive desalination of natural stones and other porous building materials with poultices. Wissenschaftlich-Technische Arbeitsgemeinschaft für Bauwerkserhaltung und Denkmalpflege e.V., München, 13 pp.