POULTICE DESALINATION USING BUFFERED RIGID GEL WITH ION EXCHANGE RESIN

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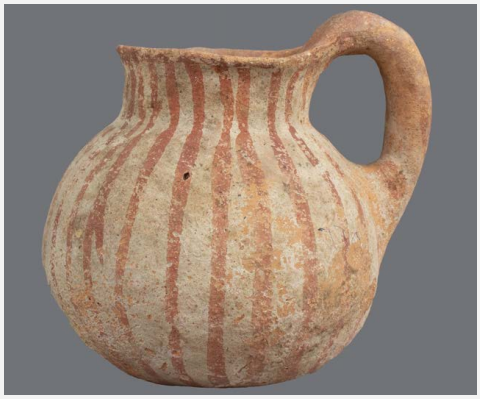
EMORY | MICHAEL C. CARLOS MUSEUM



LAND ACKNOWLEDGMENTS

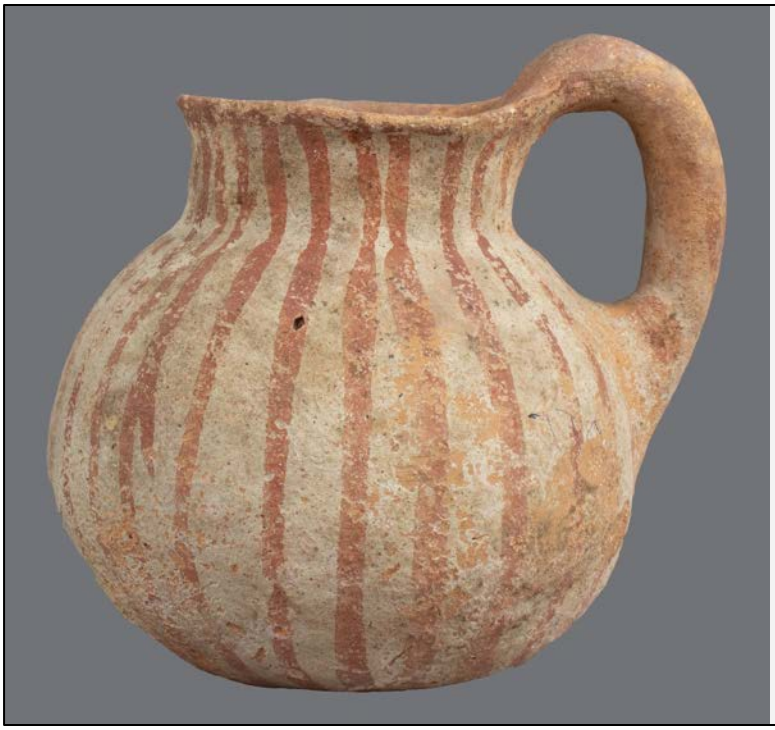
Mvskoke (Muscogee / Creek): Michael C. Carlos Museum

Lənape Haki-nk (Lenape Nation): Penn Museum

Today we are speaking to you from Atlanta, Georgia and Philadelphia, Pennsylvania. Atlanta is part of the unceded land of the Muscogee Creek Nation who were forcibly relocated to Oklahoma in the removal treaty of 1832. Philadelphia is part of the unceded land of the Lenape Nation. The Lenape people were also forcibly relocated to Oklahoma after the so called “Walking Purchase” of 1737. Today we ask you to join us in acknowledging the Muscogee Creek Nation and Lenape Nation, and we pay respect to their past, present, and future elders.

TABLE OF CONTENTS

In this presentation, we will discuss the condition and requirements of two objects, their preparation and treatment using a new poultice formulation, the results of their desalination, and what we learned through this continuously evolving treatment.



01

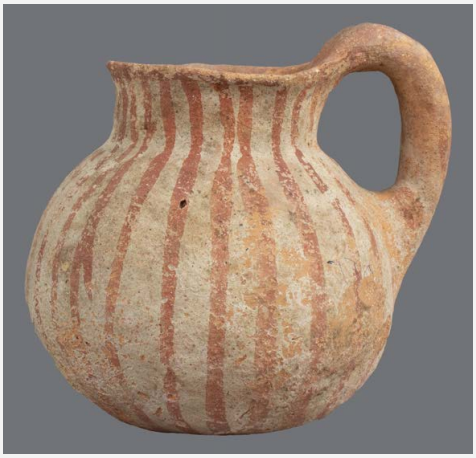
THE OBJECTS

Egyptian Funerary
Limestone Stela

Levantine Ceramic Vessel

C A R L O S M U S E U M

THE OBJECTS



CERAMIC VESSEL

A four-inch tall slip-decorated ceramic vessel with handle from the Southern Levant, possibly Ghassulian (Chalcolithic, 4600-3600 BCE).

LIMESTONE STELA

A four-foot tall limestone funerary stela from the Egyptian New Kingdom (1292-1191 BCE).

The objects presented in this study are a contrasting pair; they are from different cultures, different time periods, different burial environments, different materials, and dramatically different sizes. However, despite their differences, they are both archeological objects that were displaying signs of active salt damage and were too fragile to undergo desalination by immersion. The first object is a 4-foot tall limestone funerary stela from the Egyptian New Kingdom, and is one of the few large, relatively intact reliefs in the Egyptian collection. The second object, a 4-inch tall slip-decorated, ceramic vessel is the earliest example of Levantine decorated pottery in the Ancient Near East collection. Both were slated for display in the reinstallation of the permanent galleries at the Michael C. Carlos Museum.

LIMESTONE

CONDITION ISSUES

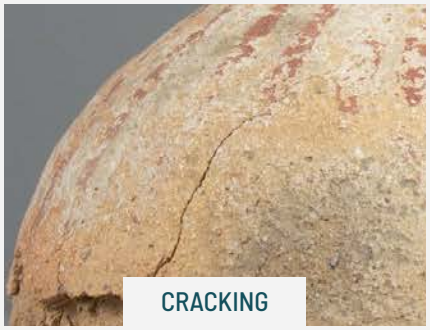
There is minimal information about the collection and treatment history of the objects prior to 2019. The limestone stela was acquired in 2009, the ceramic vessel in 2010, and both remained in climate-controlled storage, actively deteriorating for the last decade. The limestone in particular was in poor condition with surface conditions such as powdering, delamination, peeling/flaking of a possible prior coating, and a very fragile weathered crust.

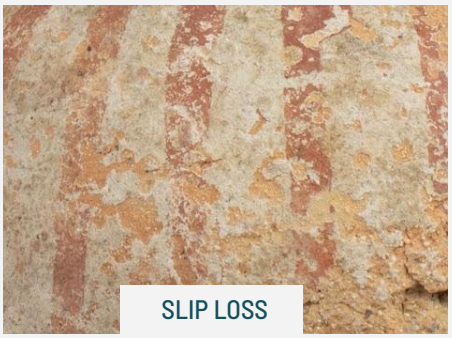
C E R A M I C

CONDITION ISSUES


SPALLING


DELAMINATION


CRACKING


SLIP LOSS

Both objects exhibited salt efflorescence, along with crumbling and spalling surfaces and disassociated flakes in their storage environments. The ceramic vessel could only be handled with a box enclosure. Microchemical tests conducted on salt crystals extracted from the ceramic surface confirmed the presence of nitrates, as well as trace amounts of chlorides.

