Coating Challenges in Cultural Heritage Conservation

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In 2008, a project between the National Park Service and the Warren Lasch Conservation Center (WLCC) of Clemson University Restoration Institute was initiated to develop a protocol for conservation treatment on a selected set of ordnance and metal architectural elements at South Carolina's Fort Sumter National Monument, to include Fort Moultrie.

One of the key purposes of this research, and a factor that sets this project apart in the field of conservation, is the ability to provide comparative testing of several removal methods as well as coating products on historic metal substrates. Preliminary testing on coupons and substrates with no historic provenance has been running alongside laboratory and on-site testing on actual historic artifacts throughout the complex chronology of the project.

The manner in which the project was designed from its inception, as a collaborative research effort, has made this work possible. Continuous, open, and effective communication between the different entities—Federal, State, and private—has been crucial in defining a goal and executing a plan that is achievable and sustainable, while contributing considerably to research and education within the multifaceted field of preservation and stewardship of cultural heritage.

CONSERVATION AND ETHICS

The American Institute for Conservation of Historic and Artistic Works (AIC) definition of conservation states: "*Conservation is the profession devoted to the preservation of cultural property for the future. Conservation activities include examination, documentation, treatment, and preventive care, supported by research and education.*" In its simplest form, active conservation can be divided into two major subcategories: stabilization and restoration. It should be said that due to ethical considerations the primary focus must be on stabilization so as to minimize the amount of restoration. Stabilization is essentially the "*treatment procedures intended to maintain the integrity of cultural property and to minimize deterioration*" (AIC Directory, 2009). Restoration, on the other hand, is "*intended to return cultural property to a known or assumed state, often through the addition of non-original material.*" Any such addition, particularly where the condition of the artifact does not call for it and is therefore unnecessary, is generally deemed to negatively affect the authenticity and thus the value of the object or artifact.

As stated previously, the main goal of conservation is to stabilize an artifact of significance. This usually means that there is a problem involved with the artifact in question. With this in mind, a very standardized protocol layout for a conservation project may involve the following steps:

1. Condition Assessment,
2. Identification of Causes for Defects,
3. Developing a Treatment Plan, Methodologies and Materials.

The last stage should also include crucial factors such as the budget, schedule, the client's needs or requirements, ethical considerations and potential limitations or constraints (e.g., health and safety, access, political or social impact) to completing the project. As the final step, any conservation approach should include a written and carefully presented post-treatment plan, or a maintenance plan. This latter should also be thoroughly discussed with the stakeholder or entity in charge of maintaining the artifact in the future.

With further regards to ethics, particularly where coatings and consolidants are concerned, it is imperative to assess and evaluate whether applying a coating or a consolidant is absolutely necessary to the survival of the artifact in question. As stated, from the conservation perspective, coating an artifact means introducing a foreign or an alien component, which, in turn, may present further considerations relating to stability in the future. Therefore, predictive assessments of the effects on the artifact and potential benefits, if any, are essential. For instance, such assessments would investigate changes to the appearance, the weight, or the structural integrity of the artifact.

COATING CONSIDERATIONS

Today, coatings are present in every single aspect of our lives. The general public rarely appreciates the entire range of values a coating can bring. At times, coatings are obvious and just admired for their beauty and shine, like car finishes. To the opposite, they become ignored or taken for granted when they are less noticeable. The average consumer may not realize, for instance, the soda they enjoy comes from an aluminum can with an inner coating applied during manufacturing that makes the drink safe and secures its taste. Coatings used for corrosion protection on aircraft superstructures or military anti-detection are other examples where they may be overlooked. Ultimately, coatings are essential to our everyday life in beautifying and protecting objects.

The field of conservation is in constant need of resins, polymers, or coatings to treat a wide variety of materials, including metal, wood, concrete, glass, ceramic, or composites, to cite just a few. These resins or polymers will be called an adhesive, consolidant, or coating depending on the object to conserve and its state of degradation. The same resin may have more than one purpose. Ideally, an adhesive fills the gaps between pieces, adheres to both surfaces, and creates a strong interface between them. A consolidant provides structural strength by impregnation of an object which makes it closely related to an adhesive, while a coating provides surface protection, and is often thought of as a pigmented layer on a surface.

Because of the nature of conservation and its requirements towards using polymers and resins, the general term *coatings* covers a wide range of systems. Varnishes and lacquers are unpigmented coatings, typically hard and glossy. Paints are usually suspensions of a solid pigment in a suitable liquid applied to a substrate or surface which dries into a solid film. Mixtures of polymer and pigment in the form of finely dispersed particles in suspension in a liquid are called emulsion paints. Finally, enamels and glazes may include a polymer and have a gloss-like appearance.

A great deal of consideration is given to which coating will best fit the conservation job. When talking about consolidation which is, in most cases, considered an irreversible process, only materials with proven stability should be employed. Resins which deteriorate rapidly by yellowing or oxidation or crosslink upon aging are not wise choices for treating objects.

Upon the assessment of an adequate coating system, several factors are taken into consideration, including surface finish desired, presence of surface details (decoration, stamps, makers marks, inscriptions), setting process adequacy, minimal shrinkage, surface cleanliness, wetting ability and adhesion, inertness towards object, type of barrier properties needed, service life cycle, user friendliness, deterioration mechanism, and environmental issues. Other properties to take into consideration are mechanical strength and, most importantly, reversibility: will the polymer be completely removable without harm to the object or will it be retreatable and/or recoatable in the future?

Inherent polymer properties, such as number and weight average molecular weights (M_n, M_w), their distribution, and glass transition temperature (T_g) should be considered to choose the best fitted system for a given conservation treatment and to predict its future behavior.

M_n gives information about properties which are only sensitive to the number of molecules present; therefore it gives indications on the polymer reactivity. On the other hand, M_w gives information about properties depending not only on the number of molecules present but also on their size or weight. For instance, polymer strength will be determined by the M_w. In conservation, a polymer slightly weaker than the object will be favored. Moreover, a thermoplastic with a relatively low M_w will be favored over a crosslinked polymer which will be difficult to revert or completely remove.

The glass transition temperature gives an accurate indication of the softness of a polymer. A too soft system will lead to dirt pick-up, and a too stiff one will lead to cracking under stress. As a rule of thumb, coating systems used in

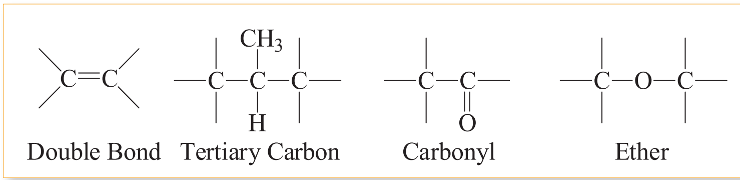


Figure 1—Destabilizing groups in polymer structure.

conservation have glass transition temperatures around room temperature, and never exceed 65°C, so they are durable and hard enough to withstand wear and dirt pick-up.

