

Poulticing sandstone: implications for subsequent weathering response

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Abstract

This research investigates application of desalinating poultices to Locharbriggs Sandstone and Peakmoor Sandstone using different poultice mixes and application methods. The project has two aims, first, to determine the impact of poulticing on subsequent stone weathering response to simulated weathering cycles and, second, to evaluate the effectiveness of different poultice mixes and application methods on removing salt from substrate material. Analysis of surface to depth samples from blocks using Ion Chromatography and Atomic Absorption Spectroscopy identified spatial patterns of substrate salt retention. Visual recording of samples during weathering simulations identified differential weathering response of blocks with Peakmoor Sandstone exhibiting the most extensive surface deterioration. This deterioration was related to the incomplete removal of salts and mobilisation of 'deep' substrate salt deposits that were drawn up to near surface material. These data demonstrate the importance of appropriate poultice selection and adherence to 'best practice' during the application process. They also have implications for consideration of adverse effects of incomplete salt removal from heavily contaminated stone.

Keywords: poultice, sandstone, weathering, Locharbriggs, Peakmoor

1 Introduction

Since removal from a quarry and placement into a building or monument stone blocks will have acquired a complex stress history [1–4] that reflects exposure conditions, for example, a polluted urban environment or general weathering activity associated with the subaerial environment. Stone is traditionally seen as an immutable building material [5], which should withstand internal breakdown but with an understanding of decay processes comes the recognition that stone has a ‘finite life’ [6]. However with repetitive exposure to chemical, physical and biological weathering processes the structure of stone becomes altered and the stone can become ‘contaminated’ by agents of weathering such as salt. This can significantly curtail the durability and lifespan of a building or monument [7, 8].

Sandstones are common in historic and new-build structures because of their availability, aesthetic appeal and comparative ease of working. However, because of their relatively high porosities (c. 20%), moisture and any contaminants such as salts can gain access to the material. The significance of salt penetration and accumulation lies in its long and short term weathering effects that result due its changes in state i.e. in a dissolved or crystalline state that may be controlled by micro-environmental factors. Both salt crystallization and the volumetric expansion associated with phase changes exploit pre-existing weaknesses such as micro-fractures and pore spaces. For that reason salt phase changing takes advantage of inherited (whether diagenetic or caused by emplacement) weaknesses to develop microfracture networks. It is well documented [1, 6, 8–12] that the presence of salt is often associated with active surface deterioration and loss of material and hence architectural detail.

Stone cleaning can be contentious [13–17] and has generated great debate and a large body of literature detailing the problems and often common mistakes which have in some instances led to accelerated deterioration of stone and discoloration of facades. Aggressive chemical and physical cleaning of stonework in the 1980’s contributed to the creation of many dilapidated facades by the 1990’s in the United Kingdom, [13] but it is important to note that many buildings have been successfully cleaned, yet the successes were over-shadowed by those that were less successful. With many conservation grants, a certain proportion of funding is allocated to surface cleaning and there are several different approaches

that have commonly been used. Poulticing is one such process and it has successfully been used in many cases (e.g. Kelvingrove art gallery and museum, Glasgow). However many arguments have been put forward addressing the suitability and efficacy of poultices as to whether they should be used and how often poultices should be applied, particularly due to the cost and time needed for their repeated application within a conservation project.

Poulticing as a 'cleaning' method was originally designed to remove salt but additives are often now introduced to remove stains, referred to as 'active' or 'chemical' poultices. In this study, poulticing has been used as a mechanism to remove salt contaminations from historical stone substrates.

An abundance of research has been carried out into the efficacy of different poultices and carrying mediums [18–24]. However, once the process of poulticing has been completed, our knowledge of the short and long-term impact on subsequent weathering response appears to be limited as the post application weathering response has been an area of neglect in the research.

This paper reports data from a laboratory based experimental study aimed at identifying the implications of poulticing for subsequent salt weathering response in sandstone under controlled laboratory conditions.

2 Methodology

Information provided in this section gives insight into the stone types, materials used, the artificial weathering regime samples were subjected to and the subsequent analytical techniques used for analysis.

2.1 Materials

Two different sandstones were used in this study: Locharbriggs a red to brown coloured sandstone of fine to medium grained texture with inherent clay laminations and Peakmoor a buff coloured sandstone of fine to medium grained texture. For further characteristic information on these sandstones see Table 1.

Table 1: Stone types and their properties used in this study

Name	Geological Age	Mineralogy and Structure	Porosity (%)	Average Permeability (mD)	Standard Deviation (σ)
Locharbriggs	Permian	Quartz, Iron-Oxide, feldspars, Silica, Mica and Smectite clays	24.9%	743 (range 119 to 2028)	432
Peakmoor	Carboniferous	Quartz, feldspars, Mica and chlorite clays	16.5%	32 (range 9 to 88)	22

The pre-mixed poultice application used in this study is not a commercial pre-packed product but rather an admixture of sepiolite clay and Poraver® (Table 2). Two poultice mixes of various ratios were tested (Table 3), as the quantity of different granular sized mediums is directly related to the advective quality of a mix.

