Desalination of Masonries and Monumental Sculptures by Poulticing: A Review

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Abstract

Desalination by poulticing, i.e. extraction of soluble salts through the application of a moistened absorbing material on the surface of the object/masonry to be treated, often leads to questionable results although the method is very commonly used in architectural conservation. In the following paper a review of the various poultice desalination techniques is presented in order to determine where the gaps of knowledge occur and what further studies and experiments are needed to improve our knowledge in that field.

Keywords: Salts, desalination, poulticing, efficiency

Entsalzen von Mauerwerk und Steinfiguren mit Hilfe von Kompressen: Ein Überblick

Zusammenfassung

Entsalzen mit Hilfe von Kompressen, das heißt das Auslaugen von in Wasser löslichen Salzen durch Anbringen von durchfeuchtetem absorbierendem Material an der Oberfläche eines zu behandelnden Objektes, wie zum Beispiel Mauerwerk, führt häufig zu fragwürdigen Ergebnissen, obwohl diese Methode oft beim Bauinstandsetzen verwendet wird. In diesem Beitrag wird ein Überblick über die unterschiedlichen technischen Varianten der Kompressenentsalzung geboten. Dabei wird gezeigt, wo es noch Wissenslücken gibt und welche Untersuchungen und Versuche notwendig sind, um unsere Kenntnisse auf diesem Gebiet zu vertiefen.

Stichwörter: Salze, Entsalzen, Kompressen, Wirksamkeit.

1 Introduction

Restorers, scientists and conservators have conceived, developed and sometimes validated many desalination methods. This issue has such an importance in the conservation field that hundreds of papers have been published on the topic, although review articles are scarce. In 2001, the journal Monumental has published an overview in French [1]. In the same year, the WTA association published in German a set of recommendations, focusing on poultice desalination [2]. The book "Mauersalze und Architekturoberflächen" [3] contains the most recent collection of papers in English and German, on desalination.

The following paper is only devoted to poultice desalination because this method, very commonly used in architectural conservation, has often produced questionable results. We have tried to go beyond the general state-of-the-art on desalination dating from 2002 [4].

2 A Brief Mention of Other Desalination Methods

Apart from poultices, methods proposed to deal with salt problems may be parted in three categories:

- Methods trying not to extract the salts but either insolubilize them or to reduce their effect by an intervention on the room climate. For treatments based on insolubilization by barium compounds, see the recent papers by Matteini [5] and Weber [6]; principles of intervention and practical examples of intervention on room climate can be found in [7-9].

- Methods trying to extract the salts from the substrate by diffusion (baths), electro-migration being sometimes proposed as an auxiliary, and convection (vacuum or water pressure extraction). An overview of the literature on these methods may be found in [4].

- Methods using microbiological reactions [10-12] or microwave ovens [13], which still remain at an experimental scale

3 Principle of Poultice Desalination

A poultice is made of one or several hydrophilic moistened materials and applied on to the object. The water penetrates from the poultice into the porous space and dissolves the soluble salts. The concentration difference between the salt solution within the object (high concentration) and the water contained in the poultice (low concentration) generates an outward ion movement (diffusion). The evaporation of water from the poultice to the surrounding air and the capillary transport from the substrate connected with this evaporation is another factor of salt migration. Finally salts may crystallise in the poultice if salt contaminated water can be driven properly into the poultice and if the drying front stays into the poultice during the evaporation phase.

3.1 Parameters

The three successive processes involved in poultice desalination - dissolution, diffusion and crystallisation - depend on several parameters.

3.1.a Moisture

The dissolution of ions in the object follows the same rules as in the bath method, but in this case, the quantity of mobilised salts depends on the depth of the moistened zone. Water which penetrates the stone comes either from a preliminary moistening, from a partial bath or another external source, and/or from the poultice itself.

- *Moisturising with poultice water*

In that case, the moisture does not go very deep into the material. For instance, water penetrates down to 2 cm in the Caen limestone after a 1.5 hour application of blotting paper [14]. This is in keeping with the capillary penetration coefficient of the stone ($2{,}3$ cm/h$^{0{,}5}$) [15]. In the crypt of the St. Marc Basilica in Venice, only two centimetres were desalinated following ten applications of cellulose powder poultice [16]. Promising experiments have shown that poultices which remained wet all over the desalination process could be more efficient than similar ones that were allowed to dry [17], but this subject is still under discussion. In the most recent reports, wet poultice desalination is considered as being less efficient than the dry procedure [2, 18]. Some poultices having a high water retention and low capillarity may dry very slowly (even if they are not kept wet) and thus ions will move towards the poultice by diffusion, which is a slow process, rather than being extracted with water from the substrate by capillary forces, a much speeder process. Consequently, desalination with such slowly drying poultices will be less efficient than with quicker drying ones[19].

It is even considered in some cases that salts may be driven inwards as a result of wet poultice desalination [20]. The latter effect, however, was also

observed with drying poultices [19, 21, 22]. Moisturising of a poultice while it is drying on the substrate should be avoided because it forces the salts in the poultice to move backwards again [23].

Unfortunately, experiences in this field are rather based on single case studies and a general applicable, theoretical well founded model is still lacking.