The setting process is an important consideration when a coating has to be applied to an object, as it can be applied as a liquid, a molten liquid, a liquid or gas pre-polymer, a film-forming emulsion or dispersion, or a polymer solution. Additionally, as in the case of acrylic polymers, they can be applied in solution, emulsion, pressure-sensitive adhesives, or prepolymers, with the application technique depending on the polymer role and the circumstance of its application.

COATINGS HISTORICALLY USED IN CONSERVATION

Materials historically used in conservation have evolved for the most part due to inadequate aging characteristics (light instability, flammability, or oxidation). Until the late 19th century, starches, plant gums and resins, proteins, glues, albumin, waxes, and fats constituted the first pool of materials utilized in conservation. Still widely used drying oils, alkyds, and a wider variety of resins became available as techniques and trades developed. In the early 1920s, cellulose derivatives and silicon compounds started to be utilized and constituted the first synthetic polymers to find applications in conservation. Another important class of widely used systems is solvent coatings. Shellac, a natural resin considered to be the oldest coating material, is hard to remove due to crosslinking upon aging. Cellulose nitrate can be used as an adhesive or a coating but shrinkage and brittleness occur once the solvent, often butyl acetate, evaporates. Moreover, nitric acid can be released by chemical degradation. Acrylic lacquers referred to by the name of Paraloids in the conservation field are light stable, remain soluble, and are easily reverted and, as such, are among the preferred choices for conservators. A formulation containing poly(methylmethacrylate) (PMMA) will be prone to stiffness, brittleness, and cracking under stress. The addition of a plasticizer can solve the issue. However, this will slowly evaporate with time which will become a problem when talking about conservation lifetime. Another way to go against brittleness is to choose formulations containing monomers with larger side chains than methyl methacrylate.

In situ polymerization systems constitute more complex formulations. Such systems include oil-based paints, alkyds, and multi-components mixtures (epoxy-based, polyurethane, or urea-formaldehyde). Natural fatty oil-based systems undergo a slow crosslinking process between oxygen and double bonds present in the polymer which make these systems susceptible to dirt pick-up and possible yellowing. Additionally, as oxygen diffusion is inherent to curing, the surface might cure faster than the bulk of the coating and confer surface shrinkage. A faster curing process might be obtained with alkyds and multi-component coating systems.

DETERIORATION/DEGRADATION OF POLYMERS

Polymer degradation translates into physical and chemical property changes which are often provoked by external factors such as heat, light, oxygen, and the presence of pollutants or impurities. Oxidation and photolytic deterioration are by far the most damaging and often occur due to impurities or additives in a formulation and not the polymer itself, as long as polymer backbones containing oxygen, double bonds, or highly reactive side chains are avoided. Destabilizing groups (*Figure* 1) will trigger crosslinking and chain scission separately or simultaneously which makes the cause of a failure difficult to diagnose. These two antagonistic mechanisms affecting the polymer properties can be introduced in a polymer structure during polymerization, processing, or aging. While crosslinking is the most inappropriate outcome as it leads to insolubility and irreversibility, chain scission results in a decrease in molecular weight which weakens the polymer. To guide conservators in their choice towards the best fitted coating system, a benchmark lifetime classification of materials was established in 1975 by Feller.[1] This four-class system provides a projected useful lifetime on the basis of accelerated aging tests. Ideally, conservators aim at polymer systems which provide 20–100 years of protection (*Table* 1).

Table 1—Projected Useful Lifetime Classification of Materials on the Basis of Accelerated Aging Tests

Class		Projected Useful Lifetime	Classification
T		Up to 6 months	Temporary contact
C		< 20 years	Unstable
B		20 to 100 years	Intermediate
A	A2	> 100 years	Excellent
	A1	> 500 years	

Polymer assessments prior to and upon aging are important parts of determining the suitability of a protective coating system for a given conservation treatment. However, standard tests used in the industry for commercial evaluation are rarely of direct relevance to conservation applications. Additionally, conservators have limited access to relevant industrial specifications, standard test results, and research investigations on polymer and coating formulation properties, mainly because the latter are costly, performed for commercial reasons, and are time-consuming.

Even though polymers used in conservation need to follow the same stringent specifications and regulations as industrial materials, evaluation methods available to conservators are simpler and less costly. Often, investigations are limited to monitoring setting properties, solubility, dirt pick-up, adhesion, and accelerated aging. The latter is a crude approximation of the natural aging process and is designed to determine the main cause of possible damage by bringing materials to extreme conditions.

COATING PRE-REMOVAL CONSIDERATIONS

Once a coating failure has been identified and the symptoms and the extent have been determined, the causes will need to be considered: the environment to which the artifact in question is subjected, the possibility of pre-existing issues (previously undetected or overlooked), inadequate or inappropriate surface preparation in the past, vandalism, or simply wear and tear from visitors' access to the artifacts.

Another commonly found issue in the case of cultural heritage is the presence of contradictory components of historical significance. Such is often the case with historic paint or coating layers on a range of historic substrates. The coating layers may be perceived as the inherent cause of the instability problem of the artifact, but the question remains: is removal ethical?

Figure 2—Bolt and nut assembly on an Endicott gun emplacement containing lead.

In addition, a frequent problem with historic coating layers is the presence of toxic components, such as lead (*Figure* 2). Thus, a decision must be made whether to break into the coating layers and expose the toxic constituents, or determine if it is possible to leave everything in place and simply seal in the problem. Should the latter decision be favored, further questions arise: if only the topmost layers of the pre-existing coating system have failed, while the layers containing lead are not only historic, but also provide the best protective performance, to what extent should removal be carried out? How would the underlying presence of lead affect the maintenance cycle of the artifact? How compatible is the historic coating system with the new system? For instance, the limitations of applying a zinc-rich primer to a non-prepared surface and the inherent failures associated with such an approach are well known.

In addition to visual assessment and mapping of failures, assessment of the coating condition may be carried out using various different methodologies largely adopted into the cultural heritage field from the industry. These methods include but are not limited to holiday/continuity testing, thickness testing, and adhesion testing.[2-3]

REVERSAL/REMOVAL TECHNIQUES

There is a range of different cleaning or removal systems that are available for coatings, whether they are historic or not. Abrasive systems are still very popular overall and some would argue they still achieve the most appropriate surface preparation for a substrate. Yet other alternatives have started emerging more recently, some of which might be more acceptable from the conservation point of view—methods that are considered to cause the minimum amount of alteration to the artifact.

