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Understanding Architectural Iron Conservation: Corrosion Studies at Fort Sumter National Monument

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UNDERSTANDING ARCHITECTURAL IRON CONSERVATION: CORROSION STUDIES AT FORT SUMTER NATIONAL MONUMENT

A Thesis
Presented to
the Graduate Schools of
Clemson University and College of Charleston

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Historic Preservation

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by
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ABSTRACT

Iron is one of the most overlooked materials in architectural conservation. Its status as a functional construction material, rather than a decorative element, often makes iron the least understood material by architectural conservators. As historic metal becomes increasingly significant in the built environment, new approaches must be developed in order to better predict and understand the corrosion process. The behavior of corrosion has been extensively studied in the engineering and conservation communities, but the two fields have developed different approaches to iron conservation. Typically, engineers classify corrosion on a macroscopic scale, while conservators approach iron on a microscopic level. Both approaches are undeniably useful. There is, however, no middle ground between conservators, engineers, and contractors, to shape better-informed decisions regarding the sustainability, longevity, and integrity of historic iron.

Famous for its role in the Civil War, Fort Sumter is now largely a ruin with few original iron artifacts intact. History has not been kind to the fort and the metal has experienced decades of exposure to the harsh marine climate—burial in sand, and multiple rebuilding campaigns. Three well understood causes of iron corrosion, the atmosphere, context, and the metal's composition, were applied to the architectural iron at Fort Sumter to determine which aspect has the greatest impact. The temperature, wind, and airborne chloride levels were tracked at Fort Sumter to determine the atmospheric corrosivity level. As surrounding materials affect the exposure of embedded metal, each material was compared to see how its composition influenced the historic iron. A selection of iron objects was chosen for further analysis using X-ray fluorescence spectroscopy (XRF), Raman spectroscopy. By studying these aspects of iron corrosion, the National Park Service will be able to form a better understanding of the corrosion of historic ironwork and implement appropriate, sensitive conservation treatments.

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CHAPTER ONE
INTRODUCTION

Structural iron components in buildings have been in use since the late eighteenth century, though it was not until the Industrial Revolution that the use of structural iron exploded in America. Relatively easy to manufacture and strong, iron could be rolled or cast into forms that allowed builders to construct lighter, larger and stronger buildings while simultaneously forgoing the wasted space of thick masonry walls. At the heart of this technological development, were the officers of the Army Corps of Engineers. Under the leadership of Major General Joseph Totten, these men studied and tested a variety of new materials that would later be incorporated into many of the nation's premier buildings of the nineteenth century.

Prior to industrialization, iron manufacturing was done primarily by local refineries selling iron stock to neighboring blacksmiths. This resulted in iron that varied widely in composition and quality, depending on the manufacturer or blacksmith. By the mid-nineteenth century, manufacturing techniques had improved to a point that wrought iron could be rolled into larger, standardized shapes instead of solely being worked by hand. At the same time, cast iron forming techniques evolved to the point that it could be poured into an almost infinite number of shapes. Driving the demand for standardized iron manufacture, the developing engineering field needed iron that was consistent in quality that would be able to span longer distances and withstand heavier loads. By the time construction of Fort Sumter's barracks began in 1851, structural iron had gained popularity in American building practice. Fort Sumter in Charleston, South Carolina played a significant role in the development of the use of structural iron in the United States. Its engineers used the island fort as a laboratory to test and implement new uses for structural iron, though this role in American history has largely been eclipsed by its role at the start of the Civil War.

The problem of how best to approach the preservation and conservation of iron in mid-to late-nineteenth century buildings has become increasingly important. The historic preservation community has inherited a material that is famously unstable, expensive to

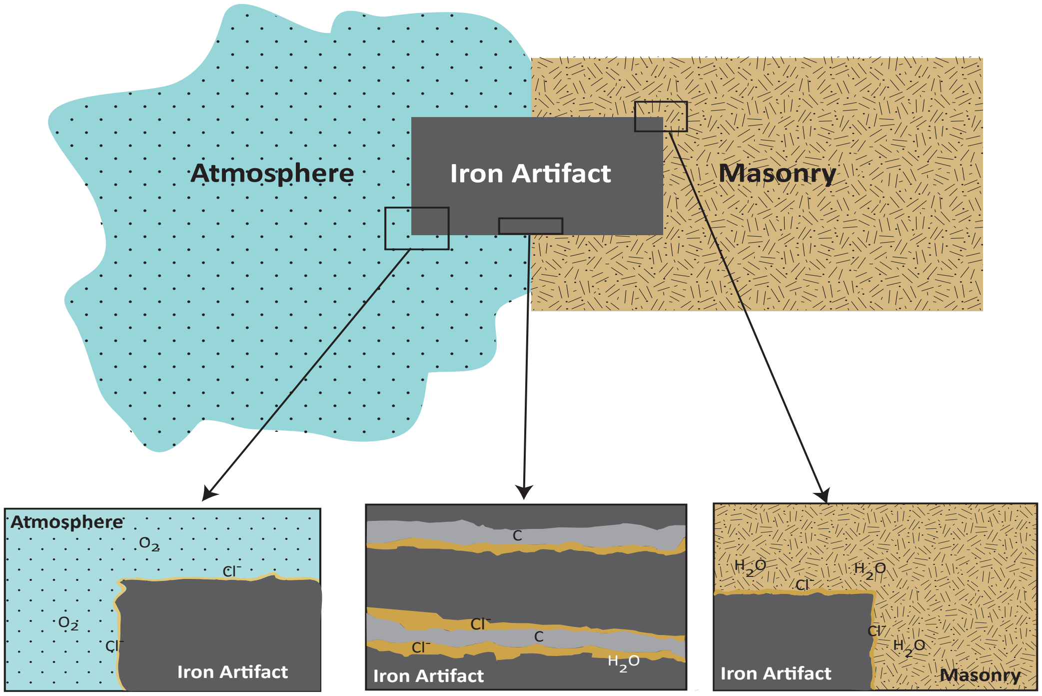

Figure 1.1 Three influential aspects to architectural iron corrosion. (drawn by author)

conserve and maintain, and, if left untreated, detrimental to surrounding material. For small objects, such as hinges and locks, it is often easier to remove the object completely and store it in climate-controlled settings. However, this option is not available for large pieces. Oxygen and rain are major, unending causes of corrosion and remain an inescapable part of architectural conservation. As an entire building cannot be moved to climate-controlled locations, architectural conservators' hands are often tied in terms of the treatment of significant architectural iron features. Cleaning and painting or replacing are often the only two cost-effective and efficient methods for treating historic iron. These options, while useful, are typically used only as a means to address the superficial conditions without further understanding why historic architectural iron is corroding. By only treating iron in a superficial manner, the historic material and its integrity cannot be fully assessed in a sensitive and informed manner.

Underneath the surface is a complex web of influences that work in conjunction with each other to dictate the long-term corrosion rate of iron. Some influences, such as water are inherently understood aspects of the corrosion process. Others are less obvious. Condensation promotes wet/dry cycles that drive the corrosion process. Salts are an invisible and detrimental force to ferrous objects in a coastal environment. Furthermore, a once protected embedded iron object can begin aggressively corroding due to water infiltration or cracks in a building. The atmosphere, surrounding materials, even the metal itself all contribute to the corrosion rate and pattern of architectural iron.

As buildings designed in the late-nineteen and early-twentieth century age and the original iron components corrode, actions must be taken to mitigate the effects of iron corrosion. Architectural iron is only increasing in popularity and the issue of its degradation will not disappear with time. It was this problem, or how to treat a historically important architectural iron piece in a sensitive and effective manner, that spurred the development of this thesis. In 2012, the tie rod in the fireplace along the Left Flank at Fort Sumter had corroded to the point that the structural stability of the entire fireplace was in jeopardy. At the time, the fireplace was believed to have been one of the last remaining remnants of the enlisted men's barracks, and the tie-rod was believed to be original. The instability of the fireplace was recognized by the staff at Fort Sumter National Monument, but the most appropriate treatment option for such a historically important piece was less clear. In order to understand the unique corrosion mechanism affecting the wrought iron tie rod, the larger more complex issue of the influences on architectural iron corrosion must first be understood. Ultimately, this thesis focused on analyzing the historic iron at Fort Sumter in order to determine what aspect of the corrosion process (atmosphere, surrounding materials, or internal structure), if any, was most influential in a building. The hope was to foster a discussion that will help the historic preservation field approach significant iron features in a more informed and sensitive manner and take early, informed actions to ensure the longest survival rate possible.

Fort Sumter serves as an excellent backdrop for this study. The fort's role in the Civil War plus its uniqueness as a nursery for new engineering thought and design, make Fort Sumter's remaining iron fragments important features in the fort. The bombardment and subsequent burial of the fort has allowed for the preservation of original iron pieces. However, due to the excavation in the 1950s and exposure to the harsh marine climate, the remaining original pieces are now threatened with more aggressive corrosion rates. Using Fort Sumter as the sole structure for analysis allowed for the opportunity to research multiple pieces in different states of degradation and varying settings. The United States Army kept meticulous records of the work done on the forts. Using this information, the manufacturer of each piece could be identified as well as dated to within ten years of its production. The known provenance of the iron fragments allowed for more comprehensive analysis of the forts multiple surroundings and microclimates. Finally, Fort Sumter National Monument is currently in the midst of a multi-year research contract with the Warren Lasch Conservation Center investigating the most appropriate methods for treating the fort's historic iron.

Chapter two examines the current European and American philosophies of architectural conservation in an attempt to understand the historical and current state of architectural iron conservation. Additionally, the chapter explores the history and current options available for examining and classifying types of corrosion. Emphasis is placed on exploring non-invasive and non-destructive analytical techniques.

The history of Fort Sumter is an important aspect to understanding the current conditions of its ironwork. Chapter four focuses on the Army Corps of Engineers' involvement in the growth of the science-based engineering field and the emergence of structural iron beams during the Industrial Revolution. The remaining iron objects at Fort Sumter were part of this growth, and thus, stand as a testament to one of the most influential and dramatic ages of American history. To better understand the existing iron's history and current conditions, a brief 'biography' of the remaining Civil War era ironwork is included.

Subsequent chapters examine three of the most commonly recognized aspects of iron corrosion. Starting at the broadest cause, chapter five discusses atmospheric corrosion of historic iron and the role that overall climatic conditions play in the corrosivity of the ironwork. Chapter six progresses to the surrounding materials, ultimately focusing on porosity and water absorption and its protective or destructive qualities in relation to embedded iron. Here, the results from previous studies were utilized in an attempt to minimize invasive testing. Chapter seven explores the origins and composition of cast and wrought iron and how the different internal structures affect an object's corrosion pattern. Micro-Raman Spectroscopy and Energy Dispersive Spectroscopy (EDS) were utilized to examine the aggressiveness of the current corrosion rate by examining the chlorine levels and corrosion products found on the interface of the metal.

Just as buildings are dynamic structures, so is iron corrosion. Each of the following chapters, on the history, atmosphere, surrounding materials, and type of metal could be further developed to more closely examine the current state of the ironwork at Fort Sumter National Monument. However, the individual study of one of these aspects only allows for a limited understanding of a larger, more complex issue. Each and every aspect of iron corrosion influences the others. In order to best understand the past, present, and future of significant architectural iron features, the entire system is best examined and understood.

CHAPTER TWO
MAKING THE CASE FOR MORE SENSITIVE APPROACHES TO IRON CONSERVATION

Architectural conservators often face the hard decision to replace or maintain historic fabric in order to ensure the longevity of a building. Sensitive conservation or restoration of any historic building is time-consuming and requires a significant capital. Because a historic structure typically needs to maintain its usefulness into the future, a restoration project often requires decisions to be made about what material or feature to save and what to replace. There are unequivocally many options to help make this assessment. One of the methods developed to facilitate making the decision between maintaining the historic fabric or replacing it with like materials is the concept of a character-defining feature of a building.[1]

A character-defining feature can manifest itself in almost any form and does not necessarily require the feature to be visible to the general observer.[2] Thus, a feature that receives this status can range from a highly visible iron gate to a hidden wooden summer beam. It can be argued that each piece plays an important role in the history of a structure, and the loss of either would result in a loss of integrity for the structure as a whole. Those architectural features that are typically awarded character-defining status are those features to which the public can easily relate. Historic preservation generally places a high priority on materials where the effects of the craftsmen are visible: masonry, interior finishes, and timber. Traditional wood and masonry construction are, for example, well-studied. On the other hand, architectural metals are often less studied and occupy a lower, sometimes sacrificial, role.

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1 An architectural feature is considered character-defining when its loss would result in the loss of a critical aspect of a historic structure. Without that feature, the building would neither maintain its integrity nor would it “read” as well as it would when the historic feature was in place.

2 The National Park Service has helped define the process for classifying features as “character-defining” and can be further discussed in: Lee H. Nelson, *Architectural Character: Identifying the Visual Aspects of Historic Buildings as an Aid to Preserving Their Character*, Preservation Brief 17 (Washington DC: United States Department of the Interior, National Park Service, Technical Preservation Services, 1988).

The archaeological and art conservation field and historic preservation have traditionally maintained separate identities in the United States. However, conservation in Europe embraces a wider range of professionals that work in both the art and architectural fields. Europeans address historic preservation issues from what Americans term as conservation. In the United States there has traditionally been a distinction between the historic preservation and conservation fields. In recent years, the American historic preservation approach is beginning to incorporate similar European ideals and ethics, but remains under a different label. For the purposes of this thesis, the term architectural conservation refers to the specific role the American conservator plays in the larger role of historic preservation.

Part conservator, part engineer, part artist, and part scientist, an architectural conservator has no clear job description. In charge of ensuring both the historic and structural integrities, its techniques are inherently more invasive than museum or archaeological conservation. Aylin Orbasli describes the European architectural conservation movement as "the sustainable management of change; it is not simply an architectural deliberation, but an economic and social issue. The concern of conservation is the past, present and future of a building."[3] Essentially, this means that when approaching a project, an architectural conservator must balance both the setting and context of a building as well as its material components. The historic preservation field chooses to conserve buildings for several reasons: nostalgia, promotion of tourism, and the development of cultural or even national identity. Few people would question the philosophical underpinning of modern historic preservation. However, some do question what and how buildings should be conserved.[4]

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[3] Aylin Orbasli, *Architectural Conservation: Principles and Practice* (Malden, MA: Blackwell Science, 2008), 38.

[4] The development of the idea of conservation and preservation is a long and difficult subject to understand, but if one is willing to tackle the subject David Lowenthal's *The Past is a Foreign Country* is a good place to start. David Lowenthal, *The Past Is a Foreign Country* (Cambridge: Cambridge University Press, 1985).

Over time, the conservation community developed a values-based approach to defining worth. The rarer the symbolic, historic, or the higher architectural or aesthetic level, the more valuable a structure was.[5] Most early preservation attempts focused on the historically important structures, (George Washington's Mount Vernon, for example) or high-style buildings (Frank Lloyd Wright's Fallingwater). As modern late-nineteenth century buildings aged and achieved historic status, the conservation community had to evolve as well. Buildings were no longer defined on their architectural or historic merit alone. Materials and rarity also became an essential judge in a structure's worth.[6]

The preservation movement traditionally focused on the buildings that highlighted the skill of the craftsman. Mystic Seaport has spent millions of dollars over the last ninety years saving, relocating, and conserving historic structures from across New England. The museum interprets the year 1876; however, more time is spent focusing on the dying era of the last true craftsmen than on the emergence of new and innovative construction technologies which occurred at the same time. The Henry DuPont Preservation Shipyard at Mystic Seaport devotes the majority of its resources to the museum's historic wooden ships that visibly bear the mark of the shipwrights who built them, instead of focusing on both the traditional and modern vessels.

During the same era when shipwrights were building wooden vessels, iron was manufactured in mills by machines and not through the skill of the local artisan unless it served a decorative function. Iron historically performed mundane tasks—clasped, bound, held, and closed. As fasteners were sacrificial and gates often not considered character-defining, preservationists, while highlighting some of the aspects of iron, quickly moved to other materials that were more craftsman oriented. For much of its history, architectural iron was considered impermanent due to its susceptibility to corrode. At Mystic Seaport's

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[5] Orbasli, 38.

[6] Paul Philippot, "Restoration from the Perspective of the Humanities" *Historical and Philosophical Issues in the Conservation of Cultural Heritage*, Readings in Conservation (Los Angeles: Getty Conservation Institute, 1996), 270.

shipyard, equally vulnerable and historic iron vessels are largely left to drown in their own corrosion.