- *Direct moistening of the material*

For a better adhesion of the poultice to the substrate and dissolution of salts, several authors recommend moistening the surface prior to the application of poultices [2, 24]. Authors scarcely provide information on the amount of water, which will logically depend on capillary suction of the stone/mortar, concentration of the salts etc. [2]. Water quantities introduced in the case study quoted in [25] was very high: 200 l/h on 7 m^2 during several days, for a maximum desalination depth of only 10 cm.

- *Moistening by a partial bath or external sources*

Excellent results may be obtained on individual stones if the water is applied on one side and the poultice applied on the opposite side [21, 26-28] as illustrated in figure 1. This method is preferred to total immersion in a bath in the cases when the object cannot be immersed, as for instance if its shape is inappropriate, its surface is weak (presence of scales), or if the hydric dilatation of the stone is too high [21, 27]. One has to be cautious with this method because fungi may develop in certain cases [27, 29]. The method is normally restricted to objects that can be moved to the restorer's workshop. On objects such as columns, it was also applied in situ by applying the poultice on on side and permanently wetting the opposite surface [30].

A similar in situ-method has been developed for brickwork: water is injected through deep holes bored into the joints of the wall (Figure 2). Simultaneously, the salt contaminated water is sucked by poultices applied on the same side of the wall [31]. In a further case study, this method ("Injektionskompressenverfahren") has been modified for thin brick walls (24 cm) having a high salt load: in that case, additional poultices are applied on the backside of the wall [32].

Salt transport into the poultice may also be forced by the adjustment of a stable, but strongly different climate below and above thin brickwork vaults to be desalinated (high relative humidity vs. low relative humidity): in this case, the drying poultice
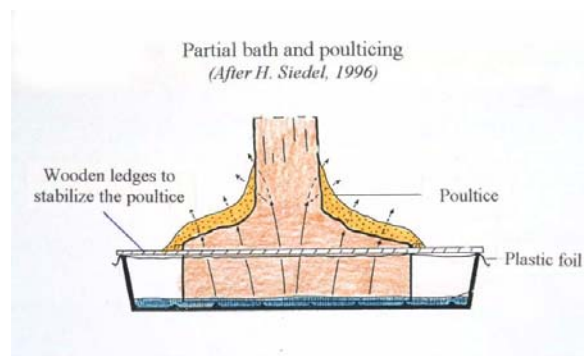

Figure 1: Desalination through partial bath and poultice, after Siedel 1996 [21]
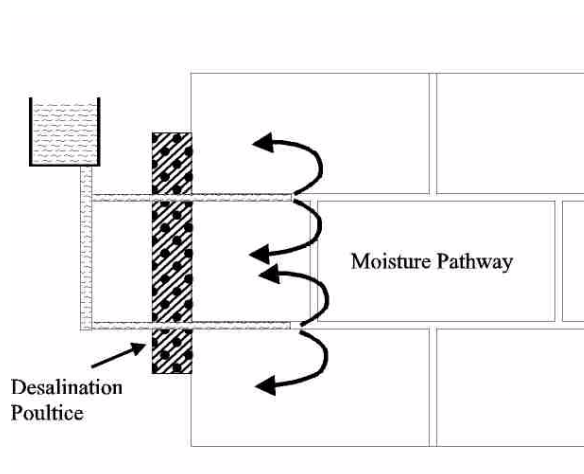

Figure 2: Water injection and poultice extraction ("Injektionskompressenverfahren") after Grassegger et al., 2003 [2]

layer is applied on the backside (above the vault, in a dry climate) to preserve wall paintings having high salt load [33].

If the conditions of the architecture allow it, a masonry may be moistened from the upper level and poultices applied on the ceiling below [34-35]. This procedure is quite risky for the structure of the building because mortars may be washed out [35].

3.1.b Poultice Composition

Among the tested materials (Figure 3), clays and cellulose compounds are most frequently used. Other compounds, either mineral (diatomite, fume silica, rock wool, viscose sponges or even lime in the case of sacrificial mortars) or organic materials such as ion exchange resins are less commonly used.
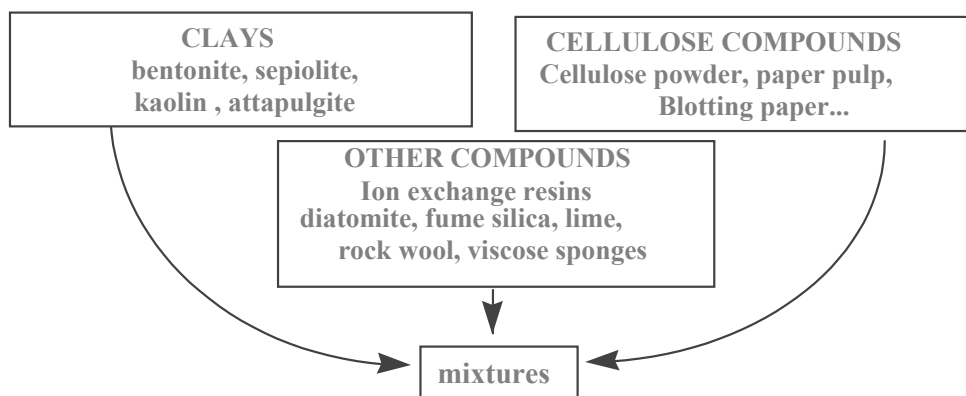
Figure 3: Materials used in poultices

• *Clays :*

Attapulgite, sepiolite, kaolins and bentonites, are often quoted in the literature, due to their good absorbing capacities and workability (Table 1).