Mechanical or Hand Tool Cleaning is an old-time favorite within the field of conservation. While commonly recognized to be slow and limited in its removal capabilities, the method is viewed as gentle on the artifact and substrate—if used correctly. Hence, the definition of goals prior to intervention is essential. If using this technique, achieving the ideal surface preparation to receive the coating system of choice is unlikely. Consequently, an earlier possibility of coating failure must be considered when constructing a maintenance plan.

Abrasive Blasting is an industrial preference. This *is* also used within conservation, but is usually employed with the softest blasting media such as walnut shell or plastic beads. Again, this may not achieve the required surface preparation outcome, but also results in minimum alteration to the artifact surface (*Figure* 3).

Figure 3—Abrasive blasting performed on mortar tube by Phillips Industrial Services.

A potential issue when using particulate abrasives on substrates with varying degrees of porosity or surface integrity is contamination of the substrate through embedding. This, in turn, may not only affect the performance of the coating applied, but may even act as a potential catalyst for corrosion.

Dry Ice and Sodium Bicarbonate methods are not considered to leave particulates or residues within or on the metal and are in many ways gentler than the so-called traditional abrasive methods. The former is known to sublime after contact with the substrate, while the latter is water-soluble and thus can be rinsed off. However, for every plus, there is a minus. These media may not be as effective as other abrasives, and these methods are often associated with high cost.

An important consideration when discussing abrasive methods as a whole is that of containment. Not only are there environmental regulations that need to be take into consideration and followed, but also health and safety protocols need to be in place and practiced. Since the majority of cultural heritage is accessible to the public, and will rely on revenue generated from visitation, it is imperative that any containment take into account public safety, access, and effects on the visitor experience.

Chemical Stripping is also a favorite within the field of conservation, mainly due to the availability and ease of use of a varied range of products. As with the mechanical or hand tool methods, chemical strippers may be more appropriate for smaller scale jobs. A significant benefit is that application of these to a fragile and detailed artifact surface is possible, since the risk of physical or mechanical damage is minimal. However, chemical means can be difficult to control in terms of the extent of removal from one coating layer to another. They are also more likely to leave behind residues, which can at times be pushed far into the porous artifact, causing further problems. In addition, some of these have quite extensive dwell times, which may not be feasible, particularly on outdoor artifacts and at public sites.

Water Jetting is an alternative to the abrasive and chemical methods, in that it is not likely to scour the substrate, and it will not drive particulates or chemicals into the artifact. There is a wide range of pressures available, allowing for the method to be tailored to each individual task. The Society for Protective Coatings (SSPC) has divided these into four categories:

- Low-pressure water cleaning (LPWC) is the use of water pressure less than 5,000psi (34 MPa)
- High-pressure water cleaning (HPWC) is the use of water pressure between 5,000 to 10,000psi (34–70 MPa)
- High-pressure water jetting (HPWJ) is the use of water pressure between 10,000 to 25,000psi (70–170 MPa)
- Ultrahigh-pressure water jetting is the use of pressures above 25,000psi (170 MPa)

From the conservation point of view, this last method is considered reasonably gentle. In addition, particularly in the case of metallic substrates, it is thought to wash out soluble salts like chlorides, which are linked to active corrosion processes.[4] Further remediation of salts may also be achieved by simple addition of corrosion inhibitors to the water during the cleaning process. The effectiveness of this washing method in potentially stabilizing or preventing further corrosion on historic artifacts that are known to have undergone considerable corrosion processes prior to treatment requires further research and investigation. In addition, while removing the soluble salts out of the metal is a desirable outcome, pushing moisture into the artifact may not be, particularly if the means of thoroughly drying it prior to coating application are not available.

Pressure itself may also be a problem. Lower pressures may not produce the required degree of removal, but are appropriate for the requirements of the artifact. However, higher pressures allow for better removal of failed coatings, but are likely to damage the artifact. Limitations may also be posed by containment issues with run-off of the treatment solution into the soil and waterways. Another issue may be the difficulty and cost of getting equipment to some remote sites, particularly if a water source is not readily available at that particular site.

Laser Cleaning (Ablation) has been gaining ground within the cultural heritage field recently, for obvious reasons. Being gentle, controllable, and versatile, changes to the substrate characteristics are minimized and also no particulates or residues are left behind. The technique shows promise for cultural heritage items, but is currently largely limited for one single factor—cost.

Superheated Water and Wet Abrasive Systems have been gaining popularity within the conservation circles in Europe. They were designed primarily for the purposes of stone conservation, but they are widely applicable for other materials too. Both systems use pressurized water, one in the form of *superheated* water without an abrasive, while the other uses a vortex with abrasive action. From the conservation point of view, there are various benefits to these systems, not least of which is how non-invasive they are on the substrate. In addition, with the superheated system, there are no residues or particulates left behind, and since superheated water is utilized, there is no wetness left on the substrate for any extended period of time. Naturally, there are limitations associated with these methodologies as well, for example, clogging of the wet abrasive system may be possible. Unfortunately, there is no known current supplier for either within North America.

PRE-COATING APPLICATION CONSIDERATIONS

Upon completion of the cleaning process, another condition assessment must be completed, focusing on the condition of the underlying artifact. The condition assessment process will once again involve visual assessment, with digital photography and a full written narrative. This core of assessment methodology may be complemented by further analytical tools, such as X-radiography, micro-Raman and micro-FTIR spectrometry techniques, handheld X-ray fluorescence (XRF) and variable pressure scanning electron microscopy (VP-SEM), energy dispersive spectroscopy (EDS), to identify substrate and corrosion product composition, superficial chloride levels, remains or residues of previous treatment campaigns just to cite a few.

It is here that the presence and degree of active corrosion becomes particularly crucial. It is likely that the standard surface preparation methods of removing all active corrosion and corrosion crusts will lead to damaging or even destroying the artifact, so naturally, other means need to be considered. There is an ongoing discussion as to whether the use of products such as corrosion inhibitors or rust converters might be beneficial when conserving cultural heritage. Some would argue that corrosion inhibitors are only useful on fresh metal surfaces, which, ultimately, is never the case with historic artifacts. Also, rust converters are known to have a benefit in stabilizing the pre-existing corrosion surface but this may only be a temporary solution to the problem. The long-term effects and performance of such products are still largely unknown. Will these products applied still be deterring corrosion processes 50–75 years from now? Or are they in fact causing further problems? In addition, rust converters are intended for superficial corrosion. If the product is allowed to diffuse through the pores and layers to the core metal what happens deep within the artifact is still undetermined.