L I M E S T O N E

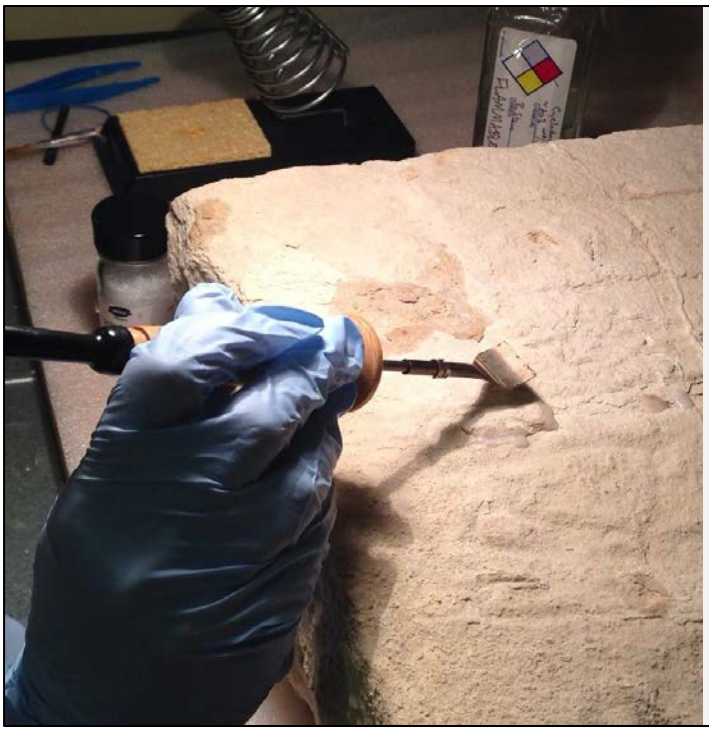
STONE CHARACTERIZATION

Testing & Analysis Included:

- X-ray Powder Diffraction (XRD)
- X-ray Fluorescence Spectroscopy (XRF)
- Microchemical Spot Testing
- Acid Digestion
- Multimodal Imaging

Conclusion: There is a high salt and clay content which could potentially compromise the stone's structural stability if submerged.

For the stela, microchemical tests and XRD determined the presence of chlorides, nitrates, sulfates, and phosphates. A handheld Bruker Tracer III-V x-ray fluorescence spectrometer (XRF) with a vacuum was used to search for lighter elements such as aluminum which might indicate the presence of clay minerals, although none were detected. Geologist Dr. William Size attempted to drill a core sample for thin section analysis from the pre-existing mount holes in the bottom edge of the stela. Unfortunately, the pressure of the drill on the soft stone produced nothing more than powder. However, acid digestion analysis of this powder allowed Dr. Size to qualitatively identify the presence of amorphous clay minerals under magnification.



02

THE PREPARATION

Egyptian Funerary Limestone Stela Treatment

Levantine Ceramic Vessel Treatment

TREATMENT GOALS

Treatment Goals for Limestone Stela & Ceramic Vessel:

1. Stabilize objects for exhibition and study by reducing surface powdering and spalling.
2. Remove maximum amount of salts without causing a loss of integrity or cohesion to internal structure of objects.
3. Cause no visible change to appearance of objects.
4. Allow for possibility of future retreatment.

In the case of both objects, the overall treatment goals were essentially the same:

1) stabilize the objects for exhibition and study by reducing surface powdering and spalling
2) cause no visible change to the appearance
3) remove the maximum amount of salts without causing a loss of integrity or cohesion to the surface or internal structure of the objects
4) allow for the possibility of future retreatment.

The poor condition of both objects demanded the more delicate desalination approach possible with poultice application. Though more easily monitored and less complex, water bath immersion was deemed too risky for both objects, given the degree of spalling and flaking and the compositional uncertainty of the stela.

L I M E S T O N E

PRE-TREATMENT

1. Temporarily stabilized using CCD
2. Consolidants tested
   - CaLoSil E35
   - CaLoSil E50
   - CaLoSil IP25
   - CaLoSil NP25
   - **10% Paraloid B-72 (w/w) in acetone**
   - Conservare OH100
   - Conservare H100
3. Faced and consolidated

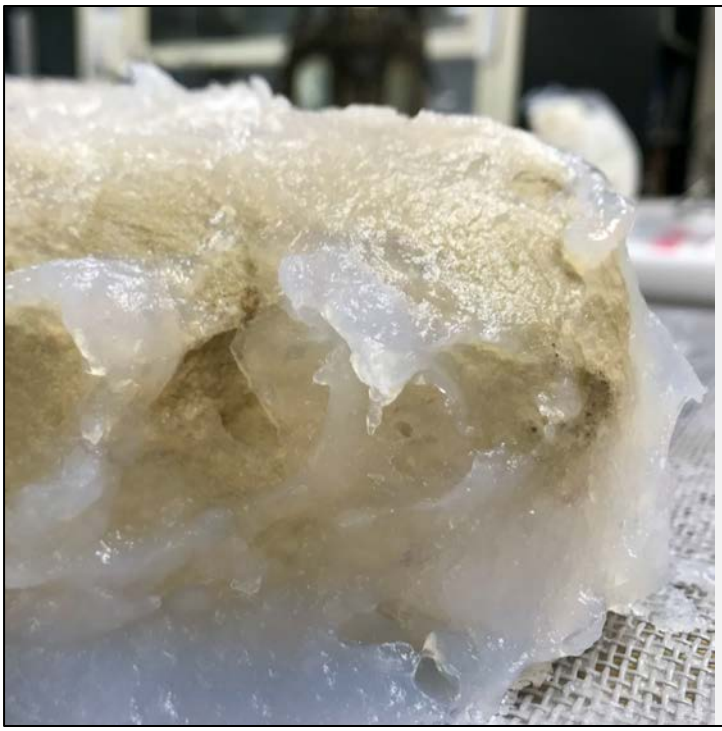
Temporary stabilization was required to secure fragile surfaces of the stela during transport from an off-site storage facility to the museum. Holt-melt cyclododecane was selected as a temporary adhesive, allowing for a quick sublimation process so that more permanent stabilization could begin soon after arrival to the lab. Consolidation and a partial facing were necessary for the limestone stela, due to the amount of powdering, lifting, and delamination seen across the surface. Dilute Paraloid B-72 solution had the best overall cohesion, minimal color shift, strong adhesion between the facing and sample, and was easily reversible. Therefore, two applications of 2% Paraloid B-72 (w/w) in acetone were applied on consecutive days to the entire stela recto. A facing of thin plain-weave cotton textile was applied with 5% Paraloid B-72 (w/w) in acetone to areas of delamination along the bottom one-third of the stela.