Table 1: The literature on clay containing poultices

Type of Poultice	Quoted by
"clay"	[16], [25], [26], [36-37]
Attapulgite	[25], [36], [38], [39-41]
Sepiolite	[25], [35-37], [41-42]
Bentonite	[36], [41], [43]
Kaolin	[27], [37], [43]

Their good adhesion is appreciated, but sometimes poultice residues are left on the substrate after desalination due to this property. Therefore they are used mainly for objects without high value, like uncarved masonry [39]. Sepiolite applied on Japanese paper was tested on precious objects, but it proved to be less efficient than cellulose powder [42]. Montmorillonite and vermiculite are the most active clays, owing to their high exchange capacity. Unfortunately, they also happen to show the highest drying shrinkage, a property which enhances the risk of detaching fragile surface layers of the objects and of loosing too soon contact with the substrate.

Clay containing materials can become plastic, i.e. workable, above a certain water content called the plastic limit. This parameter varies from 57 to 123 w % from one clay to the other. As the water content increases, the material remains plastic until it reaches a point beyond which it behaves like a mud. This second water content is called the liquid limit. The difference between those two limits is called the plastic range. An attapulgite based clay, for instance, can become plastic at 100 w % moisture

content, and remain so until 200 %. All other clay minerals, except montmorillonites have a lower plastic range.

• *Cellulose compounds*

Paper pulp and cellulose powders are often used (Table 2), because they are easy and good to work with, although they take longer to prepare than clays. They also have the disadvantage of hardly retaining water and thus show poor adhesion in vertical situations. A study performed in the British Museum showed that blotting paper absorbs salt better than cellulose powder and filter paper [42]. Another study showed that crushed newspaper could be used as a basis for poultice in the case of masonry [37]. It must be noted that some papers contain salts and that paper pulp has a tendency to dry too quickly [27]. A direct comparison in different studies [44], [45] demonstrated that cellulose poultices are less effective than mixtures with clay compounds (see below).

Table 2: The literature on cellulose based poultices

Type of Poultice	Quoted by
cellulose (cotton wool)	[26], [46]
cellulose (powder)	[16], [26], [28], [38], [42], [47-48]
Absorbing paper	[38], [40], [46]
Blotting paper	[42]
Paper pulp	[26-27], [37], [46-47], [49]
Filter paper	[26], [42]
Newspaper	[37]
Wood sawdust	[26]

- *Other compounds*

Diatomite and fume silica are scarcely used [25, 36]. Other quite unusual materials like slaked lime [26], rice powder and talc [36] and even asbestos, a highly carcinogen substance [26] are also quoted. Viscose sponges applied in several cases [30-31] have the property of being able to be washed out and used again.

Ion exchange resins have been tested with some success [26], [50] but their use does not seem to be easy, because mixtures of cationic and anionic resins, although efficient, have a slightly acid pH [51].

- *Mixtures*

Many kinds of mixtures were tested (Table 3), but the specific action of each component is not clear. A cellulose/attapulgite mixture (2:1 by weight) is considered as having a good adhesion, good workability, and a low drying shrinkage [38]. Another mixture based on cellulose, bentonite and sand (1:1:6 by volume) is also considered as having low hardness and drying shrinkage [28]; the same components in a mixture 1:1:4 (by vol.) are called "quite suitable" with respect to shrinkage, drying behaviour and efficiency of salt extraction [19]. The use of cellulose with long fibres (0,7 mm) and medium-grained sand (0,5-1 mm) in mixtures with bentonite leads to a better adhesion of the poultice, compared with smaller fibres (0,3 mm) and coarser-grained sand (1-2 mm) [52]. Lombardo & Simon obtained good results by the use of a mixture with sodium zeolite which trapped the salts inside the mineral structure and removed them from equilibrium [19]. A mixture of sand and

Table 3: The literature on poultices based on combinations of several components

Type of Poultice	Quoted by
cellulose/sand	[24], [19]
cellulose/attapulgite	[38]
cellulose then mortar	[48]
cellulose/bentonite/sand	[28]
cellulose/bentonite	[28]
lime mortar	[25-26]
kaolin/sand	[26]
kaolin/paper	[27]
kaolin/cellulose/sand	[19], [24], [44]
cellulose/Na-zeolite-sand	[19]

fumed silica was selected for the desalination of polychrome sculptures in Mimizan [53]. In 1998, Domaslowski and co-workers published a book on the conservation of brick masonries [45], in which a chapter is devoted to desalination. This chapter provides very precise data on desalination technology, and one can find comparative measurements on different poultice recipes (Figure 4).

The tested parameters are adhesion, shrinkage, workability and desalination efficiency. This last parameter represents the quantity of salts extracted versus the quantity of salts originally present in the contaminated brick. Another coefficient has been set up, Wc, which represents the ratio of the weight of water to the weight of dry poultice (constituted either of a single material or of a mixture of different materials).

It can be seen that in the conditions of the experiment, poultices made only with cellulose materials are less efficient than those containing clays. The best results were obtained with a mixture of kaolin and sand having a weight ratio 1:5.

A comparative study of different poultice mixtures on stonework under practical conditions was published by Egloffstein and Auras [44]. They also found that pure cellulose poultices were less effective than mixtures of clay minerals with cellulose and sand. Best results were obtained with a mixture of kaolin, cellulose and sand (volume ratio 1:1:4) which also gave the best results in a further comparative case study [26]. A drawback mentioned for this mixture was the strong adhesion of poultice remnants after removal (formation of grey or white veils on the surface, [44]). Japanese paper can avoid staining of the substrate and increases adhesion of the poultice [19], [44], maybe at the expense of efficiency.