From the very beginning, the aim of conserving buildings was to slow the process of decay.[7] Early iron structures are now historic because of their age and rarity. Yet, the preservation community continues to view historic iron's worth in the same manner as it did when the metal was a new, emerging structural material. Architectural conservators are more inclined to find inventive ways to conserve a historic summer beam *in situ* than they are to stabilize a corroding iron beam. For example, the historic Totten shutters at Fort Jefferson in the Florida Keys were corroding and causing the exterior scarp walls of the fort to jack and collapse. As a remedy, engineers and the Park Service chose to replace the shutters with fiberglass replicas. The end result was a fort that, while the replicas are visually similar, significant historic material was lost during the restoration treatment. By choosing to replace and not conserve an architectural element is to essentially remodel the past to what the public thinks it "should be."[8] An iron beam from 1865 is as historically important as the brick wall from the same period. It is often easier to replicate a historic iron feature than it would be to implement a sensitive conservation treatment. However, that does not mean that it is ethical to remove the historic metal artifact without significantly altering the context of the entire structure.

A discrepancy still exists in how architectural conservators view and rate a building's worth. Age, craftsmanship, rareness, and connection to historic figures all contribute to a structure's significance. A pre-Industrial Revolution building is valued for its uniqueness, its use of traditional materials, its role in society, as well as its historic importance. An early twentieth century building, like an industrial mill, while not as old, is valued for its role in society or historical importance, but few give thought to the longevity of the materials used for more modern buildings. For example, the Bethlehem Steel Stacks, in Bethlehem, Pennsylvania, have successfully been converted into a casino and events

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[7] Orbasli, 57.

[8] Lowenthal, 385.

venue that highlights the historic architectural features. However, the stacks themselves, some of the most visibly and historically important features, have received little attention and are being left to corrode away due to the lack of attention to their conservation. While the material of the stack is currently unremarkable, the lack of attention to the maintenance and preservation of the historic fabric may lead one day to the loss of the stacks' integrity, or at the very worst, loss of the stacks themselves. Thankfully, as our knowledge of a shared past develops, so does our recognition of the need to save those structures that help us understand our own cultural development.[9]

Architectural iron conservation today

Architectural conservators must carefully navigate a path full of unavoidable double standards. Authenticity and integrity are important terms, but it is rare to find two conservators who see an "authentic" building in the same way. An "authentic" structure can retain its original design, use, material, context and setting. An "authentic" building can be viewed as a structure that maintains the same appearance as it had during its period of significance. Buildings are meant to be used. In that light, the most authentic building would retain the same usage the architect or builder intended. Another conservator might view authenticity more in terms of materials. It is said that the most authentic building would be the one that retains the largest percentage of original fabric. The retention of original fabric allows people to study and better understand the past. Both are correct, but both cannot apply their own views without making compromises.[10]

Architectural conservators base their work around three guiding principles: preventative maintenance, minimal repairs, and significant modifications. These allow the historic material to be maintained as long as possible without compromising its structural integrity. A guiding principle across the conservation community is to choose the option

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[9] Lowenthal, 383-388; Orbasli, 57.

[10] Orbasli, 52.

that is least invasive and most reversible approach to a conservation project.[11] This principle has the advantage of requiring each conservator to acknowledge that no matter what is done during conservation, original fabric will suffer damage. Museum and archaeological conservators focus the majority of their work on having as little intervention with the objects they conserve as possible.[12] Architectural conservators have adopted the same values and ethics, but the nature of their work and the need to ensure structural stability means that their work is inherently more invasive than a conservator who works on smaller artifacts. A failed treatment for an art conservator would be a treatment that damages or irrevocability alters the material integrity or appearance of the artifact. Architectural conservators must contend not only with the material integrity but also the conservation of the design, context, and function of the building. A failed treatment for an architectural conservator would not only include significant loss of material, but also expands to incorporate the loss of the building or its potential for reuse. People expect not to be able to handle and manipulate conserved museum artifacts, but a building must still be used despite its "conserved" status.

This difficulty in finding a proper balance is made even more complicated when iron is the material being conserved. Brick, stone, and timber are relatively stable materials and can survive for long periods of time with little intervention. Iron is inherently unstable. Iron and its alloys, steel and cast iron, are completely man-made. Eventually, the material attempts to return to its more natural and stable form.[13] From the first moment historic iron was rolled from the foundry, it began a long and practically unstoppable process of corrosion. The material wants to return to its natural state of an ore. Making iron conservation even more difficult, corrosion is often expansive and as such, may compromise

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[11] Orbasli, 57; Giorgio Torraca, "The Scientist's Role in Historic Preservation with Particular Reference to Stone Conservation" *Historical and Philosophical Issues in the Conservation of Cultural Heritage*, Readings in Conservation (Los Angeles: Getty Conservation Institute, 1996), *443.*

[12] Readings, 443

[13] P. Lambert and A.R. Foster, "Modern Solutions to Historic Problems: Advanced Materials and Techniques in Heritage Applications," in *Structural Studies, Repairs and Maintenance of Heritage Architecture XI*, ed. C.A. Brebbin (Boston, MA: WIT Press, 2009), 175.

not just the integrity and durability of the metal objects but also that of the surrounding materials.

The Totten shutters at Fort Jefferson were arguably one of the most significant military and architectural elements at the site; yet, corrosion on the shutters caused the masonry to crack and fail. All architectural conservators must acknowledge before treatment that eventually, iron will reach a stage of "no return". Objects will no longer serve their intended function and be detrimental to the rest of the structure. The best, and most difficult, option is to save as much of the original fabric as possible for as long as possible.[14]

David Lowenthal described the modern technology as being "inhuman, sterile, and unlivable."[15] By the beginning of the nineteenth century, construction methods became more standardized. To many of their contemporaries, these new buildings, designed by engineers and professional architects, were expendable structures and lacked a visible human element that made them worth preserving. Today, the appreciation for early structural iron has changed little. According to the Secretary of Interior's Standards, materials should be replaced in kind in order to maintain a level of integrity. The National Park Service advises minimally invasive treatment of architectural cast iron, but the options for conserving architectural metal are still confined to essentially two options: replace or repaint.[16]

This mindset is detrimental to the future of historic iron. Every day historic iron is lost because few people are willing to take steps to mitigate the material's corrosion or shoulder the cost of conserving the original iron. The public has difficulties recognizing the value of structural iron because the building culture still remains in the age of structural iron. Steel beams are not novel; they are not rare. It is assumed to be easier to replace them rather than conserve them because the material is accessible and cost-effective. However, architectural conservators cannot continue to look at nineteenth and twentieth century buildings and their conservation needs from a nineteenth century point of view. Just as

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[14] S Timmons, *Preservation and Conservation : Principles & Practices* (Washington: Nat'l Trust for Historic Preservation, 1976), 271.

[15] Lowenthal, 382.

[16] Philippot, *Historical and Philosophical Issues, 268.*

it is important for conservators to maintain and protect historic stone, it is important for conservators to develop new ways to understand and conserve architectural iron.

Architectural critic John Ruskin believed that it was impossible to fully restore great architecture. That concept has carried through the preservation community. Emphasis has shifted from spectacular performances in restoration to periodic maintenance, repair and documentation.[17] No conservator would think to replace historic brick that was improperly made with a similar but better quality brick. Yet, architectural conservators are more than willing to replace historic iron with higher quality steel as the iron corrodes. The intentions may be well-meant (to protect and lighten future maintenance and conservation concerns with a better material), but replacing historic iron only results in the loss of a historic and potentially informative knowledge of historic materials and manufacturing processes. The preservation community must rethink its understanding of metal's importance in the architectural world.

As preservation extends its reaches to industrial and post-modern structures, it is becoming more important to understand iron at the core of its identity. Iron is largely ephemeral, and it is foolish to expect to be able to conserve the metal in perpetuity, just as it is foolish to expect to conserve wood for eternity. However, the superficial knowledge that most architectural conservators have of iron and its corrosion must develop in order for the world not to lose an important material that helped create the modern world as we know it today.

Today, metal is understood in varying ways by three different groups of professionals. Chemists understand the complicated process of iron production and its subsequent corrosion at an elemental level. Corrosion is understood in terms of electron dispersal and transfer and the change in molecular structures that results from a chemical reaction. Engineers study iron and its corrosion on a more macroscopic level, looking at how corrosion forms from stress, erosion, or general weathering. Artists understand iron as a fluid and ductile material that can take an almost unending number of shapes and forms.

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[17] Torraca, *Historical and Philosophical Issues,* 443.

On the other hand, architectural conservators need to be able to understand and implement different aspects of each of these disciplines if there are to be more sensitive conservation treatments to this historic material. It is only through the comprehensive analysis of the unique conditions of the materials that the balance between structural integrity with historic integrity can be found.

Conservators gain information from each of these disciplines. This has resulted in the emergence of new treatments and coatings that are beneficial and less invasive when treating historic metals. Far too often, architectural conservators view scientific analysis as a flashy and interesting but largely inconsequential step in the conservation process. However, the conservation community as a whole is developing an understanding and desire to look at historic objects in a new light. The incorporation of the scientific thought process is part of the evolving work and understanding of our historic materials.[18] As each piece develops its own lifespan and has its own unique aged characteristics, it is becoming ever more vital that the architectural conservation community understands and develops more sophisticated protocols in order to protect historic iron for our future generations.

Non-invasive ways to investigate corrosion

Most architectural conservators today perform background research and analysis on existing condition, material composition and past treatments before instituting a conservation treatment. The collaboration between scientists and conservators has allowed the architectural conservation community to advance its knowledge of buildings and materials. Paint can now be studied in a way that allows for identification of a more accurate paint composition as well as its original color. In the same way, analysis allows conservators to create a mortar that will be sensitive to the brick and stone that surround it. This is not necessarily the case for an architectural conservator's approach to metal.

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[18] Giovanni Urbani, "The Science and Art of Conservation of Cultural Property" *Historical and Philosophical Issues in the Conservation of Cultural Heritage*, Readings in Conservation (Los Angeles: Getty Conservation Institute, 1996), *446.*

The causes of corrosion are not unknown. Archaeological and marine conservators have been busy for the last forty years working with scientists to create better ways to analyze metal artifacts in order to achieve more sensitive conservation treatments. This approach has led the archaeological and marine conservation community to develop an understanding of not just how best to save their objects but also to examine what is happening to the artifacts and how a treatment will change them in the future.

The challenge for architectural conservators remains how to handle both structural and decorative iron elements in a sensitive and cost effective method. The National Register and the Historic American Building Survey use the term "character defining" as a way to describe the parts of buildings that are integral to understanding the larger building. Increasingly, these "character defining" pieces have an iron component, and are aging and changing. Nothing lasts forever, especially iron, but it would be hard to argue that something more should not be done. It is necessary for the architectural conservation community to develop a better understanding of methods to approach the conservation of objects, or they will be lost.

Fort Sumter National Monument has many of these character defining pieces. Part of the coastal fortification system created after the War of 1812, Fort Sumter, like many of its contemporary forts, was constructed with new technology in its design. The forts are complex structures composed of varying materials interacting with each other. Unfortunately, the fort has also seen more changes and more fixes than most buildings see in their lifetime. It has been built, demolished, rebuilt, re-demolished, buried and excavated. What remains is integral to telling the story of the site, but preservation and conservation of the site is complicated by the layers of history that are on top of one another. The metal objects that remain are in no way decorative pieces; all are of a utilitarian design and are embedded in a variety of materials. Shutter clamps are imbedded in brownstone and replacement concrete. Traverse rails are embedded in granite and brick. Gas piping is surrounded in nineteenth and twentieth century mortars and cements. Some objects, such as the shells embedded in the casemate walls, were never intended to be in their current position and location.

Because of their historical importance and complex nature, many of these objects must be treated *in situ*. This, unfortunately, takes conservators away from the benefits that climate-controlled, clean environment laboratories provide. Since the 1970s, conservators and engineers have studied and experimented with different ways to approach the treatment and study of historic iron and its corrosion.

Corrosion theory

How best to slow corrosion and stabilize metal artifacts has been a challenge for as long as people have been using metal for tools and buildings. The late nineteenth century saw an explosion of advice and scholarship on the most appropriate way to coat metals, particularly iron and steel, in order to prevent corrosion.[19] Scholarship changed little until after World War I when Ulick R. Evans, a professor at the Cambridge University, altered the way that people understood the corrosion process. Evans published throughout his life increasingly sophisticated studies on how corrosion formed and changed over time.[20] Though Evans is considered by and large the father of modern corrosion science, engineers and chemists everywhere began examining and building off on Evans' observations of the electrochemical process of corrosion. Largely, these projects, like Frank Speller's multi-edition work *Corrosion: causes and prevention—an engineering problem* were focused

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[19] H.B.C. Allison, "Protective Coatings for Metals: A Review of Various Processes for the Prevention of Oxidation," in *Scientific American: Supplement*, vol. 81 (Munn and Company, 1916), 7; John Percy, *On the Protection from Atmospheric Action Which Is Imparted to Metals by a Coating of Certain of Their Own Oxides, Respectively* (M. & M. W. Lambert, 1878); Allerton Seward Cushman and Henry Alfred Gardner, *The Corrosion and Preservation of Iron and Steel* (McGraw-Hill book company, 1910), *739; Paint Questions Answered: A Reference Encyclopedia Answering Knotty Problems That Confront the Painter, Decorator, and Paint Manufacturer in Their Everyday Work, with Complete Topical Index*. Painters Magazine, 1904.

[20] Ulick R. Evans, *Metals and Metallic Compounds* (London: E. Arnold, 1923); Ulick R. Evans, *Metallic Corrosion, Passivity and Protection* (London: E. Arnold, 1937); Ulick Richardson Evans, *An Introduction to Metallic Corrosion* (E. Arnold, 1948); Ulick Richardson Evans, *The Corrosion and Oxidation of Metals: Scientific Principles and Practical Applications* (St. Martin's Press, 1960); Ulick R. Evans, *The Rusting of Iron: Causes and Control* (London: E. Arnold, 1972).

on modern structures and how best to ensure their longevity.[21] Evans and Speller's early books on corrosion were the standard for engineers for many decades after their original publications.

By the early 1980s, scientists began to standardize the tests that were used to track localized corrosion on metal structures and objects. The American Society of Testing and Materials (ASTM) began publishing data on atmospheric corrosion and standards for other researchers to incorporate into their own work. A Czech scientist, Knotkova-Cermakova, published through ASTM a system of standards to classify atmospheric corrosion. The standards he created to track time of wetness, temperature, humidity and pollutants are all still utilized today. These studies were designed to help predict the optimal protective coating system and were intended to be used in combination with different design factors and fabrication methods. In the same study, Knotkova-Cermakova discussed the "wet candle" method for tracking airborne chlorides and pollutants as well as measuring the time of wetness more accurately through the use of moisture sensors. [22] A few years later, ASTM further specified ways to track corrosion in the 1986 symposium on the degradation of metals in the atmosphere. The studies focused on developing standards for long-term corrosion prediction as well as methods for tracking marine salts in the environment.[23] The techniques popularized in the late 1980s maintain their usefulness in the present-day, though some researchers are beginning to experiment with airborne chloride test methods that give more specific data. Kochi University in Japan is currently working on a method using water sensitive paper to track the pattern and size of sea-salt aerosols.[24]

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[21] G. T. Bakhvalov and A. V. Turkovskai͡a, *Corrosion and Protection of Metals* (Pergamon Press, 1965); Frank Newman Speller, *Corrosion, Causes and Prevention* (McGraw-Hill, 1923).

[22] D. Knotkova-Cermakova and K. Barton, "Corrosion Aggressivity of Atmospheres (Derivation and Classification)," in *Atmospheric Corrosion of Metals*, ed. S.W. Dean Jr. and E.C. Rhea, (Denver, CO: ASTM Special Technical Publication 767, 1980).

[23] S. W Dean et al., "Degradation of Metals in the Atmosphere : A symposium Sponsored by ASTM Committee G-1 on Corrosion of Metals, Philadelphia, PA, 12-13 May 1986" (ASTM, 1987).

[24] Nattakorn Bongochgetsakul, Sachie Kokubo, and Seigo Nasu, "Measurement of Airborne Chloride Particle Sizes Distribution for Infrastructures Maintenance," *Kochi University of Technology*; Saschie Kokubo and Masato Ono, "Calculation Model of Airborne Chloride Ion for Bridge Management Systems," *Kochi University of Technology*.