Table 2: Poultice mixture constituents

Constituent	Type	Characteristics
Binder	Sepiolite	A complex magnesium silicate clay with a high porosity content
Filler	Poraver®	An expanded lightweight glass granulate made from recycled glass

Poraver® granular size *P1- 0.1-0.3mm **P2- 0.25-0.5mm ***P3- 0.5-1.0mm

Table 3: Poultice ratio of mixture constituents

Poultice Mix	Volumetric Ratio of Constituents	Sub-set Ratios
Poultice 1	4:1 – Poraver®: Sepiolite	Poraver®: 2 x 'P1'*, 1 x 'P2'**, 1 x 'P3'*** 1 x Sepiolite
Poultice 2	5:1 – Poraver®: Sepiolite	Poraver®: 3 x 'P1', 1 x 'P2', 1 x 'P3' 1 x Sepiolite

Poultice mixes were applied on top of an interface material to prevent clay contamination on the surface of the substrate. The interface materials used in the study were: Arbocel® PWC 500 cellulose fibres (fibre length: 500 μ m) and Japanese tissue paper made from vegetable fibres, both commonly used in poultice application practices.

2.2 Procedures

Rock specimens were cut into blocks of 10 x 10 x 7.5cm and loaded with a one-off application of salt solution, in this case 1.709 moles per litre of sodium chloride was used. This salt and the concentration of solution was chosen due to its common association with salt weathering and the concentration is relative to what is found in the natural environment within the United Kingdom, a widely maritime environment. The one-off application of salt solution was carried out via capillary rise for 5 days and subsequently air dried for 6 days at a background Relative Humidity (RH) of c. 60% until block weights remained stable. Weight data were collected before and after salt loading. After drying all specimen blocks were coated on 5 sides with a clear varnish (Ronseal), and embedded in expanded polystyrene to ensure heating and cooling primarily occurred via the one exposed face (10 x 10 cm). The gap between block edges and the polystyrene were closed using a plastic sealant in an attempt to prevent multilateral mobilisation of the salt in its soluble state (see other experiments using this technique [25–27]). Moisture could then only be lost from one exposed surface.

Prior to the poultice applications the interface materials were applied as such:

- Japanese tissue (grade L2): the surface of the stone samples were sprayed lightly with distilled water before the tissue was set onto the surface. To ensure a sound adhesion to the surface the tissue was lightly sprayed with distilled water and stippled with a soft bristle brush to ensure connectivity.
- Cellulose fibres: used as an isolating layer between the clay and stone fabric. The Arbocel fibres were mixed with enough water to form a fluid paste, which allows the mass to be troweled onto the surface easily without breaching or puncturing the isolating layer.

Poultice materials were mixed with 1 part of distilled water to form a putty like paste, the poultice mixes were applied directly after the interface materials were applied and applied to pairs of specimen samples that were covered with PVC film for 72hrs to prevent initial evaporation of water. The poultice mixes were left *in situ* upon the sandstone samples for a total of 5 days, until the poultice appeared dry and to prevent re-impregnation of the salts into the sample blocks, then carefully removed and individually stored for subsequent analysis. Sample blocks with a cellulose interface were brushed lightly with a soft bristle brush to remove

any remaining cellulose fibres. Blocks were placed in an environmental chamber and exposed to the temperature cycles shown in Figure 1 for a total of 30 24hour cycles.

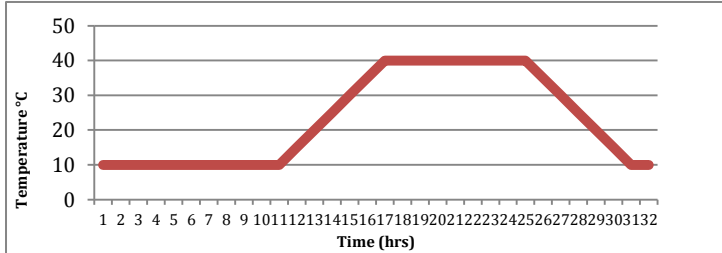


Figure 1: Temperature cycle

Samples were sprayed daily before the start of each cycle with 11ml of distilled water. At the end of the 30 cycles the exposed face of each sample block was lightly brushed to remove any loosened material which was retained and weighed.

2.3 Analysis

The following information provides specifications for sandstone and removed poultice samples post application and the analyses conducted.

2.3.1 Sandstone samples

Sandstone blocks, post poultice and post poultice with simulated weathering, were dry-cut in half from the exposed block surface to the base, to expose a cross-sectional face. Sub-sampling was conducted by extracting lateral powder samples through dry-drilling at 5mm intervals from surface to depth of each specimen. 1g of dried powdered sample was dissolved in 10ml of distilled H₂O for 24hrs on an orbital shaker and filtered through 0.22µm filter membranes. This water extraction was then used to conduct elemental analysis (Atomic Absorption Spectroscopy (AAS) and Ion Chromatography (IC)).

2.3.2 Removed poultice samples

The removed poultices were sub-sampled using a riffle splitter and placed in a temperature oven at 105°C for 24hrs. The sample weight was recorded at this point. 100ml of distilled water was added to the sub-sampled poultice, placed on a magnetic stirrer for 30mins and left in the solution for 24hrs. 40ml was decanted into centrifuge tubes and

centrifuged at 3000rpm for 5mins. Water extractions were manually filtered for 24hrs, which were then used for elemental analysis using AAS and IC.