Rock wool has recently appeared as an additive to poultices based on sand, cellulose and attapulgite. Several outdoor masonries were even desalinated using rock wool alone as poultice material, with promising results [54]. This fibrous material provides a long lasting resistance to the poultice.

Mixtures based on lime may be of interest in cases when the poultice must remain on the object for some time. Such a sacrificial layer allows to wait for a restoration campaign to start. Properties of some additives are known, even if they are not quantified (Table 4).

A blotting paper, 10 layers
B cellulose powder, Wc =12
C cellulose powder, Wc =8,3

D kaolin:sand = 1:5
E kaolin:sand = 1:8
F kaol:cell. powd.:sand = 1:0,5:4,5

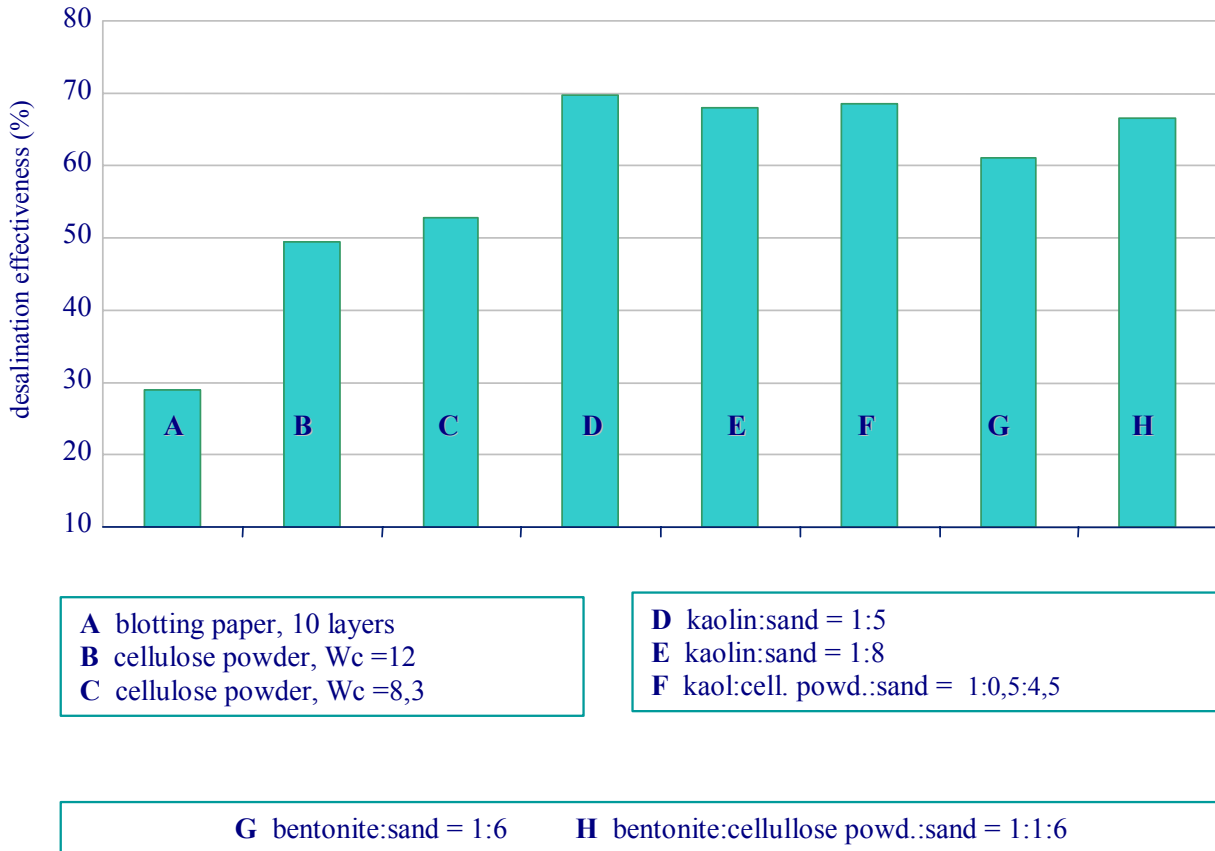**G** bentonite:sand = 1:6   **H** bentonite:cellullose powd.:sand = 1:1:6

Figure 4:   Influence of poultice type on desalination effectiveness of bricks. After Domaslowski et al. 1998 [45]

Table 4:   Properties of additives

Additive	Quoted by	advantages	drawbacks
Sand	[2], [28], [45]	Decreases drying shrinkage	-
sodium pentachlorophenate	[27]	Avoids fungae growth	-
netting (galvanized iron*, plastic**)	[25]*, [48]**	Improves adhesion	-
quaternary ammonium	[55]	Avoids fungae growth	Hinders conductivity measurements
wide-mesh hessian bands	[25]	Prevents the poultice from falling down	-
Gauze	[55-56]	Hinders surface deterioration	Reduces adhesion to substrate
Tensioactif	[51]	Improves adhesion	
Agar-agar, gelatine, proteinous gels, carboxymethyl-cellullose*	[2], [37]*	Improves adhesion*	Reduces water transfers

3.2   Other Parameters

Some materials may contain soluble salts. Salts have been found in sacrificial mortars [48] and in a commercial product based on sepiolite [37], but only traces could be detected in several clays [19] and cellulose [23].