As the scientific and engineering communities refined their techniques and standards to track and model corrosion, the conservation community[25] simultaneously incorporated these new ideas of corrosion into its own work. By 1977, the scientific, engineering and conservation fields were so closely intertwined that the U.S. Bureau of Standards gathered a group of chemists, engineers, and conservators to discuss how the fields could help advance the conservation profession. The result was a book that contains an excellent cross-section of contemporary thoughts and processes. Topics discussed ranged from reduction methods and patination, to corrosion products and prevention. The work helped set the standard of scientific approach for the next several decades.[26] While there is still significant cross-collaboration between the scientific and conservation fields, the cultural heritage community has largely developed its own research interests. This cross-over has created a discipline of its own, conservation science.[27]

The archaeological and marine conservation communities were the first to incorporate these new technologies. Europeans led the way. Instead of focusing solely on corrosion methods, B.G. Scott, a conservator with the Ulster University, utilized metallographic studies to examine archaeological artifacts. Using technology that was gained from the engineering community, Scott applied chemical analysis, X-rays and cross-sections from artifacts to study how a variety of iron artifacts were constructed.[28] These techniques helped establish a protocol for the identification of corrosion products in heritage artifacts. For the archaeological conservation community, this information

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[25] More than any other conservation concentration, architectural conservators must rely on the effective collaboration between architects, engineers, conservators, and scientists to be successful. This has developed a community that must work with each other in order to advance their own interests.

[26] B. Floyd Brown et al., eds., *Corrosion and Metal Artifacts-A Dialogue Between Conservators and Archaeologists and Corrosion Scientists*, NBS Special Publications 479 (Washington D.C.: U.S. Department of Commerce, National Bureau of Standards, 1977).

[27] The development of the field of conservation science is far too complicated and diverse of a field to summarize in one sentence, but it will be discussed later on in this chapter.

[28] B.G. Scott and C.J. Lynn, “Metallographic and Chemical Studies on a Group of Iron, Artifacts from the Excavations at Greencastle, County Down,” *Ulster Journal of Archaeology, Third Series* 39 (1976), 42–52; B.G. Scott, “Metallographic Study of Some Early Iron Tools and Weapons from Ireland,” *Proceedings of the Royal Irish Academy. Section C: Archaeology, Celtic Studies, History, Linguistics, Literature* 77 (1977): 301–317.

shed light on the type and extent of corrosion that was previously hidden underneath layers of oxidation and corrosion, but it did little to help determine the most appropriate conservation method.

Corrosion scholarship typically divides corrosion studies on a macro and micro scale. Engineers focus on the broad causes of corrosion—pitting, galvanic, and cavitation. Chemists take a more microscopic approach and study the various iron corrosion products, among which are goethite, magnetite and akaganéite.[29] It is general knowledge today that varying atmospheres and contexts influence the corrosion of iron objects differently. The engineering community has set the standards for the most appropriate way to tract atmospheric corrosion, but as many heritage artifacts come from buried or submerged contexts, atmospheric corrosion only answered part of the problem faced by conservators. Stephen Turgoose created a model to help understand the interaction between corrosion in wet soil and the accelerated effects when excavated. His work provided a chemical explanation as to why an iron object could be excavated in good condition but quickly deteriorate once exposed to air.[30]

Today, all publications that approach the conservation of metal objects contain, at least partially, a chemical description of the corrosion process. While this understanding has been refined over time, there are several general resources that maintain up-to-date analysis and explanations of the corrosion process. NACE (National Association of Corrosion Engineers) publishes studies on both modern and heritage artifact corrosion. They allow for easily accessible standards of treatment to both historic and modern metal objects.[31] Similarly, Kingston Technical Software Co., maintains the website corrosion-doctors.org. Run by corrosion engineers, the site has compiled a comprehensive overview of corrosion

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[29] "Iron Corrosion," *NACE Resource Center*, http://events.nace.org/library/corrosion/MatSelect/corriron.asp Accessed 26 May 2012; David A Scott and Gerhard Eggert, *Iron and Steel in Art : Corrosion, Colorants, Conservation* (London: Archetype, 2009).

[30] S. Turgoose, "Structure, Composition and Deterioration of Unearthed Iron Objects," in *Current Problems in the Conservation of Metal Antiquities* (Tokyo, Japan: Tokyo National Research Institute of Cultural Properties, 1993).

[31] "Iron Corrosion," *NACE Resource Center*, http://events.nace.org/library/corrosion/MatSelect/corriron.asp Accessed 26 May 2012.

history, causes, tests and treatments. The site is designed to make training in corrosion accessible for anyone who is interested.[32]

Conservation practice and advancement

In addition to the American Institute for Conservation of Historic and Artistic Works (AIC)'s ethical guidelines, metal conservators base all their work around several factors. If possible, the corrosion process should be slowed or stopped, destructive chloride ions should be removed, and the artifact should be unaltered if possible including corrosion products that could potentially yield more detailed information later.[33] With these guidelines at the forefront, treatments of artifacts have changed relatively little over the years. Early on, it was known that heat, water and a protective coating were the most successful treatments, though conservators did not always understand the exact reasons or the best methods of stabilization and protection. [34]

Conservation treatments have grown more sympathetic as the profession gained an understanding of what is and is not reversible. The core of the ethic of reversibility has promoted the development of non-destructive testing. Scanning Election Microscopy (SEM), X-Ray Fluorescence (XRF) Spectroscopy, Mossbauer Spectroscopy, X-Ray Diffraction (XRD), and Raman Spectroscopy all have become accepted methods for minimally invasive analysis of metal objects.[35]

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[32] "Measurement of Atmospheric Corrosion Factors," *Measurement of Atmospheric Corrosion Factors*, http://corrosion-doctors.org Accessed 26 May 2012.

[33] "Code of Ethics and Guidelines for Practice," *American Institute for Conservation of Historic and Artistic Works: About AIC*, May 23, 1961; May, Eric, and Mark Jones. *Conservation Science : Heritage Materials*. Cambridge, UK: RSC Pub., 2006.

[34] Margot Gayle and John G Waite, *Metals in America's Historic Buildings : Uses and PreservationTreatments.* (Washington, D.C.: U.S. Dept. of the Interior, National Park Service, Cultural Resources, Preservation Assistance, 1992); Mark Gilberg, "Friedrich Rathgen: The Father of Modern Archaeological Conservation," *Journal of the American Institute for Conservation* 26, no. 2 (October 1, 1987): 105–120.

[35] While each testing method has a complicated history of its own, they will not be discussed as their importance lies in their contribution to the conservation field and not how they were developed. Giovanna Bitossi wrote a comprehensive overview of the applications of spectroscopic techniques in heritage conservation and is a useful resource to consult for an overview of the advantages of each non-invasive technique. Bitossi neglects to specifically discuss the application of these techniques in terms of metal analysis, but the work remains applicable.

As discussed earlier with Scott's work on his examination of early Irish iron artifacts, XRD quickly became the early standard for performing a metallographic and chemical analysis of iron objects. These tests were often well out of the price range of many smaller conservation labs, but James Argo was able to develop a reasonably successful method to test for a broad range of corrosion products using acetone and a microscope when X-Ray Diffraction (XRD) was not feasible for a laboratory.[36] Slowly, SEM-EDS technology was recognized for its usefulness for metallurgical studies and identifying the elemental composition and stability of artifacts. Within the last twenty years, advancements have been made to study the aggressivity of specific corrosion products. The emergence of Raman Spectroscopy and X-Ray Florescence (XRF) allows for a more detailed and characteristic identification of specific corrosion products and how their chemical make-ups affect iron objects' stability.[37]

The hygroscopicity of corrosion products can lead to the production of droplets of acid on the historic artifact (weeping) signaling aggressive corrosion occurring on the artifact. Selwyn uses these techniques to examine both, weeping and akaganéite(β-FeOOH), on recently excavated objects and ends up verifying Turgoose's research on excavated iron objects.[38]

The search for stable corrosion products (magnetite and hematite) has been a key factor in developing corrosion treatments. For many years, the search remained elusive as different corrosion products formed in different contexts and environments. It was known that chlorides, sulfides, and time of wetness affected iron, but only through successive cases did patterns begin to develop.[39] However, no two cases appear to be the same and

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[36] James Argo, "A Qualitative Test for Iron Corrosion Products," *Studies in Conservation* 26, no. 4 (November 1981): 140–142.

[37] M.C. Bernard and S. Joiret, "Understanding Corrosion of Ancient Metals for the Conservation of Cultural Heritage," *Electrochimica Acta* 54, no. 22 (September 2009): 5199–5205; David A Scott and Gerhard Eggert, *Iron and steel in art : corrosion, colorants, conservation* (London: Archetype, 2009); Bitossi, "Spectroscopic Techniques".

[38] L. S. Selwyn, P. J. Sirois, and V. Argyropoulos, "The Corrosion of Excavated Archaeological Iron with Details on Weeping and Akaganéite," *Studies in Conservation* 44, no. 4 (January 1, 1999): 217–232.

[39] P Dillmann, *Corrosion of Metallic Heritage Artifacts Investigation, Conservation and Prediction of Long Term Behavior* (Boca Raton, Fla.; Cambridge, England: CRC Press ; Woodhead Pub.,

conferences are filled with case studies applying the same technology but achieving slightly different results. One of the most successful treatments to have been developed was the soaking of previously buried and actively-corroding artifacts in a solution of sodium hydroxide. The treatment has been utilized since the mid-twentieth century and developed as conservators refined their knowledge of the time necessary to soak the artifacts in the solution, although there is no standard.[40]

The difference in corrosion rates and in individual studies makes it difficult for there to be any definitive standard of treatment of corroded objects. The development of the Pourbaix diagram allowed conservators to apply chemical analysis to create a chart that would predict the best parameters to aid the stability of an artifact.[41] Like corrosion studies, conservation treatments originated in European countries and have retained a familiar aspect to their historic treatments. Acid pickling, plasma reduction, electrolytic methods (reduction and cleaning), and hydrogen reduction, all treatments that have been successfully employed, are detailed in textbooks and general conservation manuals.[42] Most recently, scholarship is being conducted that treats iron objects using a high pressure/temperature rinsing solution under subcritical conditions in a continuous-flow system while converting unstable corrosion products to more stable forms. Through taking samples, conservators

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2007); Robert Walker, "Instability of Iron Sulfides on Recently Excavated Artifacts," *Studies in Conservation* 46, no. 2 (2001): 141–152; Mark R. Gilberg and Nigel J. Seeley, "The Identity of Compounds Containing Chloride Ions in Marine Iron Corrosion Products: A Critical Review," *Studies in Conservation* 26, no. 2 (May 1, 1981): 50–56; Peter Gibbs, *Corrosion in Masonry Clad Early 20th Century Steel Framed Buildings*, Historic Scotland Technical Advice Note 20 (Edinburgh: Historic Scotland, 2000).

[40] Gilberg, Mark R., and Nigel J. Seeley. "The Alkaline Sodium Sulphite Reduction Process for Archaeological Iron: A Closer Look." *Studies in Conservation* 27, no. 4 (November 1, 1982): 180–184; N. A. North and C. Pearson, "Washing Methods for Chloride Removal from Marine Iron Artifacts," *Studies in Conservation* 23, no. 4 (November 1, 1978): 174–186.

[41] C Pearson, *Conservation of Marine Archaeological Objects* (London [etc.]: Butterworths, 1987); Eric May and Mark Jones, *Conservation Science : Heritage Materials* (Cambridge, UK: RSC Pub., 2006).

[42] Eric May and Mark Jones, *Conservation Science : Heritage Materials* (Cambridge, UK: RSC Pub., 2006); Michael Bussell, *Structures & Construction in Historic Building Conservation*, ed. Michael Forsyth (Oxford, UK; Malden, MA: Blackwell, 2007).

are able to daily gauge the amount of chlorides being extracted from the artifact until levels fall and remain under the detection limit of ion chromatography.[43]

Scholarly studies of ironwork have historically focused on decorative elements or emergence of the standardized structural systems. While the two have obvious similarities in their early work, scholars tend to focus on one aspect of the ironwork or the other.[44] Innovation in metal conservation has come from the marine and archaeological conservation communities. These developments have been largely ignored by the architectural conservation community. Marine conservation has been centered on the removal of chloride ions from the corrosion matrix. Scientists have tried for many years to develop accurate methods of calculating both surface and embedded chloride levels in historic iron. X-Ray Diffraction (XRD) was used for many years, but with varying amounts of success as demonstrated when James Argo unsuccessfully attempted to recreate an experiment run by his colleagues Neil North and Colin Pearson.[45] Selwyn, McKinnon and Argyropoulos's article modeling chloride ion diffusion discusses the method of using energy dispersive spectroscopy in conjunction with a scanning electron microscope. Such a method can provide a compositional comparison to assist in the identification of chlorides.[46]

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[43] Philippe de Viviés et al., "Transformation of Akaganéite in Archaeological Iron Artifacts Using Subcritical Treatment," *Metal 07* 5: Protection of Metal Artifacts (2007); Néstor González-Pereyra et al., "The Use of Subcritical Fluids for the Stabilization of Concreted Iron Artifacts," *Metal 2010: Charleston, South Carolina* (2010); "2010 Metal González"; Néstor González et al., "The Effects of Cathodic Polarization, Soaking in Alkaline Solutions and Subcritical Water on Cast Iron Corrosion Products," *Metal 07* 3 (2007); "2007 METAL González"; M.J. Drews et al., "A Study of the Analysis and Removal of Chloride in Iron Samples from the 'Hunley'," *Metal 2004* (2004); L. Nasanen, N. González, and S. Cretté, "The Subcritical Mass-Treatment of a Range of Iron Artifacts from Varying Contexts," in *Asia-Pacific Regional Conference on Underwater Culture Heritage Proceedings* (Philippines, 2011).

[44] Geoff Wallis and Michael Bussell, "Cast Iron, Wrought Iron and Steel," in *Materials and Skills for Historic Conservation*, ed. Michael Forsyth (London: Blackwell Publishing, Ltd., 2008), 123–159; Michael Bussell, *Structures & Construction in Historic Building Conservation*, ed. Michael Forsyth (Oxford, UK; Malden, MA: Blackwell, 2007); Gerald Kenneth Geerlings, *Wrought Iron in Architecture .* (Scribner, 1972).

[45] James Argo, "On the Nature of 'Ferrous' Corrosion Products on Marine Iron," *Studies in Conservation* 26, no. 1 (February 1, 1981): 42–44; Mark R. Gilberg and Nigel J. Seeley, "The Identity of Compounds Containing Chloride Ions in Marine Iron Corrosion Products: A Critical Review," *Studies in Conservation* 26, no. 2 (May 1, 1981): 50–56.

[46] L. S. Selwyn, W. R. McKinnon, and V. Argyropoulos, "Models for Chloride Ion Diffusion in Archaeological Iron," *Studies in Conservation* 46, no. 2 (January 1, 2001): 109–120.

However, the technique is still in the process of refinement as scientists seek to accurately quantify the amount of free and bound chlorides in an artifact.[47]

One of the most neglected areas of conservation science is the interaction iron has with its surrounding architectural environment. ASTM has extensively studied the effect that the atmosphere has on iron artifacts. Archaeological and marine conservators have worked to gain an understanding of the effect that the soil and water has on iron artifacts.[48] Methods of treatment have been founded on the need to convert active corrosion products to more stable products that will not cause further damage to the artifact. Gas plasma reduction was used for years as way to reduce unstable corrosion products to a more original state. Many conservators avoid this treatment due to the significant change in appearance that the treatment causes.[49] Electrolysis has also shown to be a successful, though time-consuming, treatment and has more recently shown promise in the removal of chloride ions from concrete and steel artifacts.[50]

Comparatively, little research has been done to study metal artifacts and their interactions with the surrounding context. In 2012, a group of scientists examined the effects that the composition of the metal and the surrounding environmental factors had on the corrosion of museum artifacts in Jordan.[51] The study focused on a museum which had no methods of climate control in an attempt to understand what had the largest influence on the instability of its copper-alloy artifacts: the temperature and humidity

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[47] Néstor G. González et al., "Hunting Free and Bound Chloride in the Wrought Iron Rivets from the American Civil War Submarine H. L. Hunley," *Journal of the American Institute for Conservation* 43, no. 2 (July 1, 2004): 161–174.