C E R A M I C

PRE-TREATMENT

Consolidation of cracking and spalling areas with 5% Paraloid B-72 in acetone x2

Following initial testing in an inconspicuous area, a 5% solution of Paraloid B-72 (w/v) in acetone was applied by brush to the flaking and spalling surfaces of the ceramic vessel Appropriate strength and cohesion was reached following a second application.



03

DESALINATION METHOD

Experimental Procedures

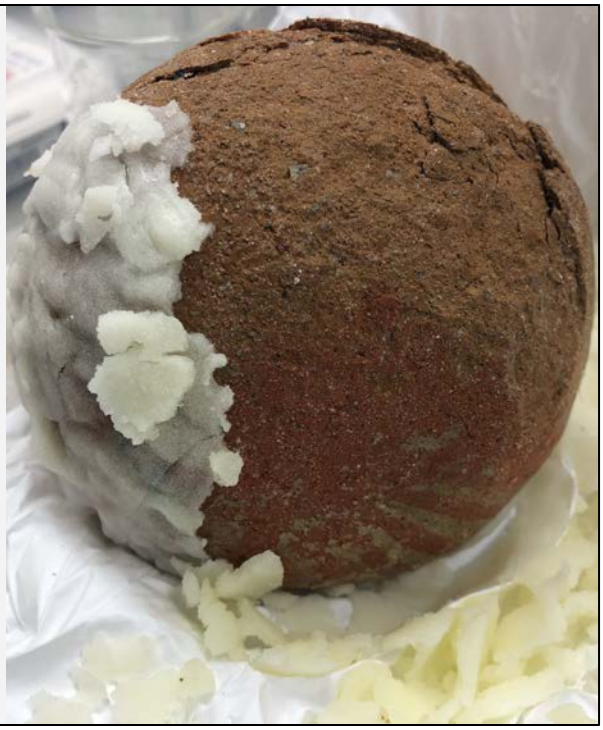
Desalination Method

Faced with the challenging conditions of these two very different objects we theorized that a wet poultice system might accomplish the needed desalination. We proposed that agarose could be formulated to draw water from the objects and hold salt anions. Following consultation with a conservation scientist at a 2018 workshop, we further hypothesized that an ion exchange resin might be added to boost the diffusive extraction mechanism with ionic attraction, and allow the gel to retain a greater quantity of anions.

RATIONALE

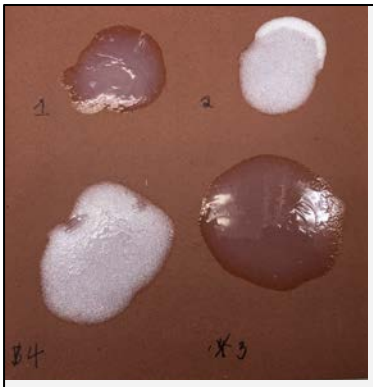
WHY AGAROSE?
WHY A WET SYSTEM?
WHY ION EXCHANGE RESIN?

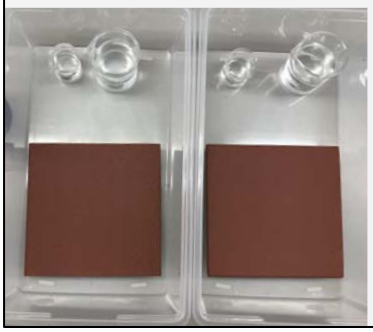
- Conformation in semi-solid state
- Harnessing diffusion and ionic attraction
- Modifiable pore size
- Lower starting conductivity
- Greater gel strength
- Maximizing ion retention with IER
- IER designed for chromatography with agarose

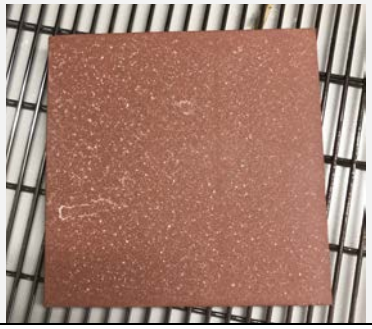


Agarose provided a number of advantages over other potential poultice materials. It easily conforms to complex topographical surfaces when poured in a semi-solid state. We chose to implement a wet poultice system, relying primarily on diffusion. Though longer in duration, diffusion-based desalination has the potential to result in a more complete extraction. However, an agarose poultice could be applied in drying form, in which case the ability to reduce the pore size of the agarose via gel concentration becomes critical. Prior studies have recognized the potential for extracting soluble salts from stone and ceramic substrates with agar, the more complex polysaccharide gel from which agarose is derived. Although more affordable, agar has a starting conductivity 2-3 times greater than that of agarose. Agarose has a greater gel strength than agar, which may be important to ensure that the poultice has enough cohesion to be removed without leaving residues.

The addition of an ion exchange resin provides an ionic component to the extraction, maximizing-anion retention. Finally, the ion exchange resin selected was intended to be used in an ion chromatography column with agarose, which added further weight to our preference for agarose over agar.







P R E L I M I N A R Y

EXPERIMENTATION

Brief trials were conducted to test the working properties and effectiveness of different desalination gel formulations on ceramic and limestone substrates.

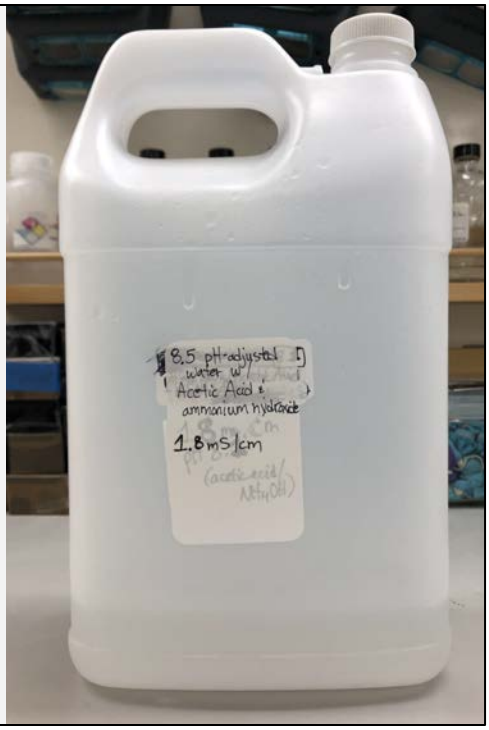
- Agarose concentration
- Presence of ion exchange resin
- Buffered and pH-adjusted water
- 6.0 pH and 8.5 pH
- Unglazed ceramic and Indiana limestone tiles

A series of preliminary trials were set up to investigate the working properties and potential efficiency of various formulations on ceramic and limestone substrates. Among these were trials comparing 2.5 and 5% agarose gels, gels comprised of agarose alone and agarose with the ion exchange resin component, gels with buffered and pH-adjusted water as the liquid components, gels at pH 6.0 and pH 8.5, and gels on unglazed ceramic and Indiana limestone tiles.