Overall, there are various considerations to be taken into account when selecting a coating system for an item of cultural significance. Prior to application the conservator must understand and to a degree predict what the effects of coating system on the artifact will be, and what the expected outcomes may be in the long term. For instance, if inscriptions or fine surface detail are present, will these become obscured by the coating layers? A decision must be made as to the extent the artifact requires coating. For example, components such as copper alloy parts, which often have a beautiful historic and protective patina, will not require coating. Additional considerations include method of application, cost–benefit analysis, future removal methods, and re-coatability challenges. All of this will be built into the maintenance and monitoring plan which is artifact specific constructed to meet the needs and interests of the artifact, the collection, the site, and all stakeholders involved.

CASE STUDY: FORT MOULTRIE AND FORT SUMTER NATIONAL MONUMENT

National Park Service Mission and Goals

"The National Park Service will protect, preserve, and foster appreciation of the cultural resources in its custody and demonstrate its respect for the peoples traditionally associated with those resources through appropriate programs of research, planning, and stewardship."[5]

Description of Project

In 2008, a collaborative arrangement was set up between Clemson University and the National Park Service to research and implement ways of sustainably managing metallic cultural heritage items located at two forts based in Charleston, SC—namely Fort Moultrie and Fort Sumter. The aim of the agreement was to assess current management and maintenance practices at the two sites, and, where deemed necessary, establish new, conservation-focused approaches to preserve the selected items for the enjoyment of future generations.

Students from the Historic Preservation Program first conducted a full inventory and condition survey of selected historic ordnance and metal architectural elements at the forts. Fabrication and repair of these metal objects have occurred from the early 1800s to the present. The majority of the large cannon located at Fort Moultrie were fabricated in the mid-1800s, while the objects associated with the Endicott Era (Batteries Bingham and McCorkle) were fabricated circa 1900. Other miscellaneous objects were fabricated and repaired over the 20th century. Some of these objects witnessed the conflict of the Civil War, and thus hold a position of great value and significance within American history.

These objects consist of two main types: large ordnance cannons, and miscellaneous architectural elements such as doors, artillery platforms, railings, and steps. Approximately 20 pieces of ordnance are currently emplaced at Fort Moultrie. Of these, six were initially selected by the National Park Service for study and treatment using the recommended protocols developed by this investigation: two Endicott rifles, a 10-in. Columbiad tube, a 7-in. triple-banded Brooke tube, and a 13-in. Seacoast mortar tube with carriage. All of these artifacts are constructed primarily of ferrous materials, with the Endicott guns and one Columbiad having copper alloy components.

The aim of the research was to develop assessment and treatment protocols that could be applicable to the entire collection of ordnance at Forts Moultrie and Sumter. Similarly, the objective was to develop and apply a protocol for the treatment of selected metal architectural elements.

Fort Moultrie, Sullivan's Island, SC

A fort was first built on Sullivan's Island from palmetto logs to protect the area against the English invasion in 1776. Known as Fort Sullivan originally, the name was changed to Fort Moultrie after the efforts of General William Moultrie during the Battle of Sullivan's Island on June 28, 1776. The fort underwent a range of fortifications until the years of World War II and is now functioning as an interactive museum site, depicting multiple stages of coastal defense history in the area (*Figure* 4).

Fort Sumter, Charleston SC

Although named after the South Carolina Revolutionary War patriot Thomas Sumter, the fort is actually a much later construction in comparison to Fort Moultrie. The construction was commenced in 1829 and was one of a series of coastal fortifications commissioned after the war of 1812. The site immediately went into action at the beginning of the Civil War when the opening shots were fired from here on April 12, 1861 (*Figure* 5).

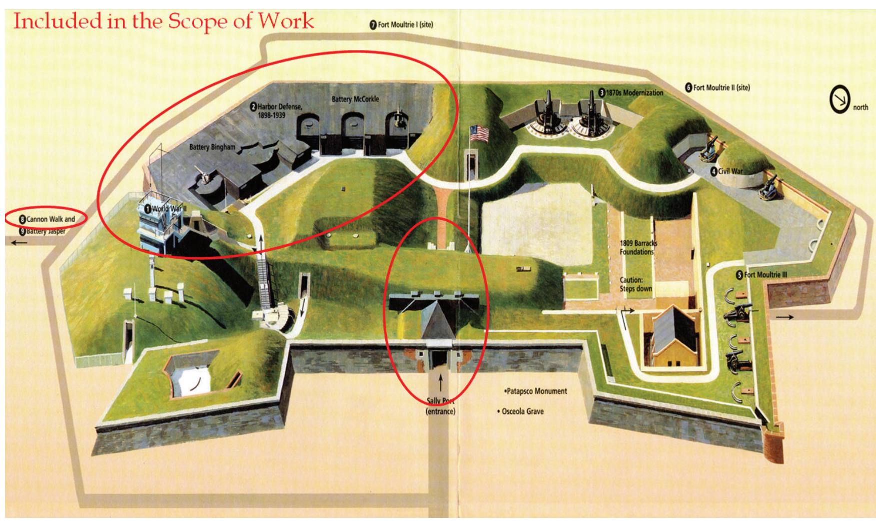


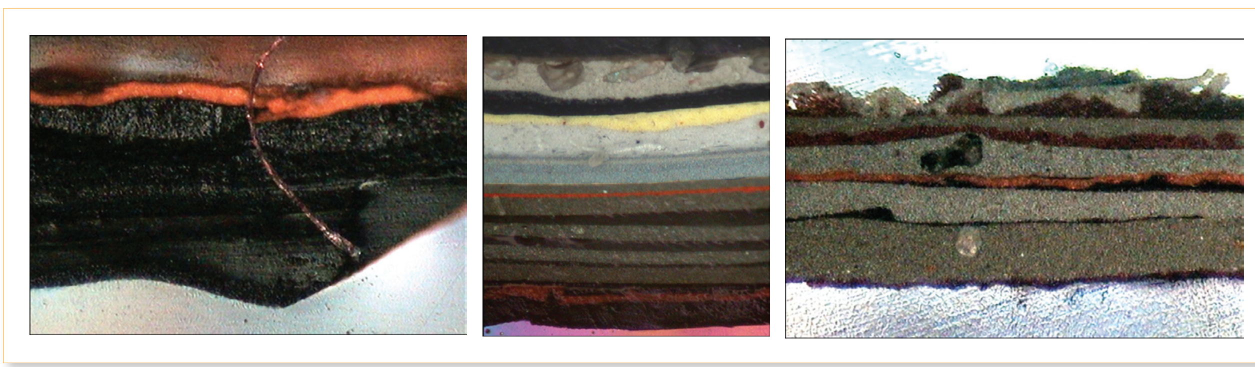
Figure 4—Current layout of Fort Moultrie, Sullivan's Island, SC, showing the areas included in the scope of work.