Generally, operators try to apply the thickest possible layer with the material they have, trying to avoid a spontaneous collapse of the material imme-

diately after application. This most often corresponds to a 1 - 2 cm thick poultice. To our knowledge, only one investigation was performed on this issue [57]. The authors found that a thick carboxy-methyl-cellulose based poultice is less efficient than several applications of thin layers of the same material.

Temperature, relative humidity, ventilation conditions, and the adhesion of the poultice influence either or both the transfer kinetics of solutions or the location of the salt deposition.

If evaporation occurs too quickly, there is a high risk of interrupting the water continuity within the capillaries, and thus induce salt crystallisation within the stone instead of outside in the poultice [26]. For this reason, some authors recommend a reduction of water transfer kinetics by protecting the poultice with a plastic film [43]. Outdoors, if the poultice remains unprotected, rain water and condensation may moisten the poultice again and induce a new penetration of salts within the stone [26]. This represents a significant limitation to forecast the duration of the desalination process. On vertical walls, gravity may lead to an irregular distribution of water in both the poultice and the substrate: Tinzl [23] found the moisture content and also the salt concentration in cellulose poultices after 10-21 days to be higher in the lower part than in the upper part of the covered area.

4 General Advantages, Drawbacks and Recommendations

It is recommended to brush an artefact before applying a poultice, because this allows eliminating an important part of surface salts [26], [58]. In the case of masonries, it is even advisable to remove renders, plasters and pointing mortars [59] if they have no historical value. In case of surfaces with high artistic value and/or unstable state, this cleaning has to be done with special care. Sometimes even additional restoration measures (as preconsolidation, stabilisation with gauze) are necessary to avoid loss of material when the poultice is applied and later removed [21], [56].

Normally, the application of poultices is made by hand on sensitive and artistic valuable surfaces. Application on larger areas of rough stonework or brickwork is also possible by gunspraying with a machine for plaster application [24], [44]. Advantages are a better adhesion and lower application costs due to the reduction of a time-consuming step in the process.

It had already been pointed out that one of the major limitation of the poultice method is that only a limited depth is desalinated [16], [39]. Desalination depth scarcely goes beyond 5 to 10 cm, although we know that walls more than 1m thick may be entirely contaminated. Decay through salt crystallisation often starts again after some time [39], [56]. A good example is given by the desalination of a room in the Tower of London, performed in the seventies.
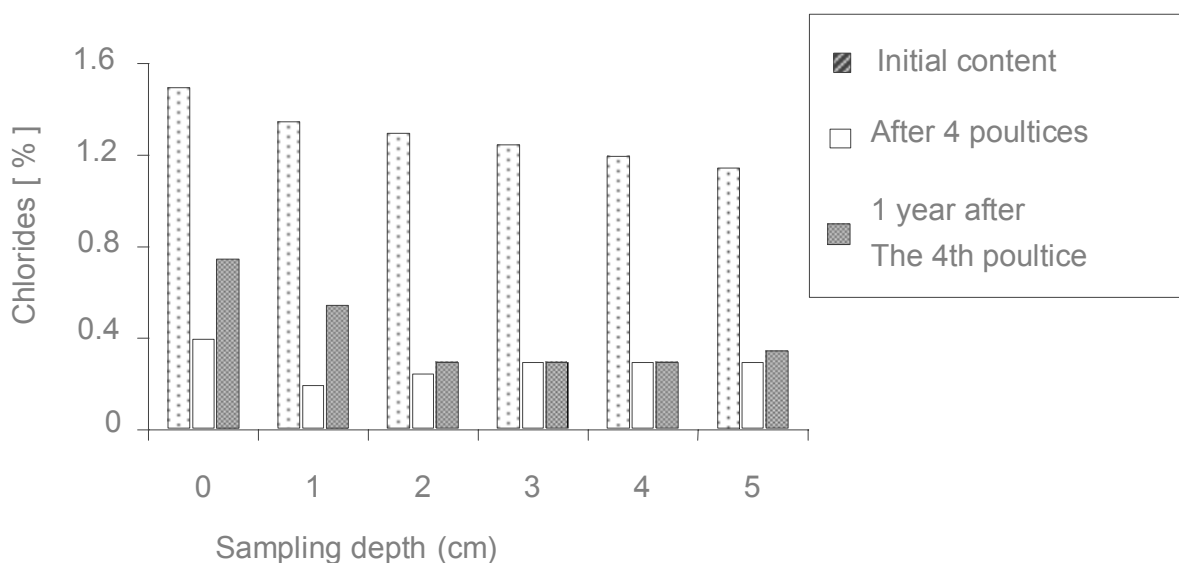

Figure 5: Evolution of the chloride content as a function of the depth in a masonry after poultice desalination. After M.J. Bowley, 1975 [39].

The medieval walls were contaminated by halite, and after 4 successive clay poultice applications, the chloride content had decreased to satisfying levels. One year later, unfortunately, the stone surface was again contaminated (Figure 5).