P R E P A R A T I O N

pH-ADJUSTED WATER

1. Add 0.5mL glacial acetic acid to 500mL distilled water
2. Set to desired pH by adding 10% NH_4OH (17 mL for pH 8.5)
3. Test pH and conductivity
4. Add 0.5 mL increments of NH_4OH to raise pH as needed
5. Add water as needed to lower conductivity
6. Dilute with distilled water to reduce conductivity

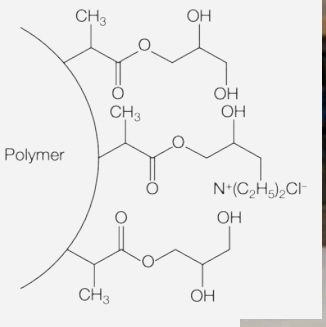


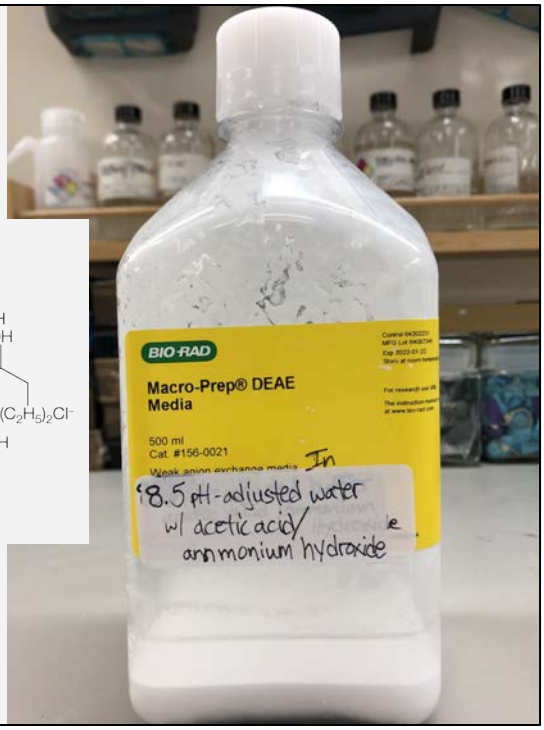
In order to minimize the risk of leaving residual salts behind, we used pH adjusted water. Recognizing that all components in the agarose and ion exchange mixture function over a wide pH range, we concluded that only pH adjustment was necessary, rather than a true buffer. Like other modifications to our method that were realized through process, we will share earlier iterations as lessons learned at the end.

P R E P A R A T I O N

ION EXCHANGE RESIN

1. Allow resin to settle
2. Decant supernatant ethanol
3. Add distilled water in 1:1 ratio
4. Shake vigorously, allow to settle, decant
5. Repeat 3-4x
6. Rinse with, and then add buffer in 1:1 ratio with resin





An ion-exchange resin is a water-insoluble medium comprised of organic polymer microbeads, typically used in ion chromatography columns to attract, separate, and exchange ions for the purposes of molecular analysis. As a weak anion exchanger, it is designed to attract anions such as chlorides, nitrates, and sulfates, while leaving behind the cations.

Macro-Prep DEAE Ion Exchange Media is shipped in supernatant ethanol and therefore has to be rinsed and replaced with the buffer solution. The resin was allowed to settle to the bottom, the supernatant ethanol decanted, and distilled water added in an approximate 1:1 ratio. The solution was shaken vigorously and allowed to settle before decanting again. The process was repeated an additional 3-4 times. One final rinse was completed with the buffer solution, so that the final slurry was roughly 1-to-1 buffer-to-ion exchange media. Once the antimicrobial ethanol was decanted, the remaining ion exchange slurry was refrigerated to prevent biogrowth.

PREPARATION

OBJECT SUPPORTS

LIMESTONE

- Wooden struts with closed-cell foam

CERAMIC VESSEL

- Acid-free tissue nest with teflon film barrier

The stela was raised on wooded struts padded with dense closed-cell foam. The inscribed recto side was placed face-down to start. The vessel was placed on an acid-free tissue nest under a Teflon film barrier.

PREPARATION

WETTING THE OBJECTS

LIMESTONE STELA

- Pre-wet repeatedly with an industrial sprayer
- Wrapped in saturated cotton sheets overnight between applications

CERAMIC VESSEL

- Misted repeatedly with Dahlia sprayer
- Water allowed to absorb between applications

Both the limestone stela and ceramic vessel were fully saturated with water prior to applying the poultice.The limestone stela was wetted with an industrial sprayer, then wrapped in saturated cotton sheets and left overnight in the chamber. This process continued until water was observed to pool on the surface, interpreted as full saturation.
Similarly, the ceramic vessel was misted repeatedly with a Dahlia sprayer and left in its chamber to promote absorption between spray applications.

PREPARATION

THE CHAMBERS

LIMESTONE STELA

- Tent constructed of PVC pipe frame covered in PE sheeting
- 2-in flaps splayed around base of lid and weighted

CERAMIC VESSEL

- Lidded plastic shoebox-size container
- Weighted on top

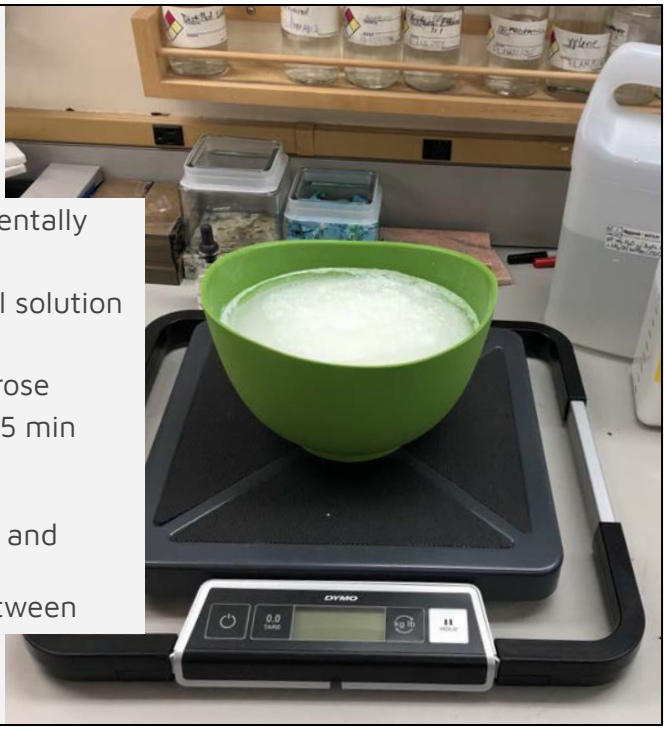
**Both contained 70% ethanol in jars to maintain moisture and discourage biogrowth.

Humidity chambers were created for each object to slow evaporation of water from the poultice system. These chambers could be opened to monitor the poultice, take samples for conductivity readings, and re-wet as necessary. A tent for the stela was made from PVC-pipe framing and polyethylene sheeting with weight bags placed on the tent flaps where they met the plastic-covered table. The ceramic was put into a lidded plastic box with weights on top. Multiple jars of 70% ethanol were placed around the interior perimeters of both chambers to maintain moisture within the poultice system and discourage biogrowth.