Figure 5—Current layout of Fort Sumter in Charleston Harbor.

Assessment, Identification, and Analysis

The first phases of the project involved carrying out surveys and assessments at the sites, to not only select the artifacts, but also to gather all possible information and data on the selected historic items. These phases involved consulting with various personnel within the National Park Service and thoroughly researching any existing records to establish origin, accession, removal, repair or addition of components, and previous treatments of the artifacts in question. Following these so-called desk-based assessments, full condition assessments of the items were carried out as discussed previously. Hence, a thorough account and record of the condition of the artifact and its conservation needs could be established.

As mentioned earlier, identification of the extent of prior coating campaigns and the existing coating composition is fundamental to designing a proper course forward. Optical microscopy and VP-SEM were utilized to observe cross-sections of paint chips, embedded in resin, which were collected on the different elements considered in this study. *Figure* 6 shows paint stratigraphies on three different items considered around Fort Moultrie. Of specific interest is the presence of an orange layer close to the surface of the object most likely to be lead. Furthermore, VP-SEM/EDS was performed to determine the elemental composition of the different layers of paint. *Figure* 7 illustrates a line scan obtained by EDS of the paint layer cross section of the Endicott gun located at Battery Bingham. This technique consistently identified the presence of lead in the orange layer mentioned earlier. *Figure* 8 depicts the elemental analysis of a cross section from the railing at Battery Bingham established by VP-SEM/EDS mapping. VP-SEM/EDS is a powerful technique to obtain quantitative and qualitative paint composition. A handheld XRF was also utilized to determine elemental composition, including the presence of salts and lead when sampling was not an option and analysis had to be performed on site.



A B C

Figure 6—Paint layer cross sections from (A) railing Battery Bingham; (B) railing deck of the Harbor Entrance Control Post; and (C) Endicott gun.

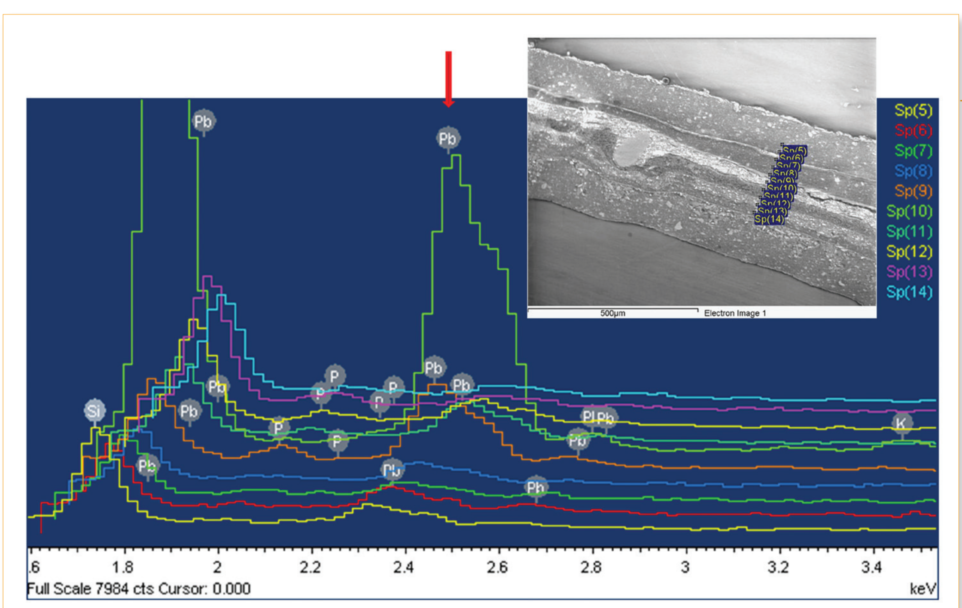


Figure 7—EDS line scan of paint layer cross-section of Endicott gun at Battery Bingham.

Micro-Raman spectroscopy is the technique of choice to identify the various iron oxide corrosion products present on the different elements to be conserved (*Figures* 9 and 10). This was an important step in the analytical assessment as it assisted in verifying if corrosion was active or passive. The presence of Akagenéite, as shown in *Figure* 11, was observed in most cases which translates to active corrosion catalyzed by constant contact with salt in the environment, especially where bare metal is present.

Decision-Making Process

Once all the data collection, analysis, and interpretation of the results had been completed, a standardized decision-making process was devised to ensure an all-encompassing, fluid method for all the artifacts. Two flow charts (shown in *Figures* 12A and 12B) were developed to enable this process.

The first flow chart was intended for the artifact itself, assessing considerations such as authenticity, significance, the condition and the location of potential problems, and the approaches required to gain and retain the most information possible of that artifact. The second flow chart was in turn more focused on the pre-existing coating; its condition, whether removal would be necessary, to what extent and what system would be the most appropriate to replace it.

Prioritization Process

Another standardized process developed and utilized for all the items was the prioritization process for treatment. Based on the condition assessment, the need and urgency of treatment from the conservation point of view was clearly understood. However, prioritization based on condition alone is not feasible or ethical when encoun-