A complete desalination cannot be attained in most cases. A good solution may be to desalinate the surface of the object in order to facilitate the setting of consolidation products and to have better conditions for the adhesion of repair mortars. This might be a crucial point for the success of a consolidation in many cases, since the reaction of consolidants is disturbed by a high salt load in the substrate [60-61]. Furthermore, in some cases, a superficial salt extraction may be sufficient, if the main cause of salt migration is suppressed: for instance, efficient measures against water penetration may reduce considerably the salt related decay problems on the upper parts of portals archivolts. Unfortunately, the level of our knowledge for forecasting such stabilisation is still very poor.

5 Accelerating Desalination by Electrophoretic Methods

5.1 Principle and Parameters

An electrical field is created within the solution (electrolyte) between two electrodes. The electrical field transforms the random diffusion of ions and charged polar species into a direct migration towards the electrodes (Figure 6). The anode and cathode respectively attract negative and positive charges.

The electrodes are placed within the poultice, on each side of the previously soaked object. This process has been tested on stone [26], [34], [38], wood [63], mural paintings [64] and bricks [65]. It is fairly well known for the removal of chlorides from concrete [62], [66]: in that case, the first electrode is placed within a poultice on the surface of the object and the other electrode is the concrete ironing system itself.
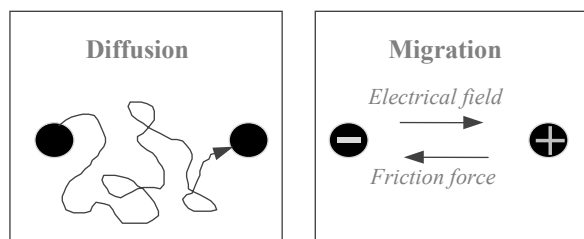
Figure 6: The presence of an electrical field transforms the random diffusion into an oriented migration. Andrade et al., 1995 [62]

The theoretical background of electrodiffusion was studied in the case of concrete. The migration processes can be expressed and quantified by the electrochemical laws of Faraday, Nernst-Planck and Nernst-Einstein [62]. The knowledge on stone is far from being complete. The efficiency of the processes has as yet not been convincingly proven, and in most cases, the process was applied without any comparison with another method, as is the case for the desalination of the brick masonry in Noisiel [65]. The only reliable laboratory study that we found [38] was performed on sandstone (Figure 7). In that case, the efficiency of the electrophoretic method seemed lower or equivalent to that of the other methods.

More recently, an in-situ comparison with a mixture of bentonite, cellulose and sand was performed on a sandstone buttress and on the brickwork of a chimney [24]. Titanium electrodes (d.c. voltage: 97 V) were applied with the poultice for 6 weeks. The efficiency of the electrophoretic method was significantly better than normal poultices in both cases (figure 8). Negative side effects were drastic changes of pH (<3 and >10!) and brown and white discoloration of the sandstone (iron compounds, TiO_2). The authors conclude that the method had a high potential for reducing the time-consuming procedure of "normal" poultices but needs a permanent control while performing [24].

6 Methods for Controlling Desalination

The most reliable method for controlling a desalination process is to directly quantify the salts present within the artefact. In most cases, nevertheless, it is impossible to take a sample from the material, and the efficiency is evaluated either by ion quantification or conductivity measurements of the desalination medium.

6.1 Direct Control on Objects

Drill cores or powder samples are collected without using water [56], [67]. Ion species are then quantified after extraction. The extraction procedure of the NORMAL 13/83 Italian standard [68] is fairly well adapted to such applications. We must admit, however, that a wide range of extraction procedures exist in laboratories: extraction time ranges from 10 minutes to 24 hours, and different water/sample ratios are selected [69]. Thus, a comparison of results obtained by different laboratories has to be handled with care, especially if gypsum is present in the sample [70].
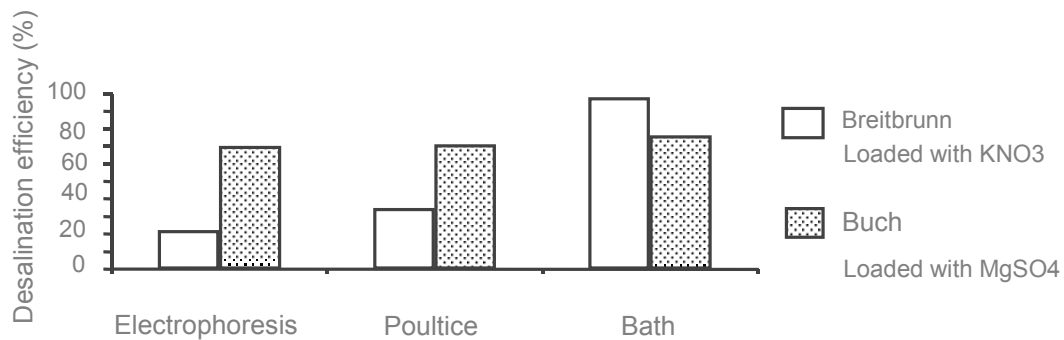
Figure 7: Comparison of three desalination methods on two sandstones. B. Legrum ,1993 [38]
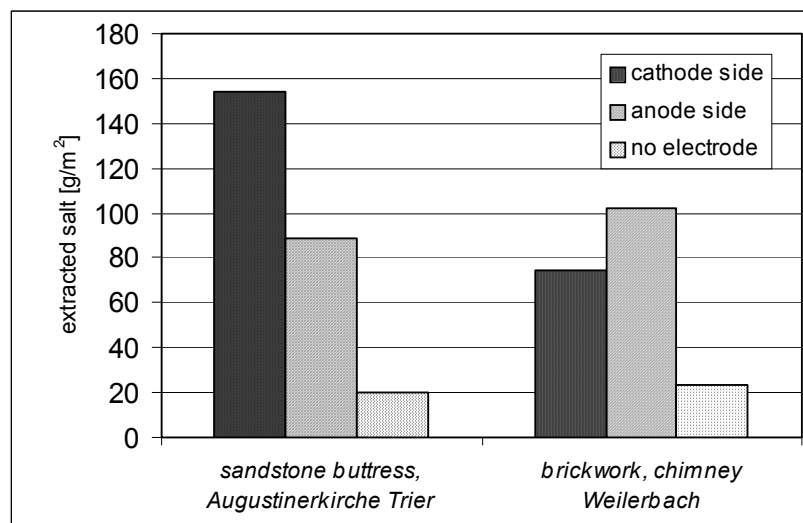