PREPARATION

MIXING THE GEL

1. 5.5% (w/v) agarose mixed incrementally into buffer/pH-adjusted water
2. 10% (approximately, w/w) of total solution added
3. Heated in microwave to melt agarose
    - 3 min increments for stela; 1.5 min increments for vessel
    - Final bursts of 30 sec
    - Time dependence on volume and microwave wattage
4. Mixed with immersion blender between increments



The gel was formulated so that agarose comprised 5.5% (w/v) of the original agarose/buffer mixture, and the ion exchange slurry comprised about 10% (w/w) of the total solution. The components were mixed together and microwaved in increments of 3 or 1.5 minutes, until complete melting occurred. The batch was ready when all components remained suspended without settling, and the mixture was viscous and translucent. The exact duration and number of microwave periods is volume- and microwave-dependent. Batches of 100mL - 200mL were enough for the ceramic vessel, and could be prepared with regular labware in one batch and mixed with a battery-powered cocktail stirrer. The surface area of the stela required several batches of gel, mixed in a 2L silicone bowl which fit into our small lab microwave.

APPLICATION

THE POULTICE

1. Liquid gel applied after melting, and allowed to slightly cool
2. Poured directly onto the surface in phases:
    - Spread over stela with spatula
    - Vessel rotated for coverage
3. Approx. 5-minute working time

The gel solution was allowed to cool somewhat (>36°C) before being poured onto the surfaces. The gel was spread with a spatula and wooden spoon over the stela, while the vessel was simply rotated to allow the gel to cover all interior and exterior surfaces as it cooled.

M O N I T O R I N G

CONDUCTIVITY

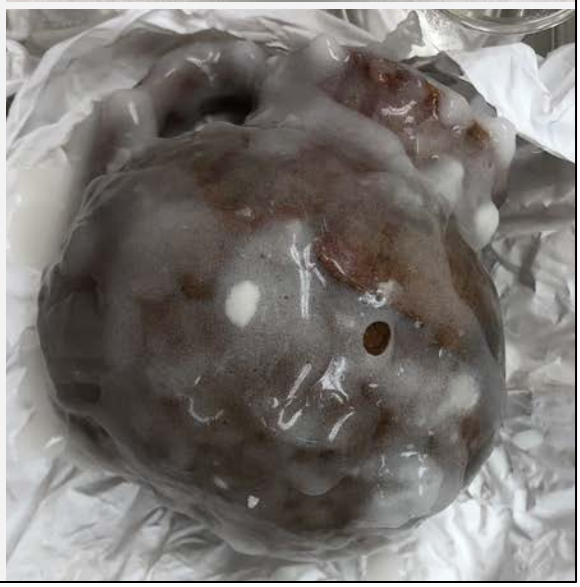
Small samples were removed from poultices and measured with Horiba LAQUATwin EC-33 Spot Conductivity Meter.

LIMESTONE STELA

- Measured every 3-4 days, later 1-2 weeks
- 12 sample zones averaged

CERAMIC VESSEL

- Measured every day, later 5-7 days
- Single measurements, then averages of 3



Samples were extracted with a 6 mm metal punch, and measured with a Horiba LAQUATwin EC-33 Conductivity Meter. Measurements were recorded in milli-Siemens per centimeter. Readings were initially taken from the limestone stela every 3 - 4 days and later every 1-2 weeks as the treatment continued. Samples were taken from 12 locations across the recto, verso, and edges. Because the conductivity of the gel on the ceramic vessel seemed to change rapidly at first, readings were taken approximately every 1-2 days from 2-3 locations.

APPLICATION

CHANGING THE POULTICE

Each object required multiple applications of the gel poultice to maintain desalination progress. The poultices peeled off relatively easily. We observed that the earlier, saltier poultices were less rigid than the later applications which drew comparatively fewer salts.

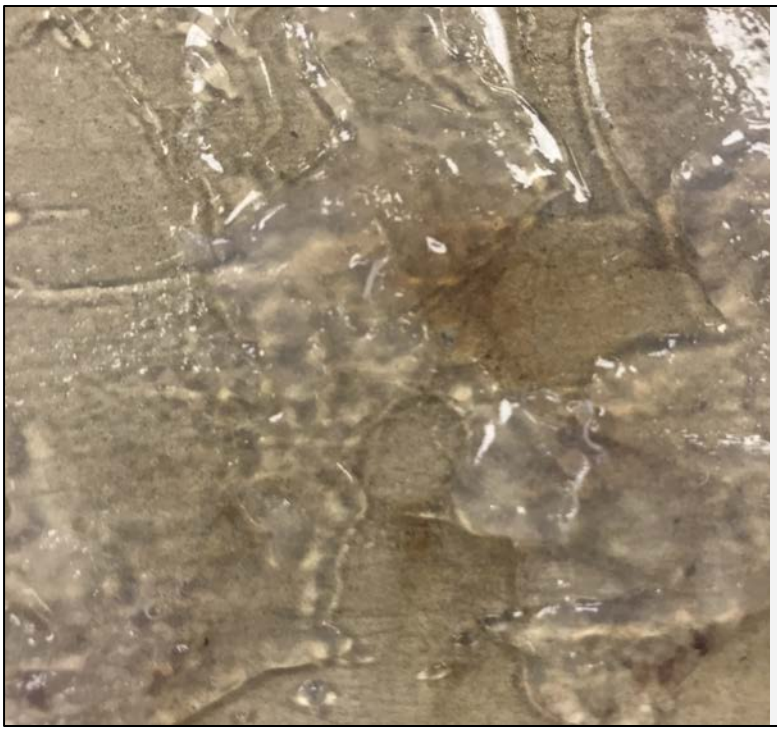
In the case of the limestone stela, the appearance of biogrowth typically determined the endpoint for each application, more so than a plateau in the conductivity readings. Following the 1st application, we added the preservative phenoxyethanol (2 drops per 100 mL of gel). If only a few small areas of growth were observed, they were cut away and cotton soaked with 70% ethanol was applied to the area. When growth became more substantial, the poultice was completely removed, any superficial biogrowth treated, and a new poultice applied. Once the desalination endpoint was reached, we applied a final “rinse” application of agarose without the ion exchange resin or preservative, to pull any preservative residues. Determination of the endpoint will be discussed in the results section.

APPLICATION

THE WRAP-UP

- Stela is currently slowly equilibrating to ambient RH, tracked with a HOBO datalogger placed underneath.
- Facing was removed and excess Paraloid B-72 reduced.
- Any dried gel residue will be carefully vacuumed.
- Separated fragments will be re-attached.

Desalination of the limestone stela continued through the COVID-19 shutdown. We have been able to access the lab on a limited basis for research as part of Emory University's Phase 2 Reopening in June. Following the final agarose-only rinse application, the jars of water have been removed from the tent and the sides have been opened to increase air circulation. The stela continues to equilibrate to ambient RH, as progress is tracked by a HOBO datalogger placed underneath. Since this image was taken, the muslin facing has been released, and some excess B-72 reduced. There is no visible gel residue on the carved surface, but the entire stela will be examined and gently vacuumed where necessary to remove any dried gel. Detached fragments will be re-attached.