[48] S. Turgoose, "The Corrosion of Archaeological Iron During Burial and Treatment," *Studies in Conservation* 30, no. 1 (February 1, 1985): 13–18; C Pearson, *Conservation of Marine Archaeological Objects* (London [etc.]: Butterworths, 1987).

[49] V. D. Daniels, L. Holland, and M. W. Pascoe, "Gas Plasma Reactions for the Conservation of Antiquities," *Studies in Conservation* 24, no. 2 (May 1, 1979): 85–92.

[50] Chi-Hao Tang, "Electrical Removal of Chloride ions from Cement-Based Materials" (M.S., State University of New York at Buffalo, 2007); P. Lambert and A.R. Foster, "Modern Solutions to Historic Problems: Advanced Materials and Techniques in Heritage Applications," in *Structural Studies, Repairs and Maintenance of Heritage Architecture XI*, ed. C.A. Brebbin (Boston, MA: WIT Press, 2009), 175–184.

[51] Abeer Arafat et al., "Combined in Situ micro-XRF, LIBS and SEM-EDS Analysis of Base Metal and Corrosion Products for Islamic Copper Alloyed Artefacts from Umm Qais Museum, Jordan," *Journal of Cultural Heritage*, http://www.sciencedirect.com/science/article/pii/S1296207412001276.

or the characteristics of the metal. The study indicated that despite the compositional differences among the artifacts, they were corroding in the same manner. This indicated the environment was the largest factor.

Atmospheric and soil corrosion studies are common-place today and can be found many locations. Thus, there is little need to dwell on these topics. While the metal objects at Fort Sumter will be treated as individual pieces, Dr. Denis Brosnan's reports on the characterization of the mortar and brick campaigns at Fort Sumter are an important first step in understanding how the surrounding context is affecting the metal.[52] As structures that have integral masonry and metal parts age, it will undoubtedly become more important to understand how these two materials interact with each other, but for now scholarship is minimal.

Archaeological and marine conservators have defined and dominated the metal conservation field, but the knowledge gained in these communities can and should be drawn into architectural conservation. As Fort Sumter experienced a variety of campaigns of build and destruction, it is reasonable to think that there will be a variety of different types of corrosion on the artifacts at Sumter. These differences require a more in depth understanding of what has happened to the objects in the past as well as what is happening to them in their current environment. For this reason, it must be acknowledged that each object will have many causes for its present condition. In order to treat them in the most sensitive manner, it is important to know how each aspect of the object's condition is affecting the others. Additionally, it is important to understand what is happening to the historic iron objects at Fort Sumter because of their location in a highly corrosive environment as well as the effect that early and prolonged interaction with different materials has on the metals. Potentially, this can create a precedent for similar future

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[52] Denis Brosnan, "Characterization and Forensic Studies of Construction Materials for Fort Sumter National Monument," January 11, 2010, Fort Sumter National Monument; Denis Brosnan, "Characterization of Restoration Mortars for Fort Sumter National Monument and Degradation of Mortars by Sea Water and Frost Action," April 19, 2012, Fort Sumter National Monument.

projects. This will allow conservators to begin a conservation treatment that is hoped to lead to a more scientific and sensitive approach to architectural metal conservation.

CHATPER THREE
METHODOLOGY

As the discipline of metal conservation evolves, it has become necessary for architectural conservators to look at historic ironwork in a more informed and sensitive manner. The goal of this research was to develop a strong understanding of what influences the degradation of the antebellum era ironwork at Fort Sumter. Engineers and architectural conservators understand that the environment, context, and composition all influence iron corrosion. Structures are dynamic and complicated; understanding the individual aspects of the corrosion process is only part of the process. A working vocabulary should be developed that incorporates the multiple levels that influence the degradation of historic iron before comprehensive and sensitive conservation standards can be developed.

The ironwork at Fort Sumter: pintles, traverse rails, and door and chimney hardware, presents a unique set of challenges. The fort has experienced multiple cycles of destruction and rapid rebuilding. Most of these rebuilding campaigns are un- documented, so little is known about the origins and early treatments of the ironwork. Additionally, the fort with its historic metal was buried in rubble and sand for sixty years as the US Army repurposed and modernized Fort Sumter. Today, the deteriorated condition obscures what the object looked like in its original form. Previous periods of treatment, visitor impact and lack of archival documentation make it difficult to ascertain an accurate rate of loss and predict the corrosion rate in the future. Because of the state and condition of the objects, many of the historic artifacts at the fort are in such a fragile state that any conservation treatments might prove ineffective.

Summary of methods

The tests performed in this thesis attempted to cover three important factors that influence iron corrosion: environment, context, and composition. The environmental tests tracked various atmospheric factors including temperature, humidity, exposure to wetness, and wind speed/direction over a period of six months (September 2012- February 2013) and airborne chlorides over a period of four months (October 2012- January 2013). The coast of South Carolina is classified by engineers as a mildly corrosive environment due to its sub-tropical climate and proximity to the ocean.[1] As a multitude of individual weather stations track conditions around the Charleston Harbor, the tests focused on attempting to gauge the temperature and moisture conditions of the most vulnerable historic iron objects at Fort Sumter: the tie-rod and fireplace lintels.

The context, or the construction material surrounding the historic iron, was studied in order to determine the composition and affect the surrounding brick, stone, and mortar has on the iron. The multiple building campaigns allow there to be an excellent study of how the surrounding building materials affect embedded iron. Materials were identified through a combination of archival research and visual analysis. The Chief of the Army Corps of Engineers and designer of the fort, Joseph Totten kept extensive correspondence and documentation of Fort Sumter's construction and his letters and reports were studied in order to discover the intended use and specifications for the existing metal objects.[2] Dr. Denis Brosnan of Clemson University conducted a variety of experiments characterizing the chemical composition of the mortar and brick at Fort Sumter. His reports continued information on the material characterization of many of the mortar campaigns throughout the history of the fort and of the brick that was used in construction and reconstruction. These documents provided a useful resource of the materials that surrounded the historic iron. [3] Additionally, a survey of the fort's antebellum ironwork was conducted to provide a guide for what currently exists, the condition of the surviving ironwork, as well as the components that surrounded the embedded metal.

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1 Pierre R Roberge, *Handbook of Corrosion Engineering* (New York: McGraw-Hill, 2000).

2 *Letters and Reports of Colonel Joseph G. Totten, 1803 - 1864* bound volume (Washington D.C.: War Department, 1864 1803), Records of the Office of the Chief of Engineers, 1789 - 1999, Record Group 77, National Archives Building, Washington DC; *Returns of Military Posts, Ca. 1800 - 12/1916* (War Department, n.d.), Records of the Adjutant General's Office, 1762 - 1984, Record Group 94, National Archives Building, Washington DC, accessed January 15, 2013.

3 Denis Brosnan, "Characterization and Forensic Studies of Construction Materials for Fort Sumter National Monument," January 11, 2010, Fort Sumter National Monument.

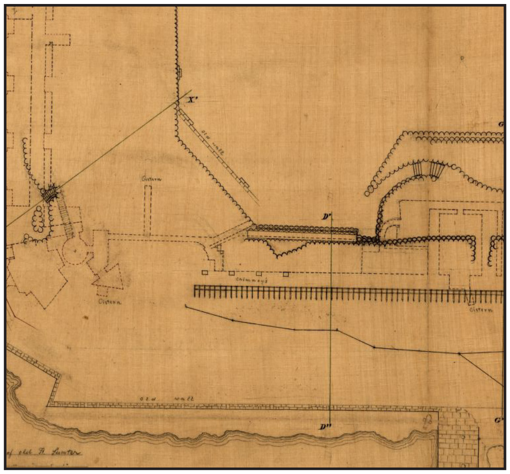
Fort Sumter's ironwork was studied using a variety of non-invasive techniques. X-ray Fluorescence Spectroscopy was utilized to for elemental analysis of the ironwork in an attempt to draw connections between the composition of the ironwork and the subsequent degradation of the material. Raman Spectrometry was used to characterize the corrosion products found on a select (6) number of artifacts that were chosen after the survey was completed for their unique condition or similar composition/context to other objects at the fort. Later, electron dispersive spectroscopy was employed in order to analyze the elemental distribution.

Atmospheric analysis

Engineers and corrosion scientists have long studied the atmospheric corrosivity levels and developed a standard for classifying the corrosivity of a specific atmosphere (ISO 9225). This standard, while descriptive and enlightening, is only useful to the extent that it can tell the probable corrosivity level. It does not tell what is actually happening on the metal interface. Nevertheless, the ISO 9225 standard has become common practice to determine the corrosion levels of microclimates. As Fort Sumter is located on a former shoal and is surrounded on all sides with fifteen foot high walls, the fort has its own microclimate that needed to be studied outside of pulling data from the local weather stations in the surrounding harbor.

HOBO Micro Station

In order to study the atmospheric conditions of Fort Sumter, a micro weather station was set up to track temperature, relative humidity%, wind speed and wind direction. General scholarship accepts the rate of corrosion depends on several factors: the amount of protective corrosion products on the surface, the amount of iron exposed to surface electrolytes, the time of wetness, and levels of exposure of the embedded metal. The goal of these tests was to quantify the periods that promote the most aggressive corrosion at



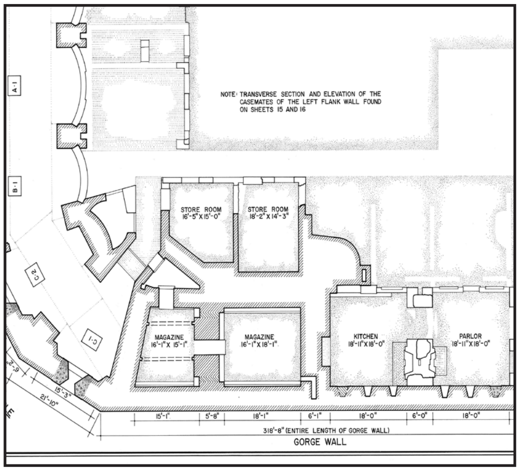


Figure 3.1: (right) The 1996 Historic America Building Survey (HABS) showing the Confederate Era fireplace next to the brick massing by the original magazine (courtesy of the Library of Congress).

Figure 3.2: (left) The 1865 plan showing the same area completely buried (courtesy of the Library of Congress).

the fort.[4] The antebellum ironwork is dispersed throughout Fort Sumter and can be found in a variety of atmospheric conditions. As this study was attempted to address the larger problem of the multiple influences to iron corrosion, each micro-climate present at Fort Sumter was not studied. However, further research into the differences in temperature and relative humidity fluctuations would likely help illuminate the atmospheric difference at the fort.

As a compromise, the weather station was placed in a way that was considered to have a similar orientation and environment to the most fragile and significant pieces at the fort. The pieces chosen to imitate are the fireplace lintels and tie-rod from the two remaining fireplaces at the fort. While no documentation exists as to their exact construction date, one fireplace is attributed to be the last remaining feature of the enlisted men's barracks on the left flank of the fort, though this will discussed in more depth in Chapter four. The other fireplace is able to be dated to between March-May 1863 during the

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[4] D. Knotkova-Cermakova and K. Barton, "Corrosion Aggressivity of Atmospheres (Derivation and Classification)," in *Atmospheric Corrosion of Metals*, ed. S.W. Dean Jr. and E.C. Rhea, (Denver, CO: ASTM Special Technical Publication 767, 1980).

Figure 3.3: The datalogger was secured in a bucket of sand to prevent having to anchor the system to the historic masonry (photo by author).

Figure 3.4: Onset temperature/RH sensor (photo by author)

Figure 3.5: Onset wind speed sensor (photo by author)

Figure 3.6: Onset wind direction sensor (photo by author)

Confederate occupation of Fort Sumter, through engineering drawings and a timeline of the Union bombardment.[5]

Figure 3.7: Anemometers in place at Fort Sumter National Monument (photo by author)

The weather station, a HOBO Micro Station datalogger from Onset Computer Corporation was deployed at the fort on September 11, 2012 and set to run for a period of six months. Originally, the plan was to attach the Micro Station to a board and set it in the ground to act as support, but it was discovered that the original brick and cement flooring still exists approximately two to five inches underneath the present ground level. It was not possible to attach the station to the masonry casemate wall (as the goal of this work, after all, was to test the materials as non-invasively as possible and not to affect the visitor experience). Instead, the station was attached to two 2x4 boards and set in a five gallon bucket filled with sand to act as a stabilization method against stronger winds. The sensors were attached and the station sealed. The sensors were stabilized through a variety of cable ties that threaded through previously drilled holes in the 2x4 boards. Data was downloaded into the HOBOware software program from the Onset Corporation every 26 days.

The general assumption is that a layer of wetness that will promote active corrosion form when the humidity level exceeds 60% and the temperature is above freezing.[6] For this reason, and to compare the differences of the microclimate of Fort Sumter to larger atmospheric patterns of the Charleston Harbor, temperature and relative humidity% (RH%) were recorded at the fort. A temperature/RH% Smart Sensor (S-THB-M00X) was installed in the Micro Station according to Onset's suggestions. A solar radiation shield was not used when mounting the sensors, but it was placed away from direct exposure from the sun and

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[5] These fireplaces, and their construction dates, are discussed further in chapter four of this thesis.

[6] P. Novak, "Environmental Deterioration of Metals," in *Environmental Deterioration of Materials*, ed. A. Moncmanova (Boston: WIT Press, 2007).

above the ground level to prevent long term saturation. The sensor was programed to take a reading every thirty seconds.[7]

Wind speed and direction were considered to be important to the atmospheric test as the wind would influence not only the dispersal rate of airborne chlorides in the atmosphere, but significant wind intensity would also influence the thermodynamic process. The wind speed would either promote condensation on the pieces by overly cooling the objects and/or drying the pieces thereby minimizing the time of wetness (which promotes electrochemical corrosion) of the iron pieces. If the wind was proven to come from predominantly one direction, it would help to identify potential hazards for the artifacts depending on their location at the fort. Two separate anemometers were installed in the Micro Station to track both wind speed and direction: The Wind Speed Smart Sensor (S-WSA-M003) and the Wind Direction Smart Sensor (S-WDA-M003). The two sensors were placed sufficiently far apart, approximately one and a half feet, so they would not interfere with the data of the other sensor and then, secured.

There were no industry standards at the time of the deployment to help guide the installation of the anemometers in a way to gauge the focal points of this study. The locations of the wind speed and direction sensors were not placed in order to gain an accurate idea of the wind outside or on top of Fort Sumter, but rather each was placed so that the sensors would track how the wind moves around the Parade Ground of the fort. There will undoubtedly be wind shadows (areas the walls of the fort block the wind in certain directions) that affect the readings, but this was considered acceptable as the objects would experience similar conditions. At the time of deployment it was noticed that the wind direction sensor was moving in a sporadic manner and the data would seem inaccurate if looked at from the angle of general weather data collection. The sensors were set to record data every thirty seconds by calculating the average wind speed/direction from a series of recordings taken every three seconds.[8]

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[7] "HOBO Micro Station User's Guide" (Onset Computer Corporation, 2012); *Atmospheric Corrosion of Metals*, ASTM 767, 250.

[8] *HOBO Micro Station User's Guide*.