3 Results

3.1 Salt profile results and weight loss for Locharbriggs and Peakmoor samples

Figure 2 presents the salt profiles of Locharbriggs samples while in figure 3 those of Peakmoor samples.

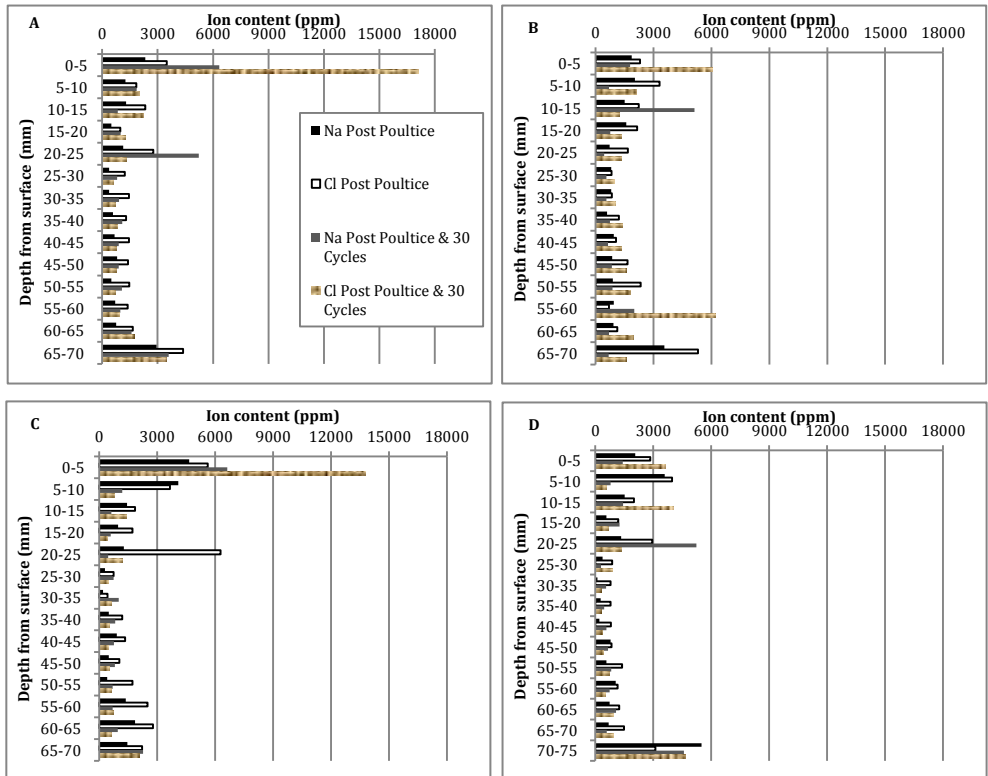


Figure 2: Combined post poultice and post poultice with simulated weathering salt profile results (ppm) on Locharbriggs samples (A with poultice 1 applied to cellulose interface, (B) with poultice 1 applied to Japanese tissue interface, (C) with poultice 2 applied to cellulose interface and (D) with poultice 2 applied to Japanese tissue interface.