04

THE RESULTS

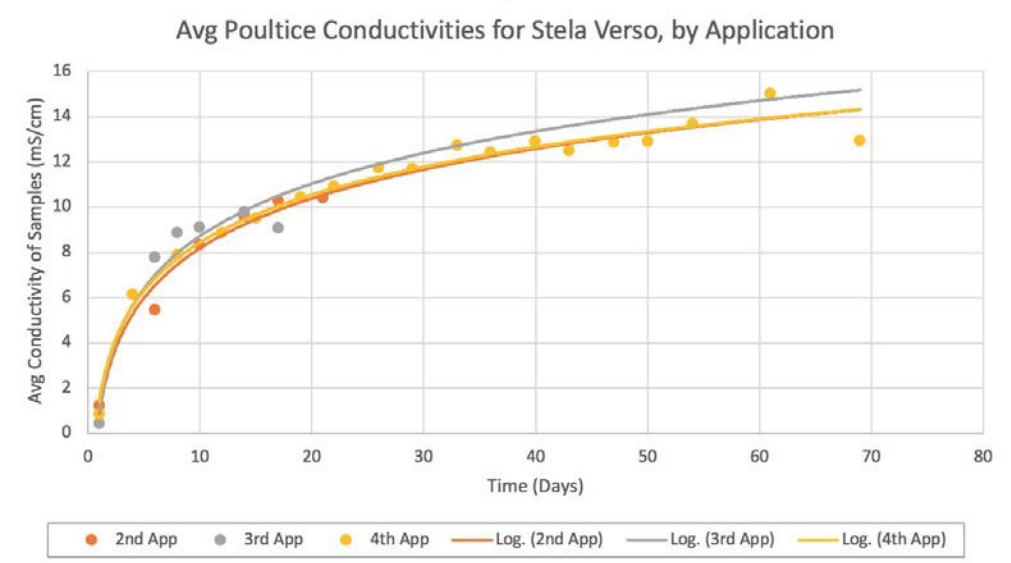
Results for Limestone Stela

Results for Ceramic Vessel

Desalination of the ceramic vessel occurred over the course of 33 days before the final agarose “rinse” application. Desalination of the limestone stela took just under 43 weeks [299 days], including the agarose rinse applications. Progress was somewhat slower for the stela, probably due to the thickness, as well as the potentially greater salt content. We were fortunate to be able to check on the poultice and monitor biogrowth on occasion in spite of the shutdown.

R E S U L T S

STELA VERSO



The stela was first treated with the carved surface (recto) face-down so that the gel was applied to the back (verso) and all sides together. In this graph, the average of multiple conductivity measurements are plotted as a function of the number of days elapsed since application. The agarose-only rinse application is excluded. In the case of the stela recto, shown here, the first poultice application has also been excluded from the graph. As will be shared in the lessons learned section, this first poultice had very poor surface contact, which resulted in low conductivity values that were not representative of the desalination progress.

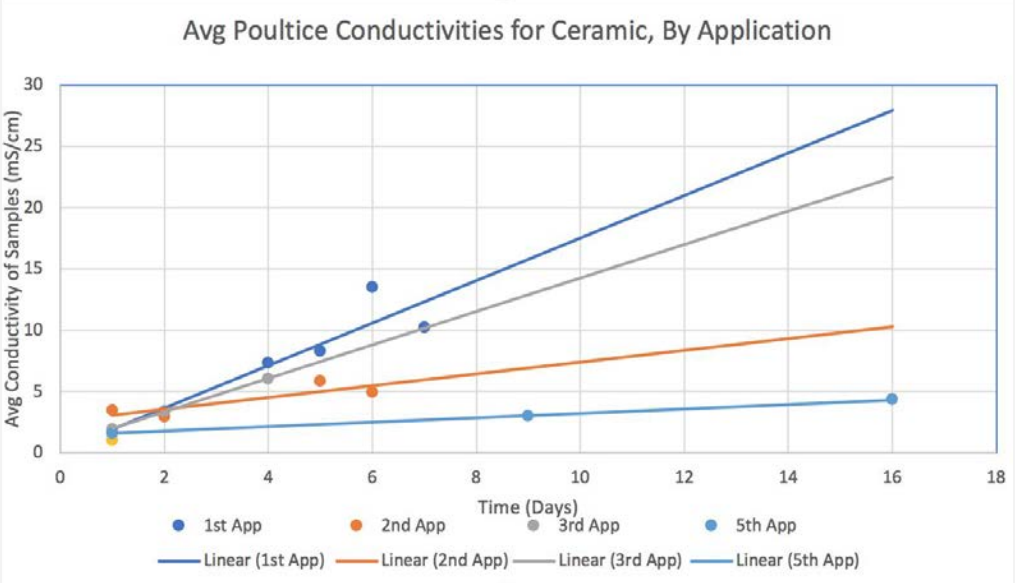
The positive slopes of the trendlines indicate that salts were extracted throughout the desalination process. For all applications, the logarithmic trendline shows that desalination occurred more rapidly at first and then slowed, which would be expected as the salt concentration gradient between the poultice and limestone decreases.

Conductivity measurements throughout the fourth application were lower than the third, suggesting the process had reached its endpoint. As further confirmation, a sample of this fourth poultice was removed from the stela and placed onto a test slab of limestone that had been soaked in saturated salt solution and allowed to dry. The conductivity of this relocated sample of the fourth poultice demonstrated that the poultice had the capacity to extract more if salts were available. We therefore concluded that the soluble salts had been sufficiently extracted from the verso and

edges of the stela.

R E S U L T S

CERAMIC VESSEL



Interestingly, the change in conductivity of the ceramic poultices (whether as a function of a single measurement or later as averages) displays a linear relationship. Instead of a rapid desalination followed by a period of deceleration, the extraction seemed to occur steadily from the first to the last day of conductivity measurement. Recall that this treatment occurred over a period of weeks, rather than months needed for the stela.

The first application showed the most rapid extraction, followed by the third application, the second application, and the fifth application. The third application was comparatively shorter and had fewer conductivity measurements, possibly obscuring the record of progress. In general, additional measurements would aid in obtaining a clearer perspective on the progress of each application.

Note that the fourth and sixth applications are excluded. These were both rinse applications of only agarose. The ceramic vessel desalination actually occurred in two distinct phases divided by several months on display when the newly renovated Ancient Near East galleries first opened. The stability of the vessel was significantly improved by the first 3 poultice applications, allowing it to be displayed as requested by the curator. Its condition on display was closely monitored, and no additional efflorescence, spalling, or flaking was noted during this time. Anticipating that more salts could be extracted, a 5th desalination poultice was applied, followed by a final

rinse with just agarose.

05
LESSONS LEARNED

And here are some of the lessons we learned and changes we made along the way...