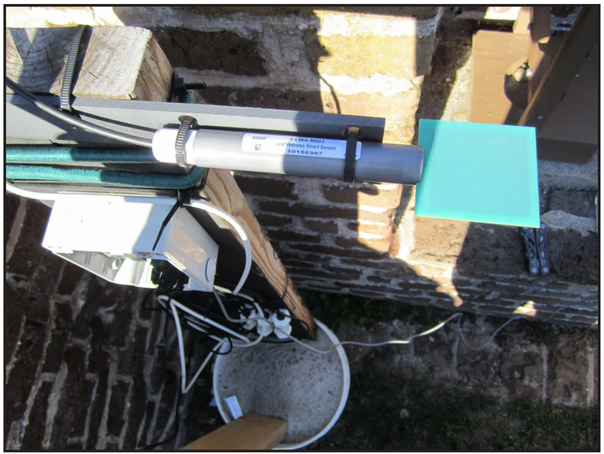

Figure 3.8: Time of Wetness sensor in place. (photo by author)

The temperature/relative humidity% sensors would undoubtedly aid in determining the average time of wetness(TOW) for the metal objects, but the sensor can do little to track actual conditions on the metal itself. As the metal artifacts at the fort will retain or loose heat in a different manner than the surrounding atmosphere, it was important to find a way to track the actual time and percentage that the artifacts would be wetted. Practicality demanded that a sensor be found that could collect this data as it was not possible to be at the fort everyday tracking the amount of time the metal artifacts were wet. Other time of wetness sensors were successfully utilized in monitoring the moisture residue level and the HOBO Leaf Wetness Smart Sensor (S-LWA-M003) was found to be comparable to the wetness sensors in the precious studies published through ASTM manuals. [9] The sensor needed no calibration and was set to record the amount of moisture on the panel every thirty minutes and keep an average and maximum percentage of wetness every hour. The sensor was designed to track the difference of the surface temperature of the object and when the dew-point temperature is below, allowing condensation to occur. The goal of this particular test was to determine what caused the maximum amount of moisture. Often linked to the most aggressive reaction, dew or sea-spray would indicate a high level of corrosivity. Humidity or rain would cause the least reaction.[10] While the Onset manual suggested placing the sensor at an angle, the sensor was placed in a way to best simulate the conditions of the lintels. The sensor was placed parallel to the ground at a height of 3’8”. As the sensor was not the same material as the lintel itself, it was expected that there would be discrepancies in the data, but the results gave an

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[9] *Atmospheric Corrosion of Metals*, ASTM 767, 250.

[10] Philip A. Schweitzer, *Atmospheric Degradation and Corrosion Control*, Corrosion Technology 12 (New York: Marcel Dekker, 1999), 9.

Figure 3.9: Airborne chloride test in place at Fort Sumter. (photo by author)

Figure 3.10: Test placed on sill along Gorge Wall (photo by author)

Figure 3.11: Bolt assembly to secure flask to weather shield (photo by author)

Figure 3.12: Test tube wrapped in gauze to collect ariborne soluble salts (photo by author)

All photos above taken by author

approximate simulation of the environment. Like the Temperature/RH% Sensor, the Time of Wetness sensor was secured to the Micro Station stand using cable ties.

‘Wet Candle’ Test

The ‘wet candle’ test method has successfully been used for many years to track the amount of chlorides in the atmosphere. The premise of the test is based on exposing a piece of gauze that has been rinsed in a one to five ratio of glycerol and deionized water. The gauze is connected to a reservoir of the same reagent water and acts as a wick. The chlorides come in contact with the gauze and are collected in the reservoir. The test was not able to track the amount of chloride ions on the surface of metal objects, but relied on the quantity in the atmosphere to help determine the atmospheric corrosivity level as discussed earlier in the ISO 9225 standard. While engineers are currently attempting to create more accurate tests that track the amount and size of chloride particles, the ‘wet candle’ method is accepted through the American Society of Testing and Materials (ASTM). ASTM Standard G 140-02 was implemented and set up and deployment of this test.

A weather shield and support was constructed of treated wood and painted to protect the test from contamination or dilution by rain water. A set of bolts attached a piece of wood to the main platform of the shield to ensure that the flask would not be removed or affected by the weather changes. The shield’s dimensions followed those suggested by the ASTM standard.[11] The shield and test were placed in a location near to the Micro Station to ensure a similar situation in order to compare the data. The test was positioned on the remains of a former sill of the officers’ barracks along the southwestern portion of the gorge wall.

The test itself comprised of a 500mL Erlenmeyer flask that acted as a reservoir. A 16 x 150mm test tube acted as the support for the gauze and was held in place by a rubber stopper that had a 15mm hole bored through the center to support the test tube. The

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[11] “ASTM G140-02 Standard Test Method for Determining Atmospheric Chloride Deposition Rate by Wet Candle Method” (ASTM International, 2008), http://www.astm.org.

stopper also had 5mm channel cut into two opposite sides of the stopper to allow for free transfer of chlorides into the collection reservoir. Each piece was prepared in the laboratory and packaged in sealed containers to prevent contamination during transport to the location.

The Erlenmeyer Flask, rubber stopper, and test tube were assembled on site and a piece of gauze 15mm by 1500mm long was wrapped in a crisscrossing fashion around the test tube. 150mm of gauze was left at either end to act as the wick. The reagent water (deionized water and glycerol) was mixed on site and filled to the 350mL mark on the flask as designated by the ASTM standards. The flask, gauze, test tube, and rubber stopper were rinsed with the extra reagent water on site. On completion of the onsite testing component, the set-up was delivered to the laboratory and dismantled under controlled conditions according to the protocol.

The flask and test tube were rinsed and the remaining reagent water and gauze were placed in a 600mL beaker. The level was brought up to 500mL and the assembly was then covered and left to soak for a period of 24 hours. Using the ASTM test method D4458, the used solution was then processed to determine the amount of chloride ions in the solution. A control sample using reagent water and gauze from the same source was processed first as well to determine the original chloride level. The chloride content was calculated according to the formula specified in the ASTM Standards G140-02.

The test was deployed on October 12, 2012 at 9:08 am. . The test was switched out on a monthly basis. In order to ensure the most accurate data, a new flask, stopper, and test tube were brought out each time and replaced the previous test. Following ASTM standards, each test was changed out at the same time to ensure accurate results. The used flask, tube, and gauze were packaged in a sealed container and brought back to the lab to avoid extra contamination.

Surrounding materials analysis

The context of the ironwork at Fort Sumter is considered to be the surrounding materials that have an influence on the metal. As much of the ironwork at Sumter is embedded in different materials, it is useful to gain better understanding of how the surrounding mortars and masonry inhibit or promote corrosion of the artifacts. At the same time, Fort Sumter was not always in the condition that it is now and for that reason, the history of the context of the site was looked at in order to understand how and when significant changes occurred that would have an effect on the pieces.

Joseph Totten, the engineer in charge of designing the third system of coastal fortifications at the time the fort was built (1829-1861), tested new materials and methods of construction and his papers, notes, and diagrams still exist in the National Archives. As well, Totten prolifically wrote to George Cullum, the engineer in charge of the construction of Fort Sumter, giving specifications and types of materials to use in the construction. By going through these letters and specifications, the original, intended design of the pieces could be mapped out and compared to the current state of the pieces.

Survey of Antebellum Ironwork

A survey was completed mapping the current placement of the surviving iron artifacts, assessing the type of metal and original purpose, authenticity and significance of the surrounding materials, atmospheric exposure level, current condition, and carrying out photographic documentation of the artifacts. This allowed for the objects to be rated and classified as most to least in need of further investigation. While there are many surviving ferrous artifacts at Fort Sumter, the survey focused on documenting those known or suspected to be from the Civil War era. The location of each piece surveyed was identified using the National Park Service's casemate identification number system and can be seen in full in Appendix One.

After the survey was completed, the results were compiled within a table that incorporated the results of historical research on Joseph Totten's designs, as well as if

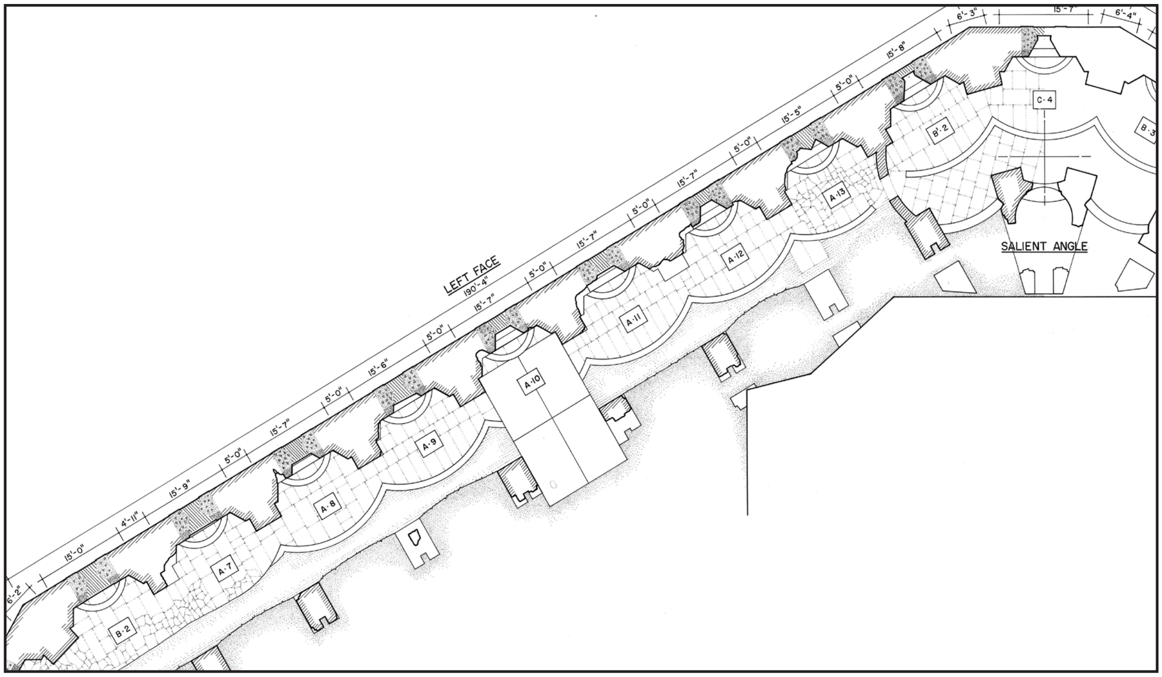

Figure 3.13: HABS drawing showing casemate names and placement (courtesy of Library of Congress).

any prior conservation work had been performed on the pieces. Six pieces were chosen from the survey for further analysis. The pieces chosen were measured and scanned as a preliminary way to quantify the rate of loss due to corrosion. The selection criteria of these artifacts were based on high and low atmospheric exposure, historic significance, type or classification of iron, and placement within the fort. The pieces that were similar in nature had one chosen to ensure that there was an acceptable level of change to shed a broader light on the research.

Compositional analysis

The goal of the compositional analysis was to determine the corrosion products present on the surface of the metal. The identification of the specific corrosion product will be able to classify an object as actively corroding or having changed to a more stable state. A heavy emphasis was placed on *in situ* non-destructive testing of the materials because of their fragile condition. X-Ray Fluorescence Spectroscopy (XRF), Raman Spectroscopy, and visual/qualitative analysis were completed using the Scanning Electron Microscope-

Energy Dispersive X-Ray Spectroscopy (SEM-EDS) through the assistance of the Warren Lasch Conservation Center. A more complete picture of the current and historic state of the ironwork was formed through the characterization of the corrosion products and type of metal.

Using the survey, six pieces were identified for further study based on a set of criteria. (Table 3.1) All pieces were assumed to be original to the site and had varying levels of exposure. The tie-rod from the Left Flank Fireplace and two fireplace lintels were selected because of their exposed and fragile state. The traverse rails along the left face were treated in August 2012 and had a consistent coating, as a result a traverse rail located at the casemate A-14 was chosen for study as there was little paint visible. Two pintle tongues were chosen as well, B-3 and A-14. The B-3 pintle tongue was chosen because the piece was extremely sheltered and never receives exposure from the sun, though the piece was the most intact. The A-14 pintle tongue, while still sheltered in the right face, receives more sun and wind exposure than B-3.

X-Ray Fluorescence Spectroscopy & Scanning Electron Microscope- Energy Dispersive X-Ray Spectroscopy

XRF was conducted on each of the selected six pieces. Additionally, several pieces that are more deeply embedded in mortar had the mortar scanned with the portable XRF to compare the chloride levels present on the surrounding mortar to the iron pieces. XRF analysis is based on single spot elemental analysis, and three measurements were taken on each piece to develop a broader image of the piece. The goal of this method of testing was

Object	Location	Casemate	Type of Metal	Surrounding Materials	Solar Exposure
Tierod	Left Flank		cast, wrought	brick/mortar	direct sunlight
Lintel	Left Flank		cast	brick/mortar	direct sunlight
Pintle & Pintle Tongue	Right Face	B1-3	cast	concrete (brick rubble), granite	shade
Pintle & Pintle Tongue	Right Face	A-14	cast	concrete (brick rubble), granite	sunlight/shade
Travese Rails (2)	Right Face	A-14	rolled wrought	granite	sunlight/shade
Lintel	Gorge Wall		cast	brick/mortar	sunlight/shade

Table 3.1 Pieces chosen for further testing

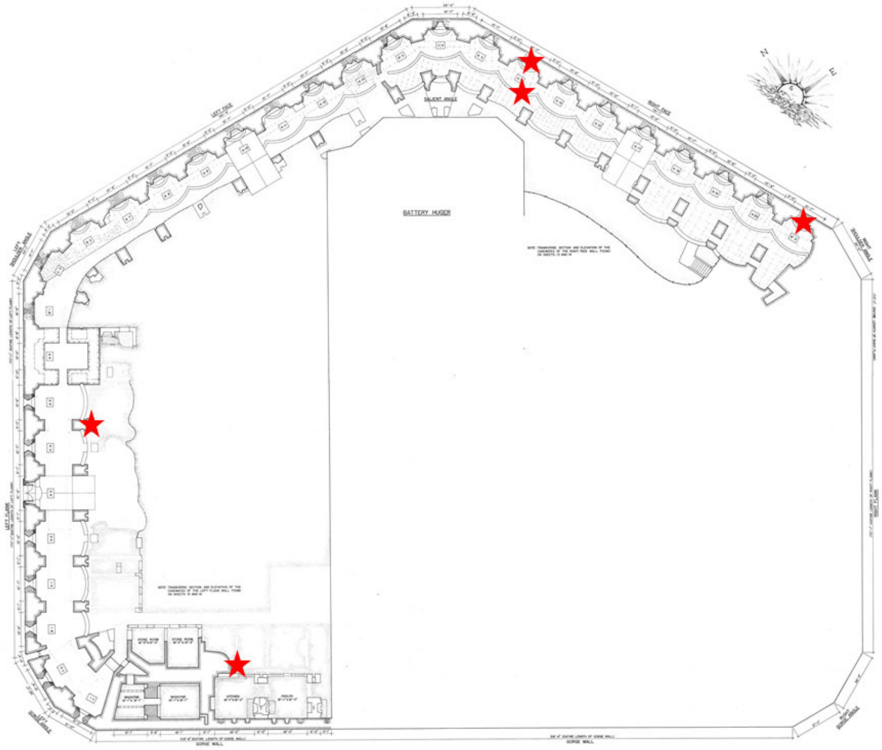

Figure 3.14: Map of Fort Sumter show placement of all samples taken. Note, the star along the left flank shows the location of both the tie-rod and a lintel.

to be able to compare the chloride levels on the individual iron pieces to identify if certain areas, conditions, or pieces at the fort show significantly higher chloride levels, thus having a higher probability for active corrosion.

SEM-EDS is not a portable form of analysis and requires the use of minute samples to be taken, but the analysis method is able to provide quantitative elemental data of a sample. From each of the six objects, a small drilling was taken using a drill and titanium bit. Energy Dispersive Spectroscopy allowed for not only an image to be formed of the metal itself but also gave closer examination of the iron pieces that is necessary for characterizing the pieces. For example, when two pieces appeared to be of similar composition during the XRF analysis, the SEM-EDS was able to help further separate the differences between the two samples by giving a quantitative analysis of the sample. Additionally, SEM was able to create an image and map the corrosion products and metal types.

Raman Spectroscopy

Figure 3.15: XRF Testing (photo by author)

Raman Spectroscopy was conducted to characterize the corrosion products on the iron artifacts selected in the survey. As Raman Spectroscopy can identify compounds, it was particularly useful in differentiating between various types of corrosion products. The artifacts at Fort Sumter experienced burial, exposure to a harsh marine climate, and destruction through the use of artillery, it was expected that pieces would show a variety of corrosion products. The analysis also was able to test for unstable corrosion products, thereby confirming the artifacts most in need of intervention. This analysis is not portable and required micro samples to be taken to the lab and examined when the artifact itself was not portable or could not fit into the sample chamber with the assistance of trained scientists. Three different sample locations were identified on each piece and scrapings were taken with a scalpel and packaged.

A true characterization of the composition of the metal artifacts would be interesting, but would only provide part of the answer to aid in developing a sensitive approach to iron conservation. Previous research already attempts to quantify aspects of corrosion, and the studies found that the composition of the element is often times the least influential.[12] While the research would undoubtedly benefit from a more in depth analysis of the pieces, the time frame of this project did not allow that level of investigation. Instead, the scope of this research was to provide a basic analysis of three different aspects of iron corrosion and compare how they interact and influence each other.