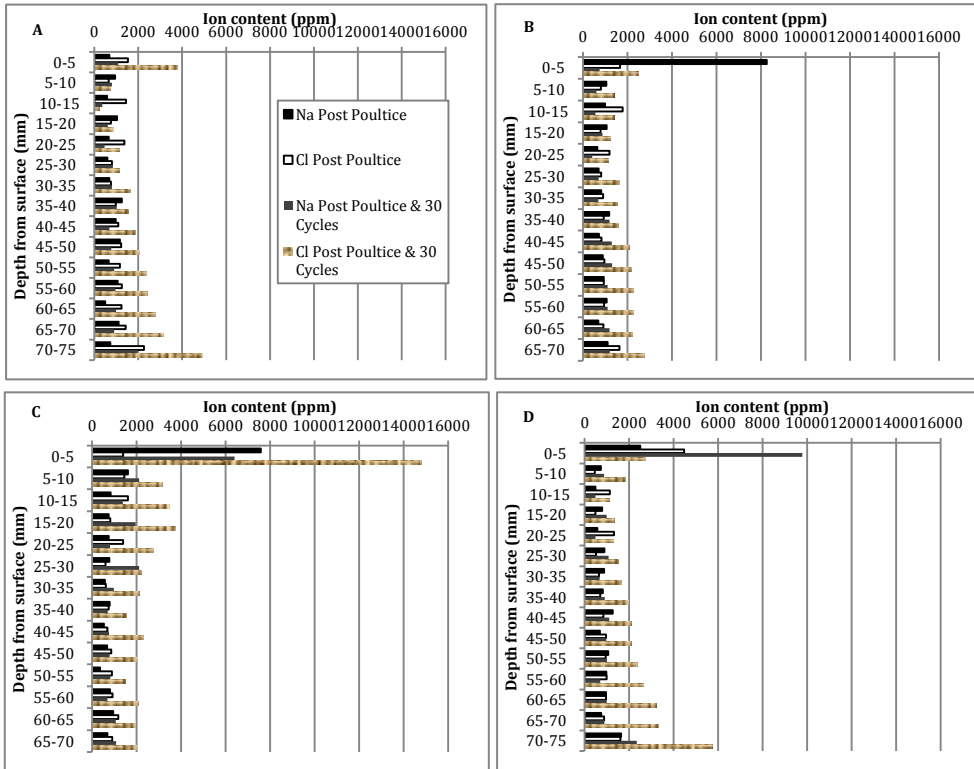


Figure 3: Combined post poultice and post poultice with simulated weathering salt profile results (ppm) on Peakmoor samples (A) with poultice 1 applied to cellulose interface, (B) with poultice 1 applied to Japanese tissue, (C) with poultice 2 applied to cellulose interface and (D) with poultice 2 applied to Japanese tissue interface.

The weight loss values of stone material are presented in Table 4.

Table 4: Weight loss data of Locharbriggs and Peakmoor samples post poultice with simulated weathering, and related to non poulticed salt free (blank) sample and one loaded with 10% NaCl.

Poultice Application	Locharbriggs initial weight before weathering (g)	Weight loss		Peakmoor initial weight before weathering (g)	Weight loss	
		(g)	(%)		(g)	(%)
Blank Sample	1323.54	N/A	0.00	1316.74	N/A	0.00
10% NaCl loaded sample	1379.58	2.09	0.15	1603.54	2.26	0.14
Poultice 1 - Cellulose interface	1365.66	1.51	0.11	1637.89	0.04	0.00
Poultice 1 - Japanese tissue interface	1399.73	1.57	0.11	1634.2	0.19	0.01
Poultice 2 - Cellulose interface	1347.67	2.37	0.18	1561.04	6.68	0.43
Poultice 2 - Japanese tissue interface	1395.02	2.42	0.17	1559.22	0.1	0.01

3.2 Salt extraction results from removed poultices

Pure poultice and natural stone sodium and chloride concentrations were tested prior to use. Table 5 reveals the minimal amount of both ions present in the materials before use while Table 6 presents Locharbriggs and Peakmoor sodium and chloride concentrations of removed water extractions from individual poultices.

Table 5: Pure poultice and natural stone sodium and chloride concentration

Materials	Na (ppm)	Cl (ppm)
Poultice 1 4:1 – Poraver®: Sepiolite	62	81
Poultice 2 5:1 – Poraver®: Sepiolite	54	46
Locharbriggs sandstone	1.5	2.5
Peakmoor sandstone	1.2	2.2

Table 6: Locharbriggs and Peakmoor sodium and chloride concentrations of removed water extractions from individual poultices.

Poultice - interface combination	Locharbriggs		Peakmoor	
	Na (ppm)	Cl (ppm)	Na (ppm)	Cl (ppm)
Poultice 1 - cellulose	11281	35052	4308	9097
Poultice 1 - cellulose	14113	46976	2813	6505
Poultice 1 - Japanese tissue	15214	46335	68323	16882
Poultice 1 - Japanese tissue	25818	48709	98385	92805
Poultice 2 - cellulose	63202	21699	6112	9663
Poultice 2 - cellulose	92822	27661	3328	5907
Poultice 2 - Japanese tissue	9843	35630	5046	8907
Poultice 2 - Japanese tissue	12868	38879	7653	7592

Duplicates of each block and poultice/interface combination were tested in this study to insure that the results (Table 6) were synonymous with each other. However, the results above indicate some differences between duplicate blocks with the same treatment combination applied. These differences in Na and Cl concentrations extracted from the near surface of the stone substrates may be due to the ionic diffusion of NaCl throughout the stone as well as the available pore connectivity. As it is already known that crystallised salts can block pore throats resulting in lesser connective pore pathways within the substrate [28].

Yet it is important to keep in mind structural controls within the stone, which will also play a part in where salt will reside, for instance Locharbriggs is heavily clay bedded which highlights the importance of micas and clays due to their “potential to ‘fix’ ions in the interlamellar spaces of the structure” [29]. McCabe goes on to explain that diagenetic processes in Locharbriggs disaggregated the mica-rich metamorphic rock liberating a pseudo-matrix that in addition to contributing to decreased porosity and increased tortuosity they also contribute to adsorption of hydrated ions. This may explain why more chlorides are detected in removed poultice 1 from Locharbriggs but the inverse can be seen in the

removed poultice 2, wherein more sodium was detected. As ions have been fixed within the clay material and hence not extracted to the same degree. Micas are also present in Peakmoor but, these are 'trapped' within the granitic rock fragments and do not exert the same influence.

Although iron was not tested for in this study, it is essential to understand that iron grains and iron coatings can also modify the diffusion of salt. As McCabe [29] has acknowledged iron 'grain coatings modify both the free charges on the pore surfaces and the contact angle (wettability) between salt solutions and the silicate grains in comparison to sandstones without grain coatings'. Locharbriggs' red- to brown colour is derived from such coatings and is noted to show well-developed iron oxide and hydroxide coatings, however Peakmoor is not abundant in iron minerals.