M O D I F I C A T I O N S

HOT PLATE

Hot plate --> microwave

- Less evaporation, and reduced amount of liquid needed
- Able to use visual cues to assess gel consistency instead of a thermometer

We made the original gel on a hot plate to maintain close control over the temperature. Microwaving was not only faster, but also reduced evaporation and thus made the mixture more precise without the complexity of compensating for lost water. This ease was crucial when making multiple large batches. While thorough heating of large quantities of gel in the microwave is challenging, longer heating increments interspersed with intense mixing allowed the opportunity to confirm the eventual melting of the agarose into a uniform gel from a simple aqueous dispersion.

M O D I F I C A T I O N S

BUFFER

- Previously used a buffer formulated with citric acid and NaOH
- Switched to pH-adjusted water
  - Acetic acid/NH_4OH formula
  - Volatile salt

The agarose/ ion exchange resin mixture was originally formulated with a buffer solution mixed from citric acid and sodium hydroxide in order to counteract any unpredictable variations in pH. Because both components could function over a wide pH range, we opted to switch to the pH-adjusted water recipe. Formulated with a weak acid and a weak base, this formula has the advantage of only partial dissociation into substituent ions. Furthermore, the salt of acetic acid/ammonium hydroxide is volatile.

MODIFICATIONS

TREATING FACES

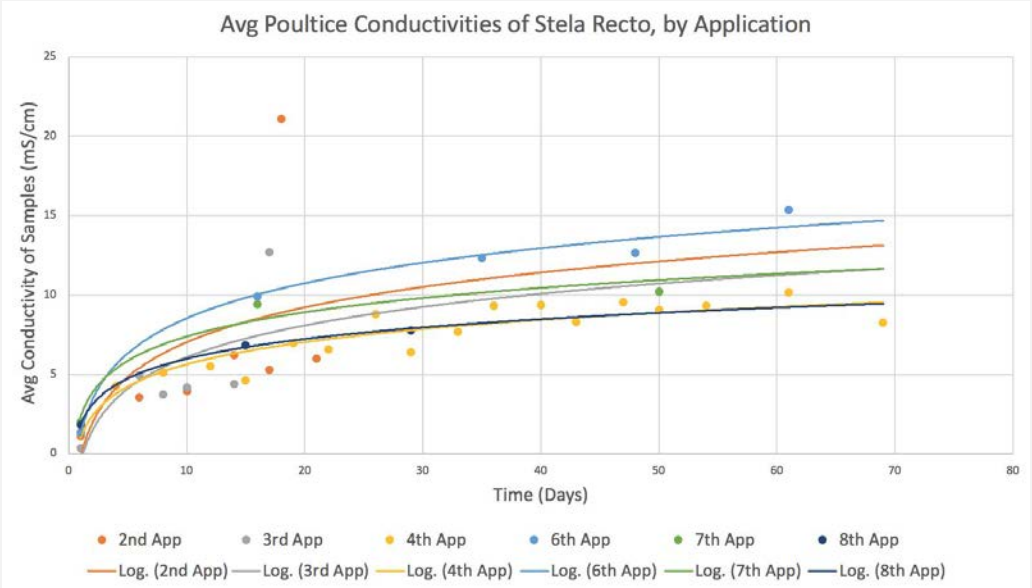
Stela eventually rotated in order to focus on one face at a time

- Poor gel contact on underside, even with screened trays and support
- Extended treatment time

It was possible to poultice the interior and exterior surfaces of the small vessel simultaneously. We had thought that it might be preferable and even necessary to also poultice all surfaces of the stela at once to continue extraction in all directions. As such, we devised and constructed a screened tray system to apply the poultice to the recto surface on the underside. Sufficient contact was not maintained after several applications, so we continued treatment of the verso and sides to the endpoint, and turned the stela over to treat the carved recto separately.

R E S U L T S

STELA RECTO



The recto therefore had more total applications of the poultice, the results of which are shown here. Saturation and high humidity were maintained throughout the treatment, which seemed to allow the salts to remain mobile. Much like the desalination of the verso and edge faces, each application effectively exhibited rapid desalination, followed by a deceleration period. By the eighth application, we decided desalination was reasonably complete based on the increasingly lower conductivities over successive applications and more rigid gels. Note that because of the unpredictability of biogrowth and the unfortunate onset of COVID-19 closures, later applications have many fewer measurements than others.

MODIFICATIONS

MAINTAINING MOISTURE

- Cracking, shrinking, lifting of poultice observed
- Need for surface contact improvement by reducing water loss
  - Re-wetting protocol
  - Dartek shroud
  - Weighted blanket in bag atop Dartek
  - Additional 70% ethanol jars

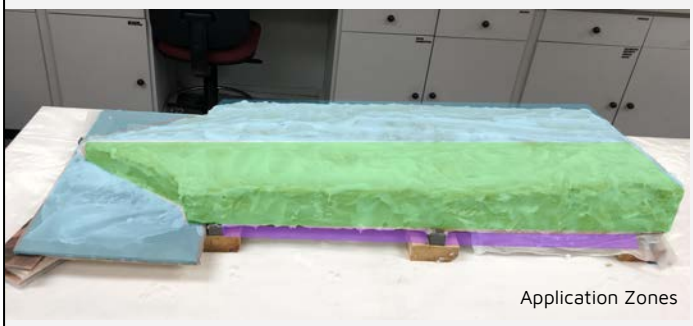
Full saturation of the object prior to desalination is crucial for the wet system to be effective. Even after fully spraying down the stela and wrapping it in soaking wet sheets overnight the limestone still took in an excess amount of water from the first poultice, which caused it to shrink, crack, and lift. We addressed this by re-wetting the surface, adding a Dartek shroud, and placing a weighted blanket sealed in a plastic bag directly atop. We also placed additional jars of 70% ethanol in water inside the humidity chamber.

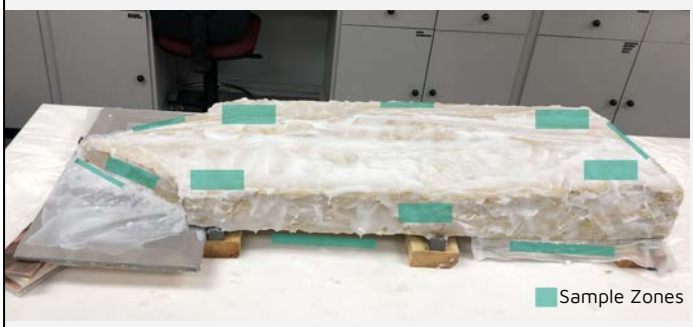
MODIFICATIONS

COUNTERACTING BIOGROWTH

- Gel cut away and stela surface treated with cotton soaked in 70% ethanol whenever growth appeared
- Preservative added after 1st application
  - 2 drops Phenoxyethanol per 100 mL gel
  - End treatment with "rinse" application of agarose only
- Light exposure was key
- Substitute plastic for wood supports

The appearance of biogrowth was unsurprising, given the sustained high humidity. Our reactive solutions were to cut out the affected agarose and treat the area locally with cotton wadding soaked in 70% ethanol in water. Our proactive solutions consisted of adding phenoxyethanol to the gel formulation following the first application, and applying a final rinse poultice of just agarose. We found in each instance that light exposure appeared to mitigate the biogrowth significantly. Substituting plastic for the wood supports might be another improvement.