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[12] Abeer Arafat et al., "Combined in Situ micro-XRF, LIBS and SEM-EDS Analysis of Base Metal and Corrosion Products for Islamic Copper Alloyed Artefacts from Umm Qais Museum, Jordan," *Journal of Cultural Heritage* (2012), http://www.sciencedirect.com/science/article/pii/S1296207412001276.

CHAPTER FOUR
EVOLUTION OF ARCHITECTURAL IRON AT FORT SUMTER NATIONAL MONUMENT

The Industrial Revolution did not merely influence the advancement of architecture in the United States during the nineteenth century. It defined it. The growth of iron production allowed for the production of architectural iron elements on a massive scale. No longer was the iron industry ruled by local and regional blacksmiths and furnaces working on a project-by-project basis. Large manufacturers like the Trenton Iron Works defined the emerging industry. A group of overlooked professionals, the United States Army Corps of Engineers, labored at the heart this industrial growth. With the emergence of the Corps of Engineers, Americans began to educate academically trained engineers, similarly to the training received by European engineers. Additionally, these professionals developed new uses of iron.

Today, the Corps of Engineers is primarily associated with the canals and locks that were built across the country in the mid-nineteenth century, but many in the Corps had little if anything to do with the construction of these waterways. As the United States grew after the War of 1812, the federal government recognized the scarcity of structures and forts that were able to withstand attack and protect the country's growing cities and harbors. The Corps addressed this lack of efficient fortification and under the guidance and influence of Major General Joseph Totten developed a new system of forts. Called the Third System of Fortifications, these forts were specifically designed not only to project national strength in the nation's harbors but to withstand any type of enemy attack. Before Totten, an academic approach to construction and engineering did not exist. Construction was based on accepted knowledge gained through experience. Few, if any, construction projects had specific mathematical and physical experiments done to assess a structure's strength and durability.[1]

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[1] Ann Johnson, "Material Experiments: Environment and Engineering Institutions in the Early American Republic," *Osiris* 24, no. 1 (January 1, 2009), 53–74.

Over the last few decades, military historians have published a number of articles and books, which have drawn attention to the importance of these forts.[2] Some scholars have focused on the importance of the engineering developments, but, by and large, the Corps and their contribution to the development of structural iron are overlooked. The Corps of Engineers helped not only to create the engineering profession as we know it today but also to promote and develop the iron manufacturing industry that defined much of American history.

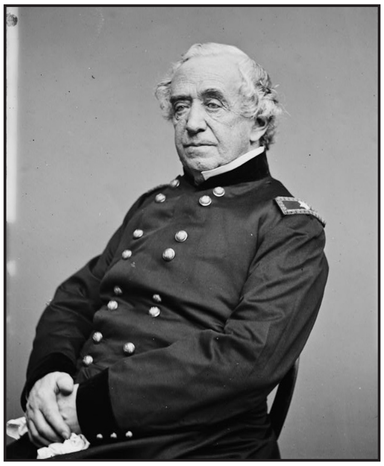
Figure 4.1: Joseph Totten (courtesy of the National Archives and Records Administration)

Leading this development was Major General Joseph Totten, an American born and trained engineer. His early training in the United States made him an unlikely source to promote the academic growth of the American engineering community. Educated at the United States Military Academy and trained under the renowned Simon Bernard, the chief of the Corps of Engineers from 1838-1864, developed the Corps into an organization that encouraged its engineers, not simply to build, but to develop better and more effective use of materials.[3] Responsible for constructing all public works and civic buildings, the Corps thrived as a hierarchical military organization that promoted the construction of large, complex structures and the flow of information from one engineer's experiments to another. The result was the creation of science-based engineering in the United States. Under Totten's guidance, the "statistical, mathematical, hydrographical

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[2] For a more military/artillery history focus see: Samuel R. Bright, "Confederate Coast Defense" (dissertation, Duke University, 1961); J. E. Kaufmann and H. W. Kaufmann, *Fortress America: The Forts That Defended America, 1600 to the Present* (Da Capo Press, 2004); Angus Konstam, Donato Spedaliere, and S. S Spedaliere, *American Civil war fortifications. 1, Coastal brick and stone forts* (Oxford, UK: Osprey Pub., 2003); Emanuel Raymond Lewis, *Seacoast Fortifications of the United States; an Introductory History* (Washington: Smithsonian Institution Press, 1970); Robert Browning III, *Two If by Sea, The Development of American Coastal Defense Policy* (Westport: Greenwood Press, 1983); John R. II Weaver, *A Legacy in Brick and Stone: American Coastal Defense Forts of the Third System, 1816-1867* ([McLean, VA]: Redoubt Press ; [Missoula, MT] Pictorial Histories Pub. Co., 2001).

[3] Johnson, "Material Experiments," 63.

report was in itself a king of technological innovation that brought West Pointers into construction without straining the national preference for empirically trained engineers."[4]

Early in its history, Totten and the Corps focused on testing the change in coping stones due to heat, diffraction of timber beams under load, and the resistance to tension and hardness in various mortars. It was not until the late 1850s that the Corps of Engineers began experimenting with improvements in manufactured cast metal that was often used in the construction of steam boilers.[5] Elsewhere, engineers and builders were beginning to experiment with the capabilities of structural iron. American iron manufacturing, and its productivity, was driven by the nation's ironmongers. In pre-industrial America, these were trained blacksmiths, makers of hand-crafted nails, fasteners, or decorative gates to name a few. After the design, each iron piece was created using a repetitive, laborious process of heating and shaping each piece by hand. As a result, architectural iron components were used sparingly. Iron was recognized for its strength and malleability, but was limited though its difficulty to work and shape on a large scale. The Industrial Revolution spurred ironworkers and entrepreneurs to assume a larger role in construction culture.

Figure 4.2: West Virginia Railroad Station showing cast iron columns and trusses. (courtesty of the Library of Congress)

Emergence of structural iron

Cast iron gained an early foothold in the construction industry due to its compressive strength and its ability to be shaped into almost any imaginable shape and size with relative ease. As a result, the metal became popular as a way to introduce structural support, decorative finishes, and a level of fire

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[4] Todd A. Shallat, *Structures in the Stream: Water, Science, and the Rise of the U.S. Army Corps of Engineers* (Austin: University of Texas Press, 1994), 105, 116.

[5] Johnson, "Material Experiments," 65.

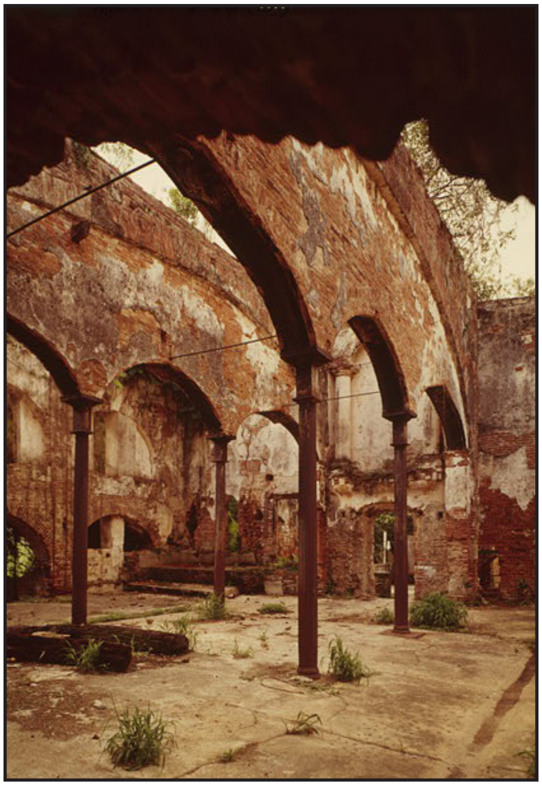

Figure 4.3: Sugar Mill in Puerto Rico utilizing combinatin of cast iron columns and masonry arches. (courtesty of the Library of Congress)

protection due to the metal's fire resistant properties.[6] Cast iron stoves replaced cooking over an open fire. Buildings were able to span greater widths through the application of columns as support, although construction was still limited by the metal's inability to span great distances due to its inherent brittleness. If a span was desired, the resulting cast iron beam would often be as large and cumbersome as a masonry vault that performed the same function.

In 1819, architect John Haviland, wrote that "the improvement and general introduction of cast iron bids fair to create a totally new school of architecture."[7] By the middle of the nineteenth century, entire buildings were constructed without the traditional masonry and wood support systems. As the iron industry grew, it became cheaper and easier to install beams, plates, and facades into buildings both large and small. The United States Corps of Engineers was quick to recognize the benefits of incorporating structural iron into its buildings. By the 1850s, it was not uncommon for towns all over the country to sport cast-iron facades. The new Cooper Union for the Advancement of Science and Art in New York (1853) was constructed using combination wrought and cast iron framing. The United States Assay Office in New York

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[6] This is not to say that cast iron is fire-proof. Quite to the contrary, early proponents of the metal's use quickly realized that the heat from fire would not only make it difficult to open iron doors and windows, but it also weaken or destroyed structural elements exposed to the fire.

[7] Haviland gains his fame from the numerous buildings he designed in the Philadelphia area in the early 19th century, many of these buildings incorporated new structural cast iron technology. Margot Gayle and Carol Gayle, *Cast-Iron Architecture in America: The Significance of James Bogardus* (W. W. Norton & Company, 1998) 37.

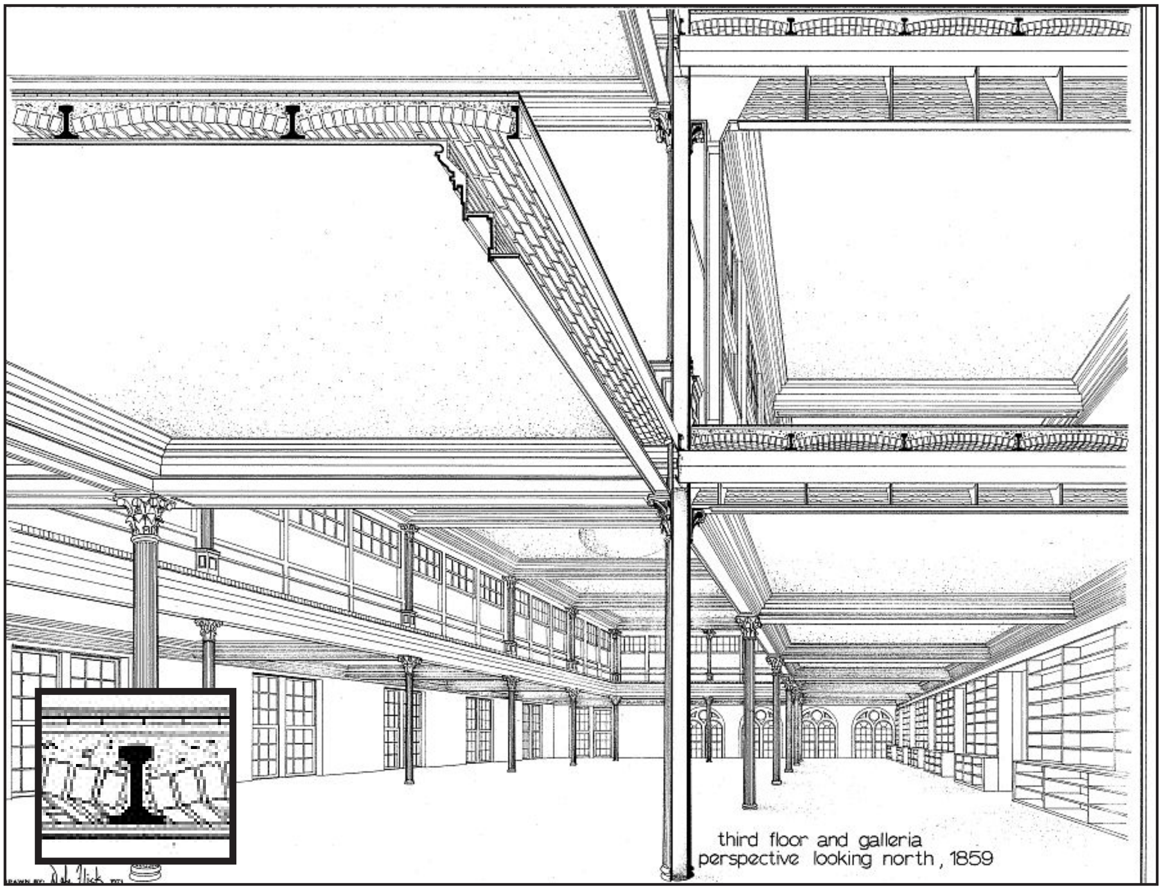

FIgure 4.4: Cooper Union Building from Historic American Engineering Record (HAEU) with enlargment of structural beam. (courtesy of the Library of Congress)

quickly followed the Harper & Brothers building in 1854. These buildings helped solidify the nation's growing interest in iron construction.[8]

Despite the rapid growth of architectural cast iron, buildings were limited in much the same way as buildings constructed using traditional masonry. Cast iron beams simply did not have the tensile strength needed to span the wider distances without adding extra bulk to the beam. By the 1840s, cast iron had seemingly reached the limits of its application in American building. This does not mean that cast iron was no longer used in construction. On the contrary, construction had reached such a point that few builders would contemplate a large structure without incorporating cast iron beams or columns into their design. Its

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[8] Charles E. Peterson, "Inventing the I-Beam, Part II: William Borrow at Trenton and John Griffen of Phoenixville," *APT Bulletin* 25, no. 3/4 (January 1, 1993), 17-20.

fire-resistant qualities and workability allowed architects and builders to construct safer and more elaborate buildings for much less cost than previously.

Wrought iron was less commonly used in structural applications. Wrought iron receives its strength through its composition which is formed during the process of working cast iron into shape, and through this process, removes and forces impurities into strand formations. Early on, bridge and railroad designers began experimenting with ways to mechanically roll wrought iron and by the early 1840s it was not uncommon to see rolled wrought iron rails in both bridges and railroads in the United States. Interestingly, American builders and architects, possibly taking inspiration from Joseph Paxton's Crystal Palace, began to order railroad ties and incorporate them into the roofs and trusses of their own buildings. The ties, while untested in an architectural environment, were thinner but proved to be stronger and easier to install than their cast iron counterparts.[9]

The Corps of Engineers was not the first organization to incorporate and test the effectiveness of rolled wrought iron, but they were quick to begin testing and experimenting with the technology. Captain Alexander Bowman, the engineer in charge of constructing the United States Assay Office in New York, was one of the first engineers to recognize the potential for rolled iron beams and incorporated them into his work.[10] Bowman worked with Peter Cooper and Abraham Hewitt of the Trenton Iron Works. Cooper and Hewitt were responsible for the creation of beams that were used in the construction of the earliest buildings that incorporated wrought iron beams as structural support: Harper & Brothers Building in New York, the U.S. Capitol, the U.S. Mint, and the Cooper Union Foundation Building.[11]

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[9] Michael Bussell, *Structures & Construction in Historic Building Conservation*, ed. Michael Forsyth (Oxford, UK; Malden, MA: Blackwell, 2007), 179-180; Geoff Wallis and Michael Bussell, "Cast Iron, Wrought Iron and Steel," in *Materials and Skills for Historic Conservation*, ed. Michael Forsyth (London: Blackwell Publishing, Ltd., 2008), 123.

[10] Coincidently, Bowman began his career as the engineer in charge of the construction at Fort Sumter in Charleston Harbor from 1841 until his appointment to construct the Assay Office in New York.

[11] Charles E. Peterson, "Inventing the I-Beam: Richard Turner, Cooper & Hewitt and Others," *Bulletin of the Association for Preservation Technology* 12, no. 4 (January 1, 1980), 15.