Figure 8: Efficiency of poultice desalination without vs. with electrodes in the poultice (cathode and anode side) after Auras and Melisa, 2002 [24].

There is no consensus on the salt thresholds that can insure reasonable conservation of objects. Chlorides are known to be able to cause degradation on stone far below 1 % by weight [71]. The limit is often considered as being 0.1 % w/w [72]. Sulphates also have a threshold in the same order of magnitude, unless they are combined with calcium to form gypsum. In that case only, higher concentrations can be considered safe. The recent German WTA Merkblatt [2] provides a recommendation table with very low concentration limits ($Cl^- <$ 0.03%, $NO_3^- <$ 0.05 %, $SO_4^{--} <$ 0.1 % by weight) that can be a good basis for further consensual refinements of the values on an international level.

The technique consisting in measuring, instead of salt content, the hygroscopic moisture content of drill powders at 95% RH, according to the RILEM TC 127-MS procedure [73] does not seem to be adequate for controlling total salt contents. First of all, salts having an equilibium relative humidity higher than 95 % (gypsum for instance) are not taken into account in the measurement. Another difficulty is illustrated by the investigation of Garrecht et al. 1991 [74]. These authors have shown that the same sandstone may have different moisture sorption isotherms if contaminated with different salts. As a consequence, if such a sandstone is loaded with comparable concentrations of different salts, its water content at 95 % RH will differ significantly. It is thus most probable that hygroscopic moisture content is not always a function the total salt content, but may depend also from the type of salts or salt mixtures in the material.

In routine analyses, the total salt content can be measured instead of single ion concentrations. The soluble salts are extracted from the sample, using
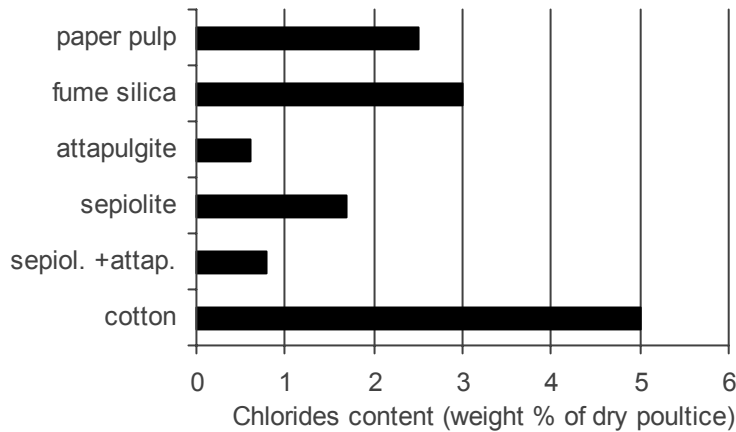
Figure 9: Chlorides content of different poultices having the same desalination efficiency (25 g/m2), expressed in wt %, after Vergès-Belmin & Bromblet, 2001 [1].

the same procedure as the one mentioned above for the analysis of ion species. After filtrating and evaporating the solution, the total salt content can be determined by a simple gravimetric measurement. This technique is less expensive and does not require sophisticated analysing techniques.

6.2 Indirect Control on Poultices

The control is performed by quantifying the total salt content, single ion species or by conductivity measurements. The poultice material must first be controlled to verify the absence of salts [19], [29], [37], [48]. Quantification of ionic species of kaolin based poultices is problematic, because kaolinite, like other clay minerals can adsorb cations, and also because this material is not easy to sieve.

Measuring the conductivity of suspensions of the poultice material in water is an easy and reliable method. If several poultice materials have to be compared, it is better to express the results in g/m^2 or $Siemens/m^2$ instead of weight% or Siemens/g [48]. As a matter of fact, the area that may be covered by poultices having the same dry weight is highly dependent on their apparent density, water retention and plasticity limits (figure 9). The same remark applies if the poultice has not the same thickness from one place to another in the same application.

Conductivity measurements may be strongly altered if ionised additives such as quaternary ammonium biocides are added to the water that moistens the poultice [55].

Many clay minerals such as montmorillonite (the swelling mineral of bentonite, sometimes also present in kaolins) may retain ions quite strongly on

their surface. This property, called *absorption capacity*, may disturb conductivity measurements [41], or extraction of salts by water for further ions quantification. The monitoring of a desalination process using clay based poultices should always take this limitation into account. Ballestrem et al. [27] suggest burning the material at 400 °C before extracting the salts for analysis.