With these mineralogical difference kept in mind, it may explain the differences in results for the Peakmoor substrate treated with poultice 1 on Japanese tissue. One theory may be the concentration of mica within each sample block is different and therefore limiting the concentration of adsorbed ions, which could be removed via the poultice. Undoubtedly differing results between duplicate samples subject to the same treatment can be explained by the varying heterogeneity of each individual sample.

3.3 Initial results post-poultice removal

3.3.1 Locharbriggs

The salt profile results post-removal of the poultice application to the Locharbriggs specimens (Figure 2) suggest that the interface used between the stone substrate and the poultice mixture can have a significant influence over the efficacy of the applied poultice. This could be due to the interface altering the pore size of the poultice, which is designed to have a finer porosity than the substrate, so when applied an advective quality can be achieved. Poultices with pores of different sizes can be obtained by varying the component types and properties such as: clay type, grain size, and cellulose fibre length but also by varying the ratios between them [23], which could either be beneficial or disadvantageous to its overall efficacy.

Some specimens, such as those of Figure 2c, show a large concentration of sodium chloride at the near surface area in comparison to other specimens. One possible interpretation is that this poultice/interface combination did not produce a sufficient advective quality to effectively remove salts out of the top surface area following one application, but rather mobilised salts to create a greater concentration in that area.

However, the analysis conducted on the removed poultices (Table 6) contradicts this interpretation due to the high concentration of sodium chloride (taken out of the stone by the poulticing) present in this poultice/interface combination. This may be a reflection of porosity and the connectivity of the pores of the Locharbriggs sample drawing salts from a reservoir of salt at depth creating a 'feeding' effect to the surface zone. Duplicate blocks were treated with the same poultice/interface combination to ensure that this result was not an anomaly. These results reveal that this combination of poultice and interface is in fact very effective at removing chlorides when applied to a Locharbriggs substrate but it is likely that a second application of the poultice treatment would have been effective in removing salts from the near surface zone. As initial results indicate it has a strong advective quality, however leaving such a high concentration of sodium chloride in the near surface zone after only one application leaves the stone vulnerable to mechanical breakdown by salt weathering mechanisms as it creates a 'reservoir' of salts that are available for driving subsequent decay.

3.3.2 Peakmoor

The results post poultice removal for the Peakmoor specimens initially suggest that the poultice 1 mixture might not have been very successful in aiding salt reduction, as the overall salt profiles of Figures 3a and 3b have not been dramatically altered. However in comparison to the results of Figures 3c and 3d it is evident that salt has been mobilised to the near surface area.

Analysis of the removed poultices (Table 6) reveal that the most effective mix for reduction of salt was the combination of the poultice 1 mix used with a Japanese tissue interface. Suggesting that poultice mix 2 with either interface used has not generated sufficient advection to remove the salts from the top surface with one application. It is important to note that all poultices applied did remove salt, however as poultice applications are a time consuming and costly method of salt reduction it is important to choose the most effective poultice mix and interface combination in relation to the specific substrate being treated.

It must be remembered that in reality the salt concentration within a historic substrate of a building is usually unknown without the use of invasive testing i.e. sample coring of stone. Therefore removed poultices should be tested for their salt concentration to ensure the concentration of salt is reducing after each application to prevent high concentrations of salt being left at the surface, and hence the possibility of exacerbating surface loss.

3.4 Post weathering simulation results

After 30 diurnal simulated weathering cycles all salt profiles changed significantly.

3.4.1 Locharbriggs

Due to Locharbriggs characteristic of greater open porosity and connected permeability there appears to be a greater mobility of salt transportation, specifically to the exposed surface area within the top 25mm of the test blocks. It is this mobility and ability for salt to be transported which undoubtedly causes damage and encourages material breakdown and therefore material loss.

The overall substrate weight loss data recorded (Table 4) from this study demonstrates that 50% of the Locharbriggs samples treated with a one-off poultice application lost more material following the simulated diurnal cycling than the salt control block. Such material loss is at odds with the reason for applying poultice treatments, which is to limit breakdown by reducing salt load within the substrate. However, to understand these results all data must be considered holistically, for instance, if Figure 2a and Figure 2c results are viewed comparatively due to similarities in salt profiles. A combination of poultice 2/cellulose interface extracted the most salt within this category (Figure 2c) but also inflicted the most material loss of 0.18%, whereas in case of poultice 1/cellulose interface, the sample was left with the highest concentration of sodium chloride within the top 5mm (Figure 2a) but generated the least material loss, 0.11%. Salts need to be removed through the surface, therefore a tension arises between the need to remove salts and the danger of leaving increased salt concentrations in the near surface zone. The solution to this problem is not straightforward, even subsequent applications may simply continue to draw salts from depth and leave them in the near surface zone rather than completely removing the threat of salt decay giving potential for setting up a salt 'conveyor belt' from depth back to the surface.