US Army Corps of Engineers and the construction of Third System Fortifications

Early on, the Corps of Engineers focused on building technology to aid in canal or fort construction and left other entrepreneurs to promote and experiment with architectural wrought iron beams. The first successes of rolled wrought iron beams encouraged the Corps of Engineers to begin their own ventures into construction with structural iron and began collaborating with Cooper and Hewitt. The Corps began to run tests tracking the application and strength of specific beams in various locations. One of these locations was Fort Sumter. Formerly in charge of construction at Fort Sumter during the 1840s, Captain Alexander Bowman, reported that they could purchase "rolled wrought iron beams, which are abundantly strong for our purposes, for less than half the price of the proposed [cast iron] beams."[12] By 1856, when the Trenton Iron Works rolled their first "true" wrought iron I-beam, the Corps adopted a wide-scale usage of wrought iron beams and almost completely discarded usage of cast iron beams and plates. At the center of this change, was an engineer, George W. Cullum, in an unlikely location, Charleston, SC[13]

Although a fort in the Charleston harbor had been planned since Joseph Totten surveyed the city and surrounding area in 1827, it took several decades for the shoal that became Fort Sumter to be turned into a man-made island and shored. By the mid-1840s, the island was stable enough to begin construction. From its earliest days, Fort Sumter was to be an important fort as Charleston was identified as one of the key strategic harbors in the South. As a result, Joseph Totten kept regular correspondence with the engineers in charge at the site.[14] Totten maintained a regular correspondence with all his engineers, but it was not uncommon for him to assign most correspondence to his aides, saving his actual correspondence for his own favorite projects: Fort Adams, Fort Trumbull, and Fort Sumter. This correspondence allowed Totten to maintain a consistent cohesive quality at all the

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[12] *Incoming Letters and Reports*, Alexander Bowman to James Guthrie, New York, October 7, 1853. (Washington D.C.: Office of the Supervising Architect),Record Group 121, National Archives Building, Washington D.C.

[13] Charles E. Peterson, "Inventing the I-Beam: Richard Turner, Cooper & Hewitt and Others," 5, 28.

[14] *Letters and Reports of Colonel Joseph G. Totten, 1803 - 1864* bound volume (Washington D.C.: War Department, 1864 1803), Records of the Office of the Chief of Engineers, 1789 - 1999, Record Group 77, National Archives Building, Washington DC.

forts he designed and maintained the flow of research and academic transfer of knowledge among his engineers.

Prior to Totten's leadership, materials were used and tested only during battle, but Totten recognized the need for quantifiable numbers to assess durability and used Fort Adams, in Rhode Island as his personal laboratory. Through his connection to West Point, he was able to attract the best students to work on his experiments and then after their training, placed them in other projects to apply that knowledge and practice.[15] Earlier forts, such as the first version of what would be Fort Delaware on Pea Patch Island, DE and Fort Calhoun in Hampton Roads, Virginia suffered from a lack of academic knowledge of building technology. Consequently, these early forts suffered from insufficient and sinking foundations from the very first days they were built.[16] It was not until scientific testing was incorporated into the plan of Fort Delaware that the engineers, Brevet Major John Sanders and Totten himself, were able to successfully implement a foundation plan that was able to withstand the weaker soils on the island itself. [17]

In the beginning, all the Third System fortifications were essentially equals. Plans and shapes changed depending on the location, but the materials and structural systems followed a specific guideline set forth by Totten. Stone, preferably granite when available, was to be used for the embrasure and casemate walls. When stone was not easily transportable to the location brick was substituted for stone. Barracks, when built on the site, were uniform in design and incorporated cast iron beams that were intended to span the distances between masonry walls. The result was a building that was considered fire-resistant, though the wood flooring and plastering diminished the fire-resistance considerably.[18]

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15 Johnson, "Material Experiments" 63.

16 J. E. Kaufmann and H. W. Kaufmann, *Fortress America: The Forts That Defended America, 1600 to the Present* (Da Capo Press, 2004)63-67; Kelli Dobbs and Rebecca Siders, *Fort Delaware Architectural Research Project*, Mid-Atlantic Historic Buildings and Landscapes Survey (University of Delaware, 1999).

17 Dobbs, *Fort Delaware*, 10.

18 John R. Weaver, *A Legacy in Brick and Stone: American Coastal Defense Forts of the Third System, 1816-1867* (Missoula, MT: Pictorial Histories Pub. Co., 2001); Rogers W. Young, "The Construction of Fort Pulaski," *The Georgia Historical Quarterly* 20, no. 1 (March 1, 1936), 41–51.

Early construction of both private and federal structures was largely dependent on regional supply and labor forces. The engineer in charge of construction of a Third System fort was responsible for hiring and contracting his workers, laborers, and suppliers. It was the duty of the engineer in charge to contract with local masons and stone cutters who would supply both labor and materials. Brick was utilized at Fort Sumter as granite had to be shipped in from long distances which would increase the cost of the fort. For Fort Delaware, granite was in plentiful supply in the neighboring states of Pennsylvania and Maryland and thus was cheaper and easier to transport, cut and shape to serve as the exterior of the casemate walls.[19] Unfortunately, many of these contracts were kept on site and have been lost over time, making it harder to track where each material originated.

For the more specialized pieces of equipment to be installed in the forts, the Army contracted with larger national suppliers. As discussed earlier, the Trenton Iron Works, later called Cooper Union, was an early contractor with the United States Government, though their relationship with the Army lasted only a few years. Specialized pieces typically consisted of ordnance equipment such as the traverse rails, and pintles and pintle tongues. These pieces required a certain amount of precision in the installation. Once manufactured, engineering reports sent to the Chief of the Army Corps of Engineers office in Washington D.C. described the shipped granite stock as being of a relatively rough quality. After its arrival, masons finished the blocks by drilling holes and local blacksmiths installed both the blocks and ordnance pieces into the fort.[20] Through this method, construction could progress quickly and efficiently as all technical materials were manufactured by trained personnel to specific guidelines and then finished to the unique plan of the fortification itself.

The combination of nationally-contracted manufacturers and locally-hired experts typified the change that occurred throughout the country during the industrialization

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[19] Dobbs, *Fort Delaware*, 10.

[20] Thanks to a comprehensive timeline of the construction of Fort Delaware compiled by the students in the Center for Historic Preservation at the University of Delaware, it is easy to gain a better understanding of the stages of construction of one of the Third System Fortifications; Dobbs, *Fort Delaware*, 24.

period. Less specialized parts, like custom-made bolts, were more affordable to manufacture and purchase locally. However, many parts required specialized machinery that was largely untested. Engineers arrived, ordered supplies, and hired laborers, all the while maintaining a regular correspondence with their superior officers at Army Corps of Engineers headquarters in Washington. Current scholarship attributes the construction of Fort Sumter to the same method of planning, design, and construction as other contemporary forts. In reality, even though Fort Sumter began construction in a similar fashion, it diverged from the normal routine early in the process. On the surface the original fort (pre-April 1861 bombardment) appeared similar to other forts, but the interior system was an entirely new design and completely untested in battle.[21]

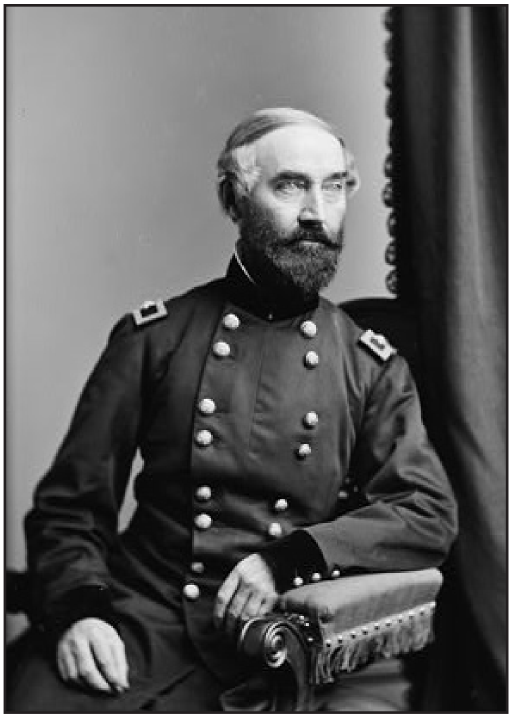
Figure 4.5: Captain George W. Cullum (courtesty of the Library of Congress)

Incorporation of structural iron at Fort Sumter

Captain George W. Cullum had taken over as the engineer in charge of construction at Fort Sumter by 1855. Cullum was a product of Totten's training system and served as an assistant engineer during the construction of Fort Adams after graduating from West Point. Prior to being stationed at Fort Sumter, Cullum was an engineering instructor at West Point, and in 1853 he briefly worked with Captain Bowman on the United States Assay Office.

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[21] John R. Weaver, *A Legacy in Brick and Stone: American Coastal Defense Forts of the Third System, 1816-1867* (McLean, VA: Redoubt Press; Pictorial Histories Pub. Co., 2001), 144.

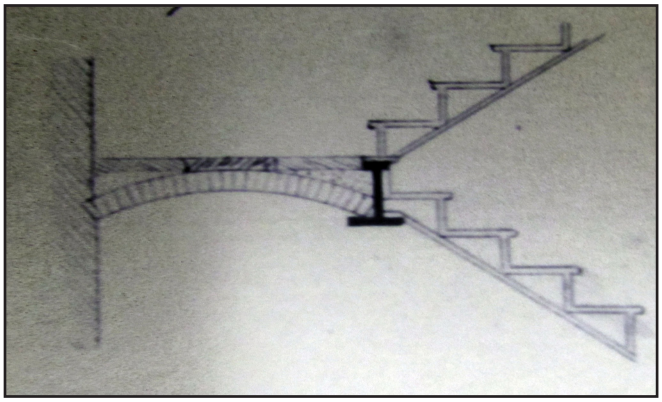

Figure 4.6: Cast iron beam supporting a masonry arch as drawn by Joseph Totten, 1851 (courtesy of Fort Sumter National Monument).

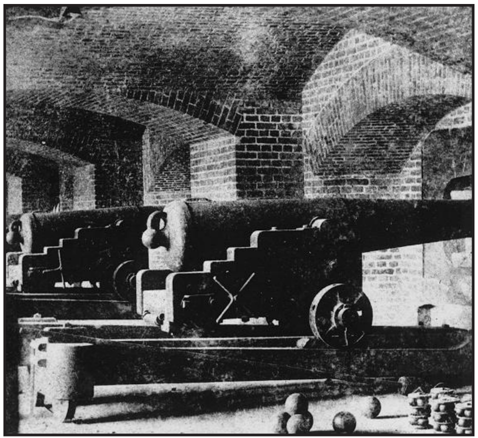

Figure 4.7: Cannon carriages were designed to withstand recoil of the cannons and aim at a wider angle (courtesy of the Library of Congress).

There, he undoubtedly was introduced to the advantages of building with wrought iron and carried that knowledge with him to his appointment in Charleston.[22]

Cullum's legacy today connects him more to his works in Fort Trumball, Connecticut and his later position as Superintendent at the United States Military Academy, but his largest influence was felt at Fort Sumter. When the time came to build the barracks and officers' quarters, building technology was in the midst of a revolution and Totten's early design, while assuredly successful, was becoming antiquated. The original intent was to tie both the officers' quarters and enlisted soldiers' barracks into the casemates. This design used the casemate walls to provide each structure with added strength and stability and create essentially one large monolithic structure that would be the fort itself. This was an unquestionable improvement over many of the earlier Third System Fortifications where Totten intended soldiers to live in the dark and usually damp casemates.[23]

Totten's plan called for the barracks' construction utilizing cast-iron beams that ran in a transverse, or parallel, pattern along the length of the barracks walls and would be

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[22] "Gen. George W. Cullum," *The New York Times*, February 29, 1892; William R. Livermore, "George W. Cullum," *Proceedings of the American Academy of Arts and Sciences* 27 (May 1891): 417.

[23] J. E. Kaufmann and H. W. Kaufmann, *Fortress America: The Forts That Defended America, 1600 to the Present* (Da Capo Press, 2004) 47.

supported by stirrups let into the masonry platform arches.[24] This design had already been in common usage since the early nineteenth century and allowed for the building to have a more open and flexible plan. Space in the interior was achieved by removing the bulky masonry walls that would otherwise serve as the primary structural support of the building and replacing them with smaller columns of cast-iron.[25] For the engineers of Fort Sumter, this large, open space was essential in the construction of the barracks. Common artillery practice in the mid-nineteenth century required significant space that allowed for both the recoil of the cannons and movement of the soldiers aiming and firing the guns. The first floor plan was intended to be connected to the casemate walls, and in case of battle, the interior partition walls would be able to be removed in the barracks thereby doubling the casemates size.[26]

While the design was successful in my of the barracks in the Third System Fortifications, Cullum requested to change the plans for Fort Sumter. He wished to switch from the heavier cast iron beams to allow for “light, wrought-iron joists which

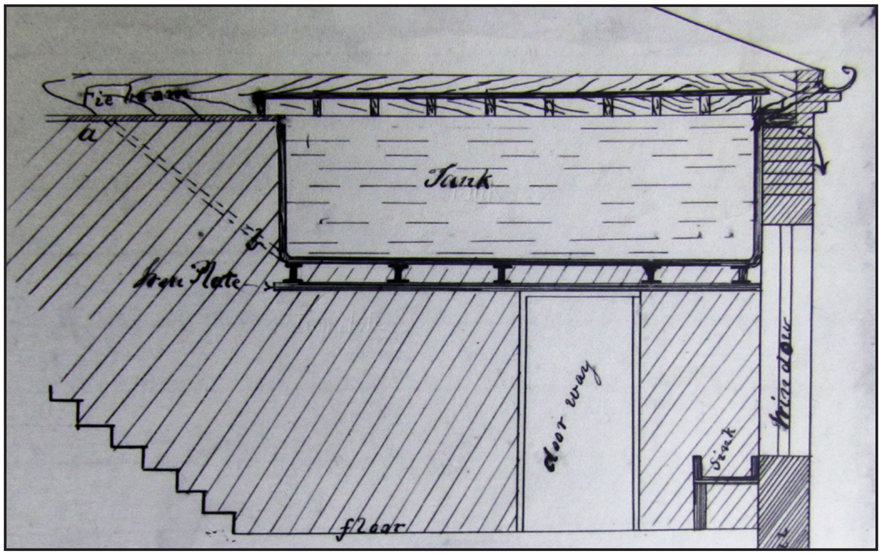

Figure 4.8: Sketch detailing placement of wrought iron beams to be placed in barracks to support cistern tanks. (courtesy of Fort Sumter National Monument)

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[24] A more detailed construction history of Fort Sumter can be found in the following citation: Frank Barnes, *Chronological Construction History with Architectural Detail* (Fort Sumter National Monument: Department of the Interior: National Park Service, 1959) 18.

[25] Bussell, 175.

[26] Barnes, 25.

ran longitudinally in the buildings and were supported by the end walls and two central wrought-iron girders."[27] This design separated the barracks from the casemate walls causing the quarters to be distinct structures from the rest of the fort. This change added the benefit of keeping the barracks fire-resistant while lightening the load of the building as a whole without losing needed strength. A change order, altering the barracks plan, may seem minor, but Totten was famous for keeping strict control over the construction processes of the forts. He rarely allowed any engineer to contribute to or change the plan. Cullum not only suggested a new design, he argued for a complete and relatively untested new material to be incorporated into the fort itself.

This change was likely allowed to occur because of the close working relationship Totten maintained with Cullum. Throughout his career, Cullum routinely corresponded with Totten on engineering matters and theory. Through the letters, it was clear that both men greatly respected the other's opinion. When Cullum wrote to Totten and asked to change the previously approved design which tied the barracks to the casemate walls, the letter and suggestion came more from a respected colleague than a subordinate. The change, Cullum argued, would not only allow for a more uniform settlement of the barracks, as it would be independent from the older (and theoretically more settled) casemate walls but also would cost less than the cast iron girders as the iron joists weighed significantly less than the cast iron.[28] A skeptical Totten, responded:

> I have been aware, for some time, that such joists and girders are getting into extensive use, and have little doubt that they will-perhaps they ought to do so now- supplant cast iron beams, generally, but as yet, I have not seen the matter placed sufficiently-beyond doubt to warrant their substitution in applications to our structures, in cases where the latter from long experience and the highest authorities are known to be sufficiently-lasting and economical.[29]

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[27] Barnes, 18.

[28] *George W. Cullum to Joseph Totten, 3 January 1856.* Letter. "Engineer Records of Fort Sumter," 1845-1886, Department of the Interior, National Park Service, Fort Sumter National Monument.

[29] *Joseph Totten to George Cullum, 11 January 1856*. Letter. "Engineer Records of Fort Sumter," 1845-1886, Department of the Interior, National Park Service, Fort Sumter National Monument.

Figure 4.9: Early bombardments caused the barracks to fall early. (courtesy of the Library of Congress)

Coincidently, the highest authority on the construction of cast iron beams and platform arches was Totten himself, but acknowledging that he knew little of this new technology, he still asked for a report quantifying the strength and cost of such beams.