M O N I T O R I N G

THE PROGRESS

- Early variation in measurements
  - Led to averaging 3+ samples
  - Division into “zones”
- Measurement frequency
  - More in first week
  - Fewer needed as desalination progressed
- Salt absorption caused loss of gel cohesion and rigidity
  - Early applications harder to fully remove
  - Removal of later applications easier as desalination progressed

We observed that conductivity values could vary widely across the poulticed surface and decided to average the measurements to represent the progress of each application. We also noted that conductivity increased more rapidly in the first few days after a poultice was applied, so more frequent readings during the first week are useful. As the poultice remains in place, this increase in conductivity will taper and fewer readings, weekly or perhaps bi-weekly, are sufficient to track progress. We also observed that as the agarose poultice absorbed salts, it lost some cohesion and rigidity. This suggests that as the desalination reaches an endpoint, the gels should be more rigid and more easily removed.

M O N I T O R I N G

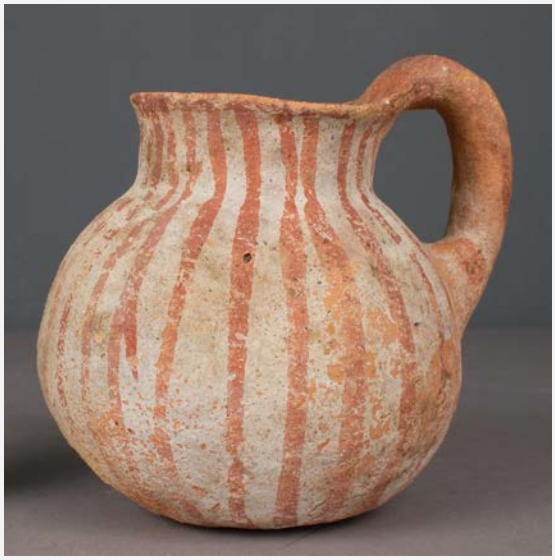
INVALUABLE TOOLS

- 2L Silicone microwave-safe mixing bowl
- Kitchen-size immersion blender
- Spot conductivity meter (Horiba LAQUATwin EC-33 Conductivity Meter)
- 6mm hollow carbon steel hole punch with wide-chip interior flute for taking samples
- Wooden skewer or handle of swab for extracting samples from punch
- Silicone-tipped flat chisel Colour Shaper for manipulating sample onto sensor

A number of tools proved invaluable. For mixing quantities, a 2L microwave-safe silicone mixing bowl and a kitchen-size immersion blender were well-sized for the task. Taking uniformly-sized samples was aided by the use of a 6mm hollow carbon steel hole punch cutter, with a wide-chip interior flute to allow for easy sample extraction with a wooden swab end. A silicone-tipped flat chisel Colour Shaper was used to manipulate the sample into place on the sensor of the conductivity meter; the soft tip provided gentle pressure without scratching the sensor.

F U T U R E

RESEARCH QUESTIONS



- Optimal formulations and duration for
  - Salt characterization
  - Substrate composition
  - Substrate porosity
  - Substrate pore size
- Effect of ion exchange resin on gel pore size and porosity
- Identification of objective measurable endpoint

Ceramic Vessel AT

Our experimental trials were short in duration and were devised with a direct view to the specific treatments at hand. Much more experimental research could be executed to determine the optimal formulation of the poultice gel, especially as it relates to precise salt characterization and also to the composition, porosity, and pore size of the substrate.

While the pore size is a less significant factor for a wet, diffusion-based poultice system, it should be noted that the addition of the ion exchange resin to the agarose gel likely affects the pore size, distribution, and porosity of the rigid gel. With further experimental testing, an even more effective combination of agarose and ion exchange resin may yet be determined for wet or dry systems.

Identification of an objective measurable endpoint continues to be of interest. Preliminary calculations suggest that it may be possible to compare the rate of extraction during a single poultice application with the surface area of the poultice and volume of the object. Such an equation might provide a numeric endpoint, allowing for balance of beneficial prolonged slow extraction against the inevitable risk of biogrowth.

THE CONCLUSION

EFFECTIVE.

- Maintain system saturation
- Deter and treat biogrowth
- Ion exchange resin may increase rate of desalination in early stages
- Weigh object sensitivity against projected limitations

Limestone Stela After Desalination

Using a semi-rigid agarose gel as a wet poultice system for desalination of limestone and low-fired ceramic objects is effective. Attention must be paid to maintaining saturation of the substrate-gel poultice system, and the onset of biogrowth must be monitored over the course of each application. Adding an ion exchange resin may slightly accelerate salt extraction in the very earliest stages, but more research is needed to establish the degree to which this component is beneficial and how it is affected by the concentration of gel components. Ultimately, an object's condition and potential sensitivity to immersion must be weighed against project limitations of time and materials costs.

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S E L E C T E D

REFERENCES

Bertasa, M., Chiantore, O., Poli, T., Riedo, C., di Tullio, V., Canevali, C., Sansonetti, A., and Scalarone, D. 2017. "A study of commercial agar gels as cleaning materials." In *Gels in the Conservation of Art*, edited by L.V. Angelova et al. London: Archetype Publications Ltd. 11-18.

Cremonesi, P. 2013. "Rigid gels and enzyme cleaning." *New Insights into the Cleaning of Paintings: Proceedings from the Cleaning 2010 International Conference, Universidad Politecnica de Valencia and Museum Conservation Institute.* 179-183.

Cremonesi, P. 2016. "Surface cleaning? Yes, freshly grated Agar gel, please." *Studies in Conservation, 61* (6). 362-367.

Cremonesi, P. and Casoli, A. 2017. "Thermo-reversible rigid agar hydrogels: their properties and action in cleaning." In *Gels in the Conservation of Art*, edited by L.V. Angelova et al. London: Archetype Publications Ltd. 19-28.

Dinator, Michele. "It Works! First Steps Towards a New Gel Based Treatment for Salt Extraction in Archaeological Pottery." 47th Annual Meeting in New England. American Institute for Conservation. Mohegan Sun, Uncasville, CT. 16 May 2019. Poster presentation.

Martins, J., Dionisio, A., and Neves, O. 2017. "Agar gel for anca limestone desalination." *Procedia Earth and Planetary Science, 17*, 754-757.

Pel, L., Sawdy, A., Voronia, V. 2010. "Physical principles and efficiency of salt extraction by poulticing." *Journal of Cultural Heritage* (11). 59-67.

Sansonetti ,A., Casati, M., Striova, J., Canevali, C., Anzani, M., and Rabbolini, A. "A cleaning method based on the use of agar gels: New tests and perspectives." *12th International Congress on the Deterioration and Conservation of Stone.* Columbia University, New York, 2012.

Sawdy, A., Lubelli, B., Voronina, V., Pel, L. 2010. "Optimizing the Extraction of Soluble Salts from Porous Materials by Poultices." *Studies in Conservation, 55* (1). 26-40.

These are a few of the references we consulted for this project. A more extensive list will be included in our post-prints paper.