It is evident from these results that the use of different interfaces upon a Locharbriggs substrate leads to very different salt profile outcomes post-weathering, such as Figure 2b in comparison to Figure 2c. Wherein the former poultice/interface combination extracted the second highest amount of salt but similarly resulted in the second highest material loss, even though the top surface of Figure 2b had significantly less salt concentrated in the top 5mm. Although, the overall salt profiles differ between same poultice/different interface combinations the substrate weight loss percentages have been fairly similar, e.g. 0.01% difference

between samples related to Figures 2a and 2b, whereas those related to Figures 2c and 2d showed exactly the same weight loss. This seemingly contradiction where high concentrations of salt in the near surface zone generated similar loss as those samples with lesser concentrations within the near surface zone suggests that the simulated weathering cycles may have been stopped prematurely before a major breakdown threshold was crossed. Thus only a small insight into Locharbriggs behavioural response to weathering has been witnessed and could be considered episodic rather than steady in terms of the rate of breakdown [10].

3.4.2 Peakmoor

The behaviour of Peakmoor samples provided contrasting results. The poultice/interface combination shown in Figure 3a extracted the most salt from the substrate (Table 6) and did not generate a large concentration of salt within the top 25mm. It also resulted in minimal material loss of 0.01% of the initial block weight, significantly less in comparison to the Peakmoor salt control block (Table 4). Although the sample considered in Figure 3a shows no material loss, in relation to its counterpart Figure 3b, the poultice/interface combination used extracted a considerably lower amount of salt, suggesting that this poultice/interface combination is not as effective on a Peakmoor substrate.

The greatest amount of material loss recorded during the simulation experiment was from a Peakmoor sandstone sample treated with poultice 2/cellulose interface. Analysis showed that significant amounts of NaCl had accumulated in the upper 5mm of stone (Figure 3c), which subsequently contributed to surface blistering and granular disintegration resulting in a loss of 0.43% of the initial block weight. Finally, Figure 3d shows a very different salt profile in comparison to its counterpart (Figure 3c) where to a lesser extent salt is concentrated within the top 5mm which led to much less material loss from the surface (0.01% of the total block mass). Such differing results between the same poultice mixes appear to reflect the type of interface used indicating that a cellulose interface potentially improved the advective effectiveness of the poultice in comparison to the Japanese tissue. However, these data must be viewed with caution as this experiment only tested the subsequent weathering response after one poultice application. The difference in results may also reflect the fact that the experimental cycles stopped before the block considered in Figure 3d shifted from a relatively stable condition to one of instability and breakdown.

4 Discussion

The results provided have brought to light areas of impact wherein these results could prove to be beneficial, which will be discussed below. In the context of practitioners approaching historic stone, the present study is significant. Data reported here highlight the importance of avoiding single poultice applications, as a one-off poultice treatment may allow damaging salts drawn towards the surface to remain in the near surface zone, where a second application could potentially remove these. However, if project funding is not sufficient for applying poultices multiple times it may be considered that it might be more beneficial not to poultice at all than to apply the treatment once.

4.1 Interface suitability

These data also illustrate the importance of selecting an appropriate poultice interface as this can have a significant impact on efficiency of salt removal. The use of a cellulose interface proved to be most efficient in aiding the mobility of salt, which may be due to several reasons:

- 1) A fibre length of 500 μ m or less can create a finer porosity at the surface zone creating a more effective advective quality.
- 2) To apply the cellulose interface it must be soaked to create an unbroken layer of approximately 1.5cm thick. The addition of water enables salt solubility and therefore increased salt mobility.
- 3) The layer of cellulose provides a greater area and pore space for salt to relocate to rather than the use of Japanese tissue interface.
- 4) A cellulose interface is usually favoured because of its 'sticky' quality, providing better adhesion to vertical facades.

However, despite these advantages cellulose also has several disadvantages:

- 1) Difficulties when the poultice is removed as cellulose fibres can remain on the stone surface, especially if the surface is rough and uneven. This can be removed by aggressive brushing but may jeopardise a friable surface.
- 2) Previous research [24] indicates that cellulose can be prone to mould development. In relation to the previous point, if cellulose fibres are left on the stone substrate and cannot be removed by agitation there is a risk that mould could develop or become a breeding ground for organic material.
- 3) Using cellulose to prevent clay contamination of the substrate surface means that it should be used as an individual layer

between poultice and substrate. However, cellulose as part of the poultice admixture will not prevent clay contamination and sometimes a powdered veil will be left on the stone surface that has been poulticed, causing discolouration and difficulty in removal.

- 4) The addition of water is necessary to make cellulose adhere to stone, however cellulose has a poor water retention, therefore the addition of too much water can make application to vertical surfaces difficult. There is also a risk that the wet cellulose can saturate the stone beneath, therefore mobilising salts deeper into the block, which may lead to a re-emergence of efflorescences [18, 30].
- 5) Furthermore, when a large amount of water is used to bind the cellulose, it may take a longer time to dry out in comparison to a clay poultice, resulting in the cessation of its advection and recontamination of salt from the wet cellulose back into the substrate if the poultice is not promptly removed.

This research shows the significance of attempting to understand the behavioural response of sandstone post-treatment, as this area has generally been neglected in the assessment of conservation treatments with focus being on the effectiveness of the stone treatment. It is when issues are ill addressed that problems concerned with treatment based conservation methods can result in detrimental damage rather than preservation. It is well known in the conservation world that treatments cannot be applied on a one-case fits all scenario basis but must be case-specific.