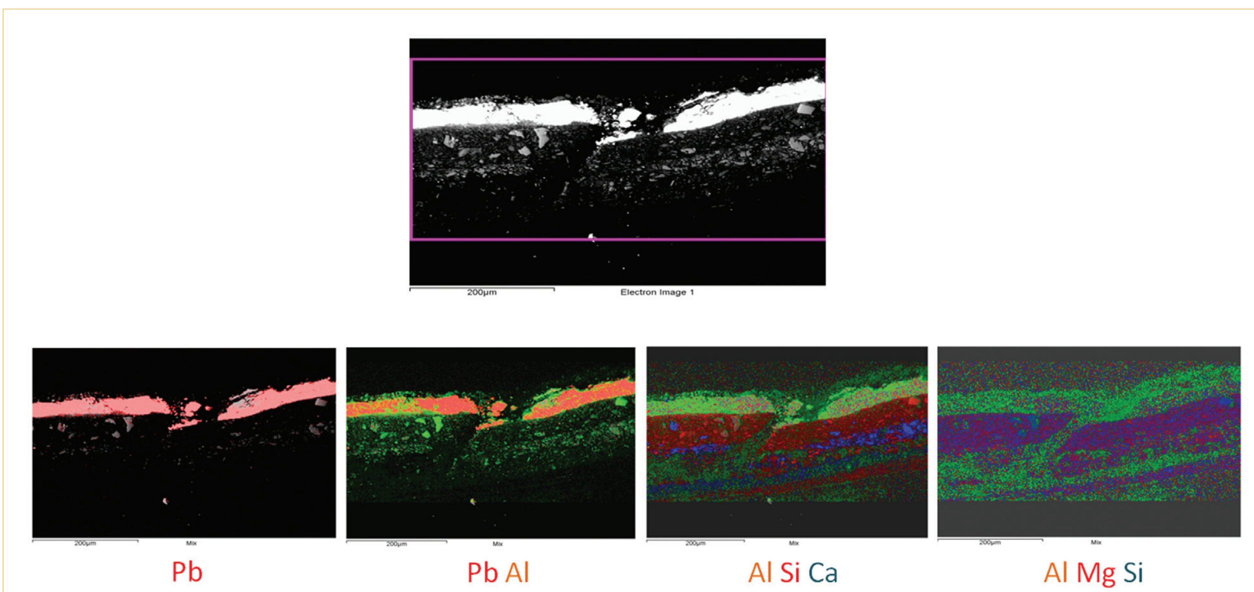


Figure 8—VP-SEM/EDS mapping of paint layer cross-section of the railing at Battery Bingham.

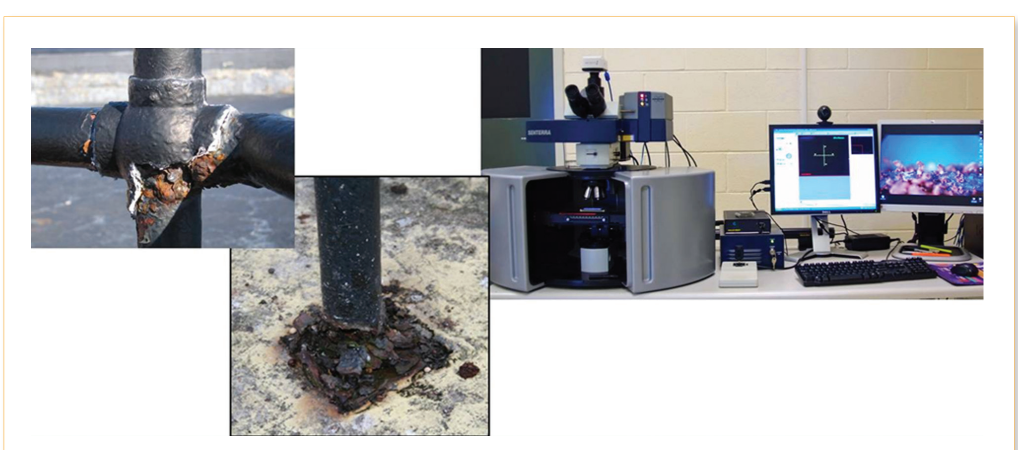


Figure 9—Active corrosion on battery railing elements was investigated using micro-Raman spectroscopy.

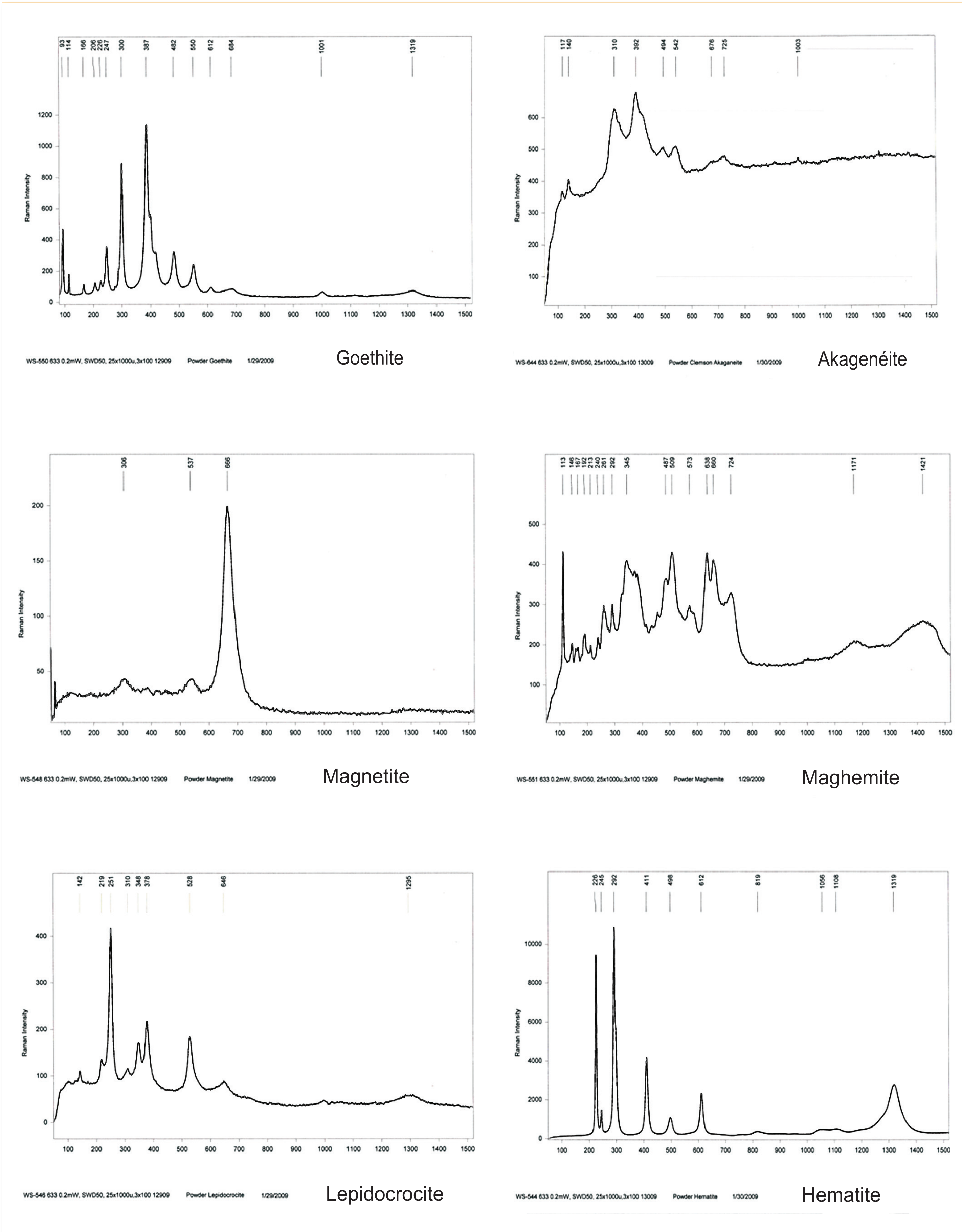


Figure 10—Raman spectra of iron oxide corrosion products.