Some authors tried to set up criteria for the evaluation of poultice desalination. Figure 10 illustrates one of these recommendations [75]: desalination is supposed to be successful if the evolution of the conductivity follows a regular decrease. In reality, there are cases when desalination may follow exactly the recommended trend but still be unsuccessful, because the salts are eliminated only down to a limited depth, as shown in figure 11 [16].
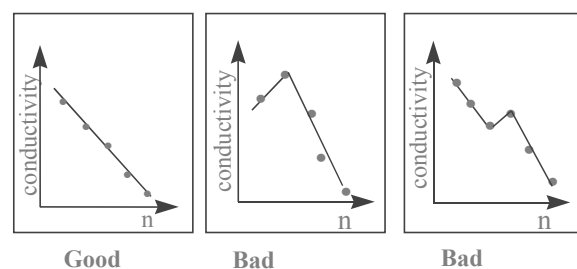

Figure 10: Recommendation for an optimal desalination, according to Ciabach & Sjibinski [75]. n = number of poultices. The curves represent the conductivity of each successive poultice applied to the object. It was proved that even if the "good" evolution is achieved, desalination may not be successful.
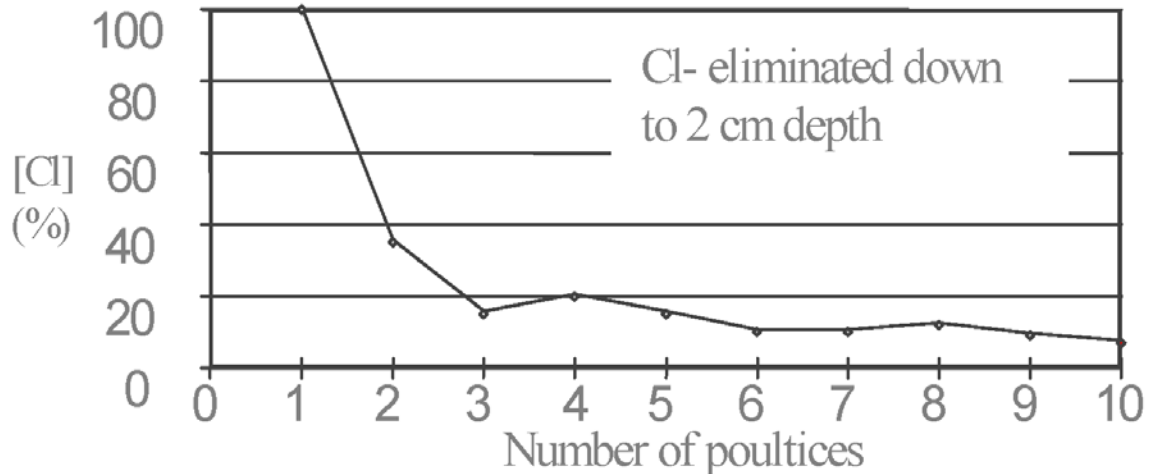
Figure 11: Follow-up of the chloride content during poultice desalination. The authors noticed that desalination was effective only down to 2 cm depth. After Fassina & Molteni, 1994 [16].

The poultice is removed when it detaches spontaneously from the substrate [16], [67] or when it is completely dry. Then a new poultice is applied, and the process is started again once, twice or more times. One often considers that a desalination procedure reaches its end when there is no further decrease in the conductivity of the poultices. This in fact does not mean that the desalination is performed for the whole object, but just that the moistened depth that depends on the quantity of water available from the poultice, and on the capillary suction of the substrate, has been desalinated. In some cases, the desalinated zone only reached a depth of 1 to 2 cm.

7   Conclusion

The poultice method may be efficient if the whole material can be moistened, for instance when the object is partially immersed in a bath on one side, and covered by a poultice on the other side, or the continuous, directed migration of moisture through the substrate into the poultice can be maintained in a different way. In most cases, poultice desalination remains partial, even if salt contents may be reduced to very low levels near the surface of the object. Electrophoretic methods are far from being convincing when applied to poultices, excepted, perhaps, in the case of concrete.

Desalination should be controlled, if possible, by quantifying the salts remaining in the object itself. Controls performed on poultices do not constitute a guarantee for a complete desalination, and thus cannot be considered reliable. The only information one may get from the salt content in poultices is whether salt extraction is still in progress (if salts are still present in the poultice, one can expect further poulticing to extract salts) or has come to an end (salts are no longer present in the poultice, so further poulticing would not be useful). Nevertheless, in most practical cases it will not be possible from the economic point of view to perform a very high number of cycles (although small amounts of salt could still be extracted with further cycles). The point when the procedure shall be stopped can be assessed if one follows the salt content in poultices (efficiency of further extraction vs. costs).

Salt transfer modelling is an issue that still requires further research. It has been fairly well studied for copper alloys [76], concrete [62] and bricks, stones or glass recovered from shipwrecks [77]. Hitherto existing approaches [78-79] are not yet fully applicable to practical conservation. Advanced modelling will surely constitute a huge step forward in the improvement of desalination methods. This is particularly true for poultices, the properties of which are not sufficiently known. We may even say that the existing methods for measuring water and water vapour transfers are not adapted to those fragile materials. Some efforts should be made in elucidating these points.

Another question that remains for stone restorers to deal with is whether or not it is worth it to desalinate outdoor sculptures or masonries knowing that only a few centimetres will be desalinated. A corollary question that comes to mind is whether one should desalinate to enable further treatments like consolidation and the application of repairing mortars to be performed in better conditions.

Acknowledgements

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