4.2 Ethics of conservation intervention

Intervention via conservation treatments to historic stone fabric is ruled by 'ideal' vs 'reality' ideology; in terms of the expected outcome of the treatment results, these expectations can differ greatly between the building owner and the skilled practitioner. This can be an area of contention between both parties when a building owner expects to see a remarkable change in the appearance of the masonry post treatment application. It is common for compromises to be made in overall expectations of conservation projects in order to seek the balance between 'best practice', funding available, building owners expectations and the desire and quality of expertise available.

The decision to intervene via conservation treatments is undoubtedly dictated by the on going debate and ethical approaches associated with

conservation. Building conservation is distinctly different from the physical processes of repair and adaptation. According to English Heritage [30] “it is an attitude of mind, a philosophical approach, that seeks first to understand what people value about a historic building or place beyond its practical utility, and then to use that understanding to ensure that any work undertaken does as little harm as possible to the characteristics that hold or express those values”.

Masonry behavioural response then, as well as now, is still not fully understood, but attempts into understanding the response is vital to prevent the mistakes of the past and to aid successful application of surface treatments for the future.

5 Conclusions

This study highlights the need for further research into the behavioural response of masonry post surface treatment applications. As an initial small-scale laboratory investigation it has revealed that applying one poultice application could potentially accelerate the degradation rate of the masonry surface instead of slowing the weathering process, but also highlighted the importance of interface selection. In order to adhere to best practice, it now appears to be significant to include trial panels for poulticing, not only to assess the efficacy but also to monitor the behavioural response of the substrate post-application. However, the monitoring period is up for debate as this is circumstantial to locality, exposure to moisture ingress, as well as threat of freeze and thaw in the natural environment. It is apparent from the results presented that if project funding is limited or does not cover the costs for repeated poultice applications it may be more beneficial for the future of the masonry to not apply poultices. This must be carefully considered by a skilled practitioner who can investigate the extent of salt contamination of the masonry before progressing with a desalinating surface treatment.

Furthermore, the mineralogical composition of the stone type being treated much be kept at the fore, as this may or may not exert limitations in the extractability of the poultice and the subsequent weathering response after removal. With this in mind it must be remembered that masonry stone such as sandstone is inevitably variable in its heterogeneity and mineralogical composition that may dictate to what extent salt extraction is possible.

These initial results into the behavioural response of sandstone post surface treatment applications have widened the scope for future

research. Rationale for proposed future research into sandstone behavioural response post surface treatment applications at Queen's University Belfast has been derived from the lack of geomorphological knowledge post treatment and what the subsequent weathering response impact has on the material. Data obtained will be beneficial to the debate of conservation intervention by inheriting the viewpoint that stone is a complex material and this must be remembered when addressing the issue.

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References

- [1] McCabe, S., Smith, B.J., Warke, P.A. Preliminary observations on the impact of complex stress histories on sandstone response to salt weathering: laboratory simulations of process combinations. *Environmental Geology*, (52) (2006), 251-258
- [2] McCabe, S., Smith, B.J., Warke, P.A. Sandstone response to salt weathering following simulated fire damage: a comparison of the effects of surface heating and fire. *Earth Surface Processes and Landforms* (32) (2007) 1874-1883
- [3] McCabe, S., Smith, B.J., Warke, P.A. A Legacy of Medieval Mistreatment in NE Ireland. *Geological Society: Special Publications* 333, London, 2010
- [4] Smith, B.J. Scale problems in the interpretation of urban stone decay In: *Processes of Urban Stone Decay* (Eds.) B.J. Smith & P.A. Warke. Donhead Publishing LTD, London, (1996), 3-18
- [5] McAlister, J.J. Analytical techniques for the examination of building stone. In: *Processes of Urban Stone Decay* (Eds.) B.J. Smith & P.A. Warke. Donhead Publishing LTD, London, (1996), 32-43
- [6] Smith, B.J., Gomez-Heras, M, McCabe, S. Understanding the decay of stone-built cultural heritage. *Progress in Physical Geography* 34, (4) (2008), 439-461

- [7] Camuffo, D. Acid rain and the deterioration of monuments: how old is the phenomenon? *Atmospheric Environment* (26B), (1992) 241-247
- [8] Turkington, A.V. Stone durability In: *Processes of Urban Stone Decay* (Eds.) B.J. Smith & P.A. Warke. Donhead Publishing LTD, London, (1996), 19-31
- [9] Price, C.A., Brimblecombe, P. Preventing salt damage in porous materials. In: *Preventive Conservation: Practice, Theory and Research*. International Institute for Conservation, London, (1994), 90-93
- [10] Smith, B.J., Magee, R.W., Whalley, W.B. Breakdown patterns of quartz sandstone in polluted urban environment: Belfast N. Ireland. In Robinson, D.A., Williams, R.B.G. (Eds.) *Rock weathering and landform evolution*. Wiley, Chichester, (1994), 131-150
- [11] Goudie, A. & Viles, H. *Salt Weathering Hazards*. John Wiley and Sons, Chichester, 1997
- [12] Warke, P.A., McKinley, J., Smith, B.J. Variable weathering response in sandstone: factors controlling decay sequences. *Earth Surface Processes and Landforms* (31) (2006), 715-735
- [13] Ashurst, N.A. *Cleaning Historic Buildings: Volume 1 substrates, soiling and investigations*. Donhead, London, 1994.
- [14] Maxwell, I. Stone cleaning, for better or worse? An overview. In Webster, R.G.M (Ed) *Stone Cleaning: and the nature, soiling and decay mechanisms of stone*. Donhead, London, 1992.
- [15] Andrew, C.A, Young, M.E., Tonge, K.H. *Stone Cleaning: A guide for practitioners*. Historic Scotland & The Robert Gordon University, Aberdeen, (1994), 1-3
- [16] Vicente, M.A., Vicente-Tavera, S. Clay poultices in salt extraction from ornamental stones: A statistical approach, *Clay and Clay Minerals*, (49:3) (2001), 227-235
- [17] Coath, J. Sandstone conservation and repair in *The Building Conservation Directory: Twentieth Anniversary Edition*. Cathedral Communication Limited, (2013), 106-109