tered with tangible cultural heritage. Historical significance must play an equally important role, but, like the former, cannot be considered as a lone-standing criterion. A perfect example of where effective communication is absolute key is an exercise of listing such criteria together for each artifact and by such means prioritizing artifacts for order of treatment. It is fair to say that the prioritization process was possibly one of the more challenging tasks within this complex project, and was truly only made possible by the combined effort and fluid communication between all stakeholders. A segment of the results of the prioritization process can be seen in *Table* 2.

Repair versus Replace

Another important consideration with projects such as the one exemplified here is the concept of repair and/or replace. Although never a desired outcome or solution,

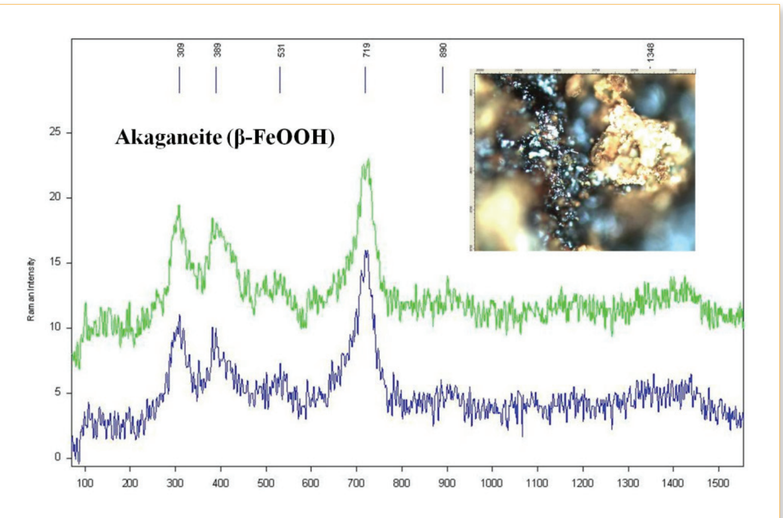


Figure 11—Raman spectra of Akagenéite as found on various ferrous artifacts.

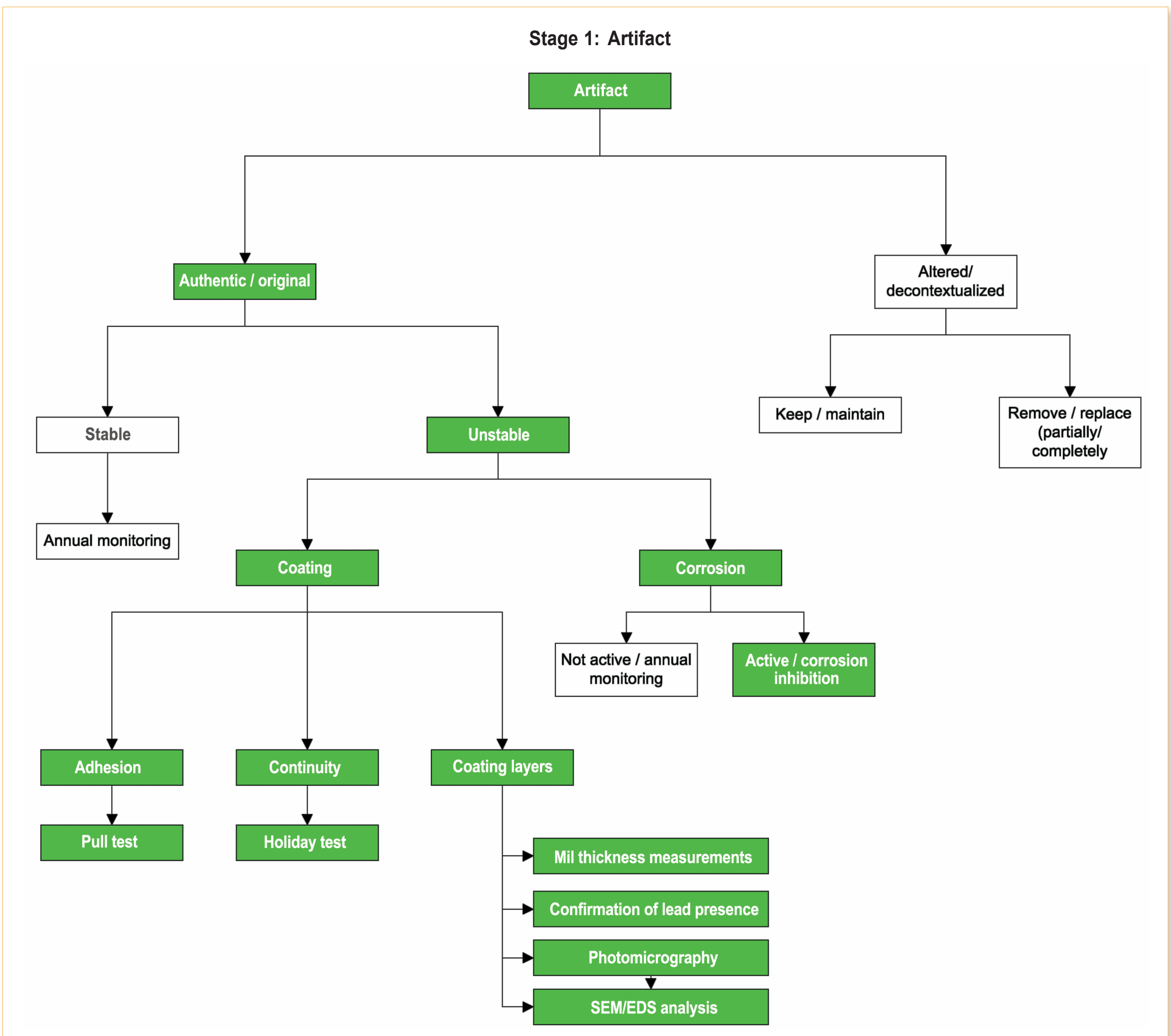


Figure 12A—Decision-making flow chart.