- [18] Auras, M. Poultrices and mortars for salt contaminated masonry and stone objects In *Salt Weathering on Buildings and Stone Sculpture*, Proceedings of SWBSS, Ottosen, L.M., Rørig-Dalgaard, I., Larsen, P.K, Brajer, I., Bøllingtoft, P., Marciniak, M., Svane, M. (Eds.) National Museum Copenhagen, Denmark, Technical University of Denmark, Lyngby, (2008), 197-217
- [19] Bourgès, A., Vergès-Belmin, V. Comparison and Optimization of five desalination systems on the inner wall of Saint Philibert Church in Dijon, France. In *Salt Weathering on Buildings and Stone Sculpture*, Proceedings of SWBSS, Ottosen, L.M., Rørig-Dalgaard, I., Larsen, P.K, Brajer, I., Bøllingtoft, P., Marciniak, M., Svane, M. (Eds.) National Museum Copenhagen, Denmark, Technical University of Denmark, Lyngby, (2008), 29-40
- [20] Bourgès, A., Vergès-Belmin, V. Application of fresh mortar tests to poultrices used for the desalination of historical masonry. In *Materials and Structures* (44:7) (2011), 1233-1240
- [21] Doehne, E., Price, E. *Stone Conservation: Overview of Current Research*. The Getty Conservation Institute, Getty Publications, California, 2010
- [22] Lubelli, B., van Hees, R.P.J. Desalination of masonry structures: fine tuning of pore size distribution of poultrices to substrate properties. *Journal of Cultural Heritage* (11) (2010), 10-18
- [23] Lubelli, B., van Hees, R.P.J., De Clercq, H. Fine tuning of desalination poultrices: try-outs in practice. In *Salt Weathering on Buildings and Stone Sculptures*, Proceedings of SWBSS, I. Ioannou & M. Theodoridou (Eds.), Limassol, Cyprus, (2011), 381-388
- [24] Vergès-Belmin, V., Heritage, A., Bourgès, A. Powdered Cellulose Poultrices in Stone and Wall Painting Conservation Myths and Realities. *Studies in Conservation*, (56: 4), (2011), 281-297
- [25] McKinley, J.M., McCabe, S. A Geostatistical Investigation into Changing Permeability of Sandstone During Weathering Simulations. *Geographical Analysis* (42) (2010), 180-203
- [26] McCabe, S., McKinley, J.M., Gomez-Heras, M., Smith, B.J. Dynamic instability in surface permeability characteristics of building sandstones in response to salt accumulation over time. *Geomorphology* (130) (2011), 65-75

- [27] Smith, B.J., Srinivasan, S., Gomez-Heras, M., Basheer, P.A.M., Viles, H.A. Near-surface temperature cycling of stone and its implications for scales of surface deterioration. *Geomorphology* (130) (2011), 76-82
- [28] McCabe, S., Smith, B.J., McAlister, J.J., McAllister, D., Srinivasan, S., Basheer, P.A.M., Curran, J.M. Linking climate change, moisture dynamics and salt movement within natural building sandstones: implications for salt transport by diffusion. In *Salt Weathering on Buildings and Stone Sculpture, Proceedings of SWBSS, Limassol, Ionnou, I. & Theodoridou, M. (Eds.) University of Cyprus, (2011), 63-70*
- [29] McCabe, S., Smith, B.J., McAlister, J.J., Gomez-Heras, M., McAllister, D., Warke, P.A., Curran, J.M., Basheer, P.A.M. Changing climate, changing process: implications for salt transportation and weathering within building sandstones in the UK. *Environmental Earth Science* (69) (2013), 1225-1235
- [30] Sawdy, A., Heritage, A., Pel, L. A review of salt transportation in porous media, assessment methods and salt reduction treatments. In *Salt Weathering on Buildings and Stone Sculpture, Proceedings of SWBSS, Ottosen, L.M., Rørig-Dalgaard, I., Larsen, P.K, Brajer, I., Bøllingtoft, P., Marciniak, M., Svane, M. (Eds.) National Museum Copenhagen, Denmark, Technical University of Denmark, Lyngby, (2008), 1-28*
- [31] Martin, B., Wood, C., McCaig, I. (Eds.) *Practical Building Conservation: Conservation Basics*, English Heritage, Ashgate Publishing Limited, Surrey, 2011