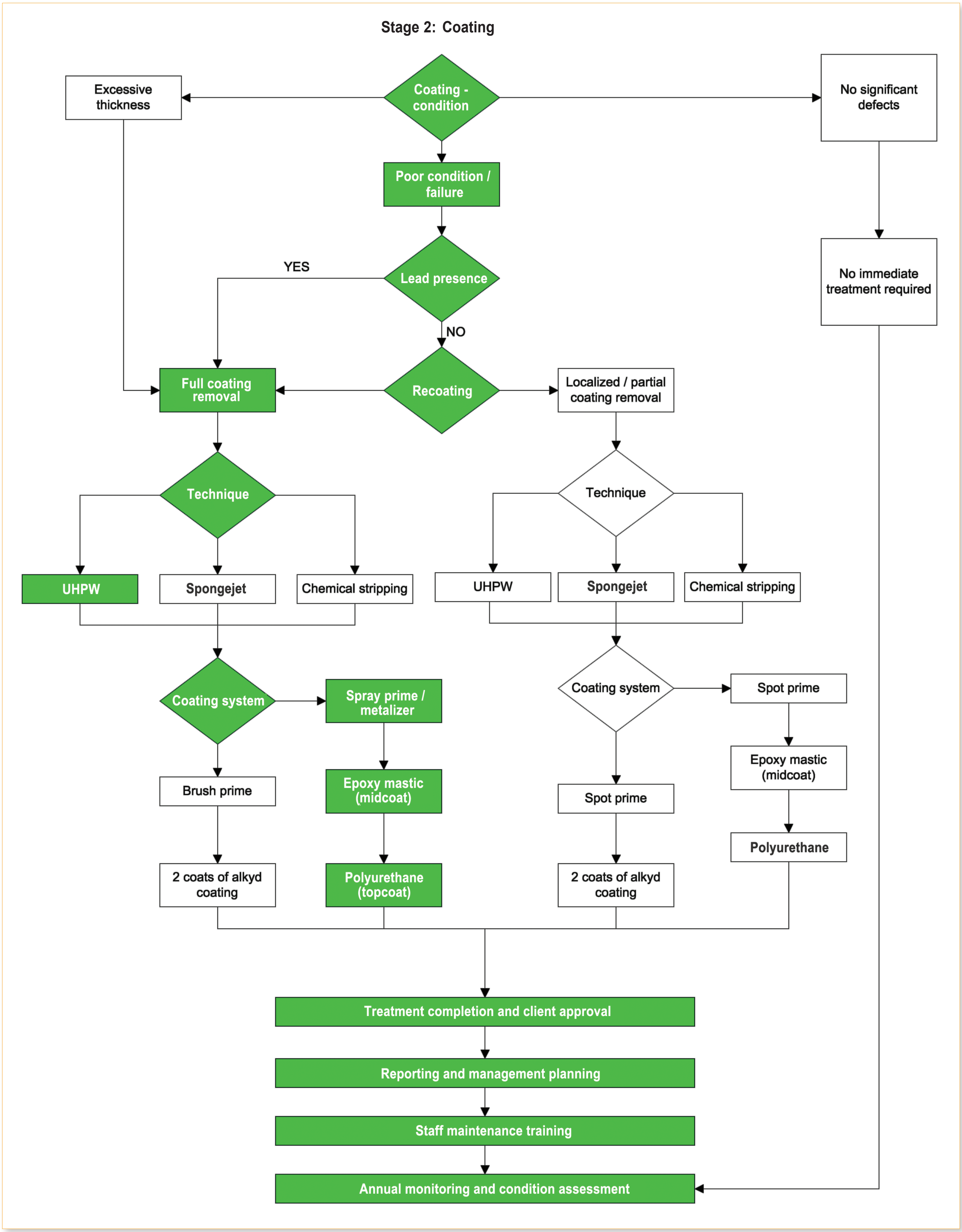


Figure 12B—Decision-making flow chart.

Table 2—Example of Prioritization Process for Treatment Followed in This Case Study

Artifact	Historical Significance	Treatment Urgency	Pb Present	Removal Method	Coating Type
Seacoast mortar	Very high	Very high	No	Abrasive	Epoxy-urethane
Carriage	Not original	Very high	No	To be replaced	
Bingham rifle	Very high	Medium	Yes	SpongeJet	Epoxy-urethane
10" Columbiad #1	High	High	No	Abrasive	Alkyd
10" Columbiad #2	High	High	No	Abrasive	Epoxy-urethane

there are instances where replicating an item of cultural heritage or part of one is the only option. This is particularly true where the item has a structural role and is simply no longer fit for purpose. This was the case with some items at Fort Moultrie, where, for example, the 13 in. Seacoast mortar tube carriage was not only found to be severely corroding, but also from the typological studies, evidence of fabrication processes and comparison with similar items, was found to be a later addition to the tube itself. Therefore, after thorough documentation and recording, the carriage was removed, and a new, more accurate replica constructed. Another similar situation was discovered with some angle supports underneath the decking of one of the gun emplacements within the fort, where the supports had lost a remarkable amount of their load bearing capability through corrosion and, thus, raised a safety concern. New supports were fabricated to not only support the decking, but also to typologically match the originals.

Coating Solutions Available; Comparison of Coating Systems

As explained, one of the main objectives of the project has been to develop options for the National Park Service to allow for more sustainable and cost-effective management and maintenance of their items of cultural heritage. Extensive testing and comparison of performance of different coating systems against each other is currently in progress. Some 20 coating systems have been applied to steel coupons with different surface preparation levels and placed on an exposure rack installed at the dock of Fort Sumter. Regular and continuous monitoring of the performance of these systems will be carried out over a number of years. Also, "real-life" testing of some of these systems on selected historic items at both forts has been allowed by the National Park Service. In an extremely rare opportunity to quantitatively assess coating performance on actual historic substrates, comparative studies are being carried out on the performance of an oil-based alkyd system, previously selected by the NPS for their maintenance protocol, versus a modern coating system recommended by the industry.

CONCLUSION

It can confidently be argued that what ultimately has made this project possible is effective communication between the different entities involved. It cannot be stressed how important constant liaison between the stakeholders, owners, conservators, scientists, manufacturers, service providers, and the industry is, although such communication may be challenging at times, mainly due to linguistic and terminological barriers from one discipline to another.

As stated above, education and outreach are a crucial component of this project. It has been widely understood across the different disciplines involved in the project that efforts and findings must be reported to the public and other potentially interested entities. Conservation is a profession that has a reputation of happening behind closed doors. However, this has been gradually changing and it is now widely recognized that communication along and across disciplines is vital for growth and development within the field.

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