Cullum's reply would not only result in Totten allowing the barracks to be built as Cullum wished, but also the barracks are possibly one of the first buildings to incorporate the newly developed I-beam in the country. Cullum wrote , "the beams and girders which I propose to use made by Mssrs. Cooper and Hewitt at Trenton Iron, and which have been were tested by Captain Bowman of the Corps of Engineers."[30] Cullum acknowledged that the previously used beams that went into the New York Assay Office were already deemed insufficient and of an inferior quality to what existed presently and supplied a detailed report assessing the strength and cost of these newly rolled beams.[31]

At its completion, Fort Sumter, a tiny man-made island, could boast as good of living conditions as any soldier could expect if he was stationed on the mainland. There was a gas plant providing adequate light, cisterns in the roof that allowed for running water, coal stoves for heat, large windows, and adequate ventilation and separation between the magazines and living quarters. Unfortunately, the remarkable fort was to be ultimately destroyed and rebuilt periodically over the next four years of the Civil War. In the end, the fort would barely be a shell of its former existence, and it is here that the problem of how to conserve and protect what was originally the first of its kind begins.

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[30] *Cullum to Totten, 11 February 1856*. Engineering Records.

[31] *Cullum to Totten, 11 February 1856*. Engineering Records.

Figure 4.10: After the destruction of the barracks, the I-beams served a second life as support for a barbed wire fence to ward off a potential land invasion. (courtesty of the Library of Congress)

Figure 4.11 Fort Sumter in ruins at the end of the Civil War. (courtesty of the Library of Congress)

Figure 4.12 Excavator dumping excataved dirt over the scarp wall during the 1950s excavation (courtesy of Fort Sumter National Monument).

Figure 4.13: Fireplace grate that was discovered during the 1955 excavation (courtesy of Fort Sumter National Monument)

Figure 4.14 Left Flank and parade ground being excavated during 1956 excavation (courtesy of Fort Sumter National Monument)

Throughout the bombardment campaigns, the newly developed rifled cannon was able to destroy the masonry walls that were designed to withstand bombardment from traditional cannons. Fires gutted and destroyed the barracks and officers' quarters. The I-beams and girders from the destroyed barracks were reused to provide stabilization of the exterior of the fort and served as posts where soldiers could run barbed wire to help protect against a land attack during the night while the Confederate soldiers rebuilt and strengthened the fort. As the fort continued to receive fire from the Union batteries on the mainland, the Confederates filled in the remaining casemate walls with a mixing of debris, sand, and cotton bales. [32]

While little textual documentation chronicles the downfall of this fort that was once at the forefront of the engineering world, surviving pictures are able to tell a more complete story. Unfortunately, there are few remaining pieces of the historic and game-changing ironwork left at the fort. What remains today stands as a silent testimony to the importance and ingenuity of the engineers and soldiers at Fort Sumter.[33]

At the end of the war, Fort Sumter was a rubble-filled ruin. Barnes stated that the fort, "had been reduced to an earthen and masonry ruin, with only eighteen of the lower-tier casemates and four second-tier casemates intact and usable to any appreciable degree, beneath the sloping debris."[34] After the war, very little was done to clean up and rebuild the fort until the 1870s when the Army finally enacted plans to change and rebuild the fort. Work concentrated on shoring up the walls and building a new Sallyport, or entrance, into the fort as the original Sallyport was heavily damaged during the war. The earthquake of 1886 halted these plans by once again destroying much of the fort. The fort was largely abandoned until the 1890s when the Army began constructing the newly developed

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[32] John Johnson, *The Defense of Charleston Harbor, Including Fort Sumter and the Adjacent Islands. 1863-1865.*, reprinted in 1970 (Freeport, NY: Books for Libraries Press, 1889) 122.

[33] A comprehensive history of the remains of the fort can be found in Frank Barnes's History of Fort Sumter. Frank Barnes, *Fort Sumter: December 26, 1860* (Fort Sumter National Monument: Department of the Interior: National Park Service, 1950); Frank Barnes, *Chronological Construction History with Architectural Detail* (Fort Sumter National Monument: Department of the Interior: National Park Service, 1959).

[34] Barnes, *Fort Sumter: February 17, 1865*, 1.

Figure 4.15 Left Face showing exisiting traverse rails from Historic American Buildilng Survey Documentation. (courtesy of the Library of Congress)

and considerably stronger Endicott Batteries as the replacement to the traditional masonry forts. In order to accomplish this, the original Parade Ground had to be filled in approximately to the level of the existing casemate walls, thereby leaving any remaining original fort remains buried.[35]

By 1955, the Army had relinquished the running of the Fort to the National Park Service. The Park Service, wishing to restore the fort back to its period of significance, began a multi-year excavation project. Work concentrated on the Gorge Wall, Left Flank, Left Face, and Right Face. Surprising many of the excavators, remains of window bases, floors, and fireplaces dating from the original fort were found amongst the rubble and sand along with remnants of whitewash and wooden door surrounds. Unfortunately, much of the iron remains were corroded beyond recognition and discarded. Some artifacts however, such as the fireplace grate from the officers' quarters, were found and sent to the National Park Service Collections Center further inland.[36]

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[35] Barnes, *Fort Sumter: February 17, 1865*, 32-40.

[36] Rock Comstock, Jr., *Excavation Report: Fort Sumter National Monument, June 17-30, 1955* (United States Department of the Interior, National Park Service, 1955), Fort Sumter National Monument, 7.

Today, Fort Sumter retains only a few pieces of its original ironwork. Along the Left Flank and Left Face, several traverse rails remain in their original places. Additionally, along most of the fort, there are the remnants of the original pintles and pintle tongues that connected the cannons to the embrasure walls. If Fort Sumter had somehow escaped the damage of the bombardments, the fort would undoubtedly be famous for the remarkable engineering firsts in the use of early structural iron technology. Unfortunately, the war did happen and the fort was destroyed, but that only makes what remains even more significant to study. The remaining ferrous objects tell the story of a nation's emergence as an engineering leader.

<u>The remnants of the Civil War era ironwork at Fort Sumter National Monument</u>

The existing ferrous pieces can be divided into two main building campaigns: Civil War Era and Endicott Era. Most of the objects that date from the Endicott Era exist in and around Battery Huger and remain separate from the rest of Fort Sumter. The homogenous nature of the Endicott Era metalwork, leads many of the pieces to be easily dated. The Civil War pieces are not so easily definable. There are pieces that date from the construction of the fort, as well as pieces that date from the Confederate Occupation up to the 1870s rebuild attempt. A more complete survey of the Civil War era iron objects is included in the appendix, but the following pages give an overview of the more significant pieces themselves.

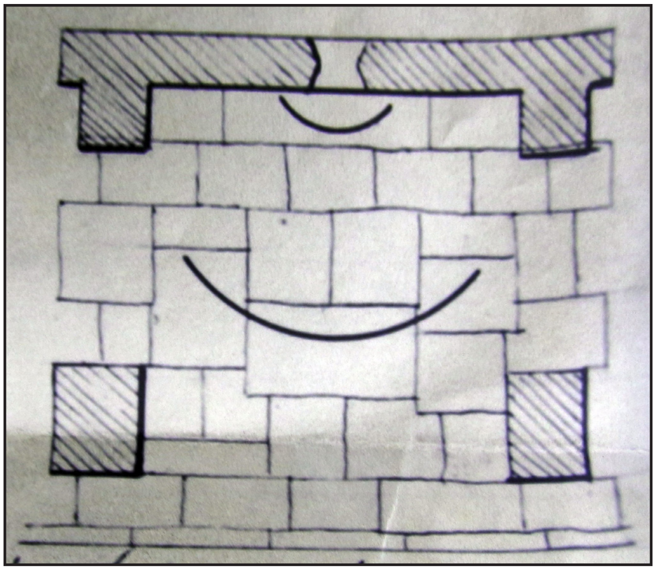

Figure 4.16 1852 sketch from Joseph Totten depicting the traverse rail and center placement. (courtesy of Fort Sumter National Monument)

Traverse Rails

The traverse rails were among the earliest iron objects to be installed within the fort, and were arguably the most important installation for the Army. The rails were a Totten design and remained fairly standard throughout the construction of the fort. Plans were in place to install these as early as February of 1852, but the actual installation of the rails did not occur until several years later when the stones they were to be set in had been placed and settled. The engineers allowed the stones to settle for several years, as the 3½" x 5/8" irons needed to accurately and securely support the cannons and carriages. Meanwhile, the Corps of Engineers, in typical fashion, tested and retested the stones by installing a few cannons, firing them, and then measuring the cracks that appeared after the first usage.[37]

It was not until 1856 that the traverse rails were completely installed in the fort, though it is probable that many were installed much earlier than 1856. Up until that time, construction had focused mainly on the exterior scarp walls, foundations, and first level of embrasures. The rails, according to Totten, should be set in stone and lie in a thin bed

Figure 4.17 Traverse Rails inside Right Face casemate at Fort Sumter (photo by author)

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[37] *J.D. Kurtz to Joseph Totten, 20 May 1852* "Engineer Records of Fort Sumter" transcribed letters, 1886 1845, Department of the Interior, National Park Service, Fort Sumter National Monument.

of mastic asphalt, a mixture of asphalt and sand that would serve to fasten the metal to the stone and provide a basic layer of water resistance to the undersides of the traverse rails.[38] Unlike many of the smaller metal pieces which could be constructed on site by local blacksmiths, the rails themselves were supplied by the Army Ordinance Department. The rails would be ordered as needed throughout the construction process and shipped to the site.[39] There is some misunderstanding as to whether the traverse rails were made from steel or the more typical rolled wrought iron. All contemporaries refer to the traverse rails as irons. As iron remained in the usual lexicon at the time, it is probable that the reference to iron simply denotes the material as being a ferrous metal.[40]

The traverse rails survived multiple bombardments due to their placement in the fort, flush against the granite and bluestones. Likely, the bombardment had the added advantage of preserving the existing traverse rails as they were quickly buried and remained so until the 1950s excavation. Today, the rails' exposure is leading to rapid corrosion and few rails are left, though the iron bolts that held the rails in place to the granite stones are in significantly better condition. The conditions that allow for the bolts to be better conserved than the rails will be discussed more in depth in Chapter Eight.

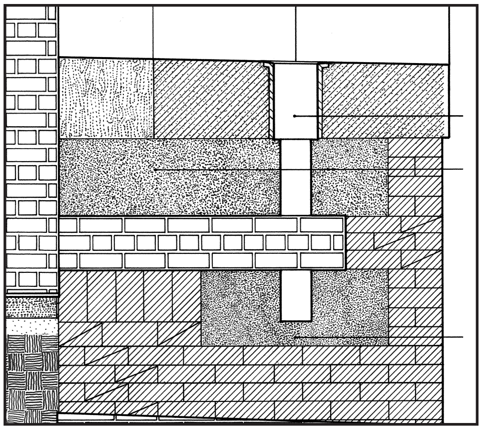

Figure 4.18 HABS documentation showing section cut for placement of pintle and pintle tongue. (courtesy of the Library of Congress)

Pintles and Pintle Tongues

Similar to the traverse rails, the pintle tongues, pintles, or centers as they were called by the engineers were manufactured and shipped down to Fort Sumter as needed. The pintle is made up of two complementary parts: a cast-iron bolt, or pintle that is

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[38] Barnes, *Chronological Construction History* 10; Letters to Kurtz, 24 February 1852.

[39] *H.G. Wright to G.W. Cullum, 9 June 1856.* Letter. "Engineer Records of Fort Sumter" transcribed letters, 1886 1845, Department of the Interior, National Park Service, Fort Sumter National Monument.

[40] Fort Delaware, 15.

embedded in the casemate wall, and cast iron tongue that extends from the pintle and attaches to the cannon carriage. These pintles worked in a similar fashion to the shutters and would later play a prominent role in the defense and later degradation of other Third System Fortifications.[41] Intended to serve as an anchor for the cannon and carriage, the pintle and pintle tongue were designed to pivot along the traverse rails and allow for the cannon to have a wide angle to fire, but minimize the amount of open shutter space for enemy fire to enter the casemate walls.[42]

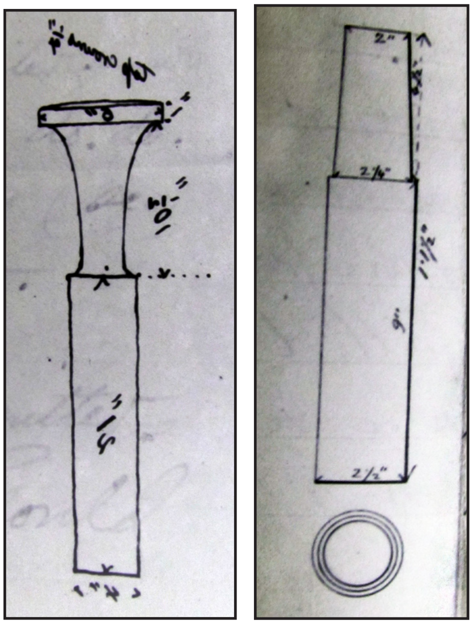

Figure 4.19 & 4.20 1584 sketches detailing pintle tonge (left) and pintle (right) (courtesy of Fort Sumter National Monument)

The pintles were designed by Totten as part of the Fort Adams project in the 1830s and changed little from their development to their incorporation into the fort. Totten already had a history of installing his self-opening and closing shutter system, and it is strange that he chose not to have the engineers install this system at Fort Sumter.[43] The original design called for the pintles to have a 4" diameter and be embedded with a cast iron sheath at the opening to prevent damage from local fire. By the time the pintles were installed at Fort Sumter, they had grown 2 ½" to be 6 ½" in diameter with a ¾" cast-iron sheath on top. Following the original designs, the pintle was embedded through two sets of granite blocks that would be able to withstand the recoil of cannon fire. Engineering reports agreed that embedding pintles in brick and mortar was not sufficient enough to withstand prolonged firing, thus most designs required the pintles to be embedded in masonry.

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[41] Fort Jefferson, in the Florida Keys, has had a particularly tough time successfully conserving their iron pintle bolts and shudders. In fact, the corrosion of the shudders at the fort is causing the entire scarp wall to jack apart and fall into the water.

[42] Barnes, *Chronological Construction History*, 12.

[43] Robinson, Willard Bethurem. *American Forts-Architectural Form and Function*. Urbana: Published for the Amon Carter Museum of Western Art, Fort Worth, by the University of Illinois Press, 1977.

Testing showed that even in the early stages, early corrosion and the stress of firing was known to crack the surrounding masonry. In the testing done at Fort Sumter in 1851, engineers observed that cracking:

> commenced at the top of the semicircular iron arms of the Pintle Irons and extended horizontally; generally on both sides in the Embrasures fired from, and on an average 5 or 6 inches long; in those not fired from, only a small crack, on an inch on only one side. This would seem to show that the expansion and contraction of the pintle irons has started small cracks, which have been further opened by the sudden shocks upon the pintle irons.[44]

The pintles and pintle tongues were considered important enough technical objects that the Army contracted with specific manufacturers, similar to the traverse rail contracts. Documentation shows that many pintles and pintle tongues at Fort Sumter could have come from one or two separate suppliers, though the foundry itself is not named. In 1856, Captain Cullum asked Gen. Totten to send pintles and the pintle tongues from a foundry in New

Figure 4.21: HABS image showing intact pintle along Left Face. While the exact casemate is unknown, this pintle is no longer in existance. (courtesy of the Library of Congress).

Figure 4.22: Image detailing corroded and broken pintle from Right Casemate (photo by author).

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[44] *J.S. Morton to Joseph Totten, 20 May 1852.* Letter. “Engineer Records of Fort Sumter” transcribed letters, 1886 1845, Department of the Interior, National Park Service, Fort Sumter National Monument.

York (Watervilet, NY) instead of from a foundry in Old Point Comfort because of the lack of communication and transportation capabilities from Old Point Comfort to Charleston.[45]


Figure 4.23 HABS image of Left Flank Fireplace. (courtesy of Library of Congress)

Despite the bombardment and the success of the rifled cannons during the war, the pintles are remarkable in their ability to survive. Likely, their placement in two large granite blocks assisted in their high survival rate. These pieces have largely been forgotten as time has passed, probably due to the fact that they are not nearly as prominent in the fort itself. Most of the pintles still exist and are in remarkably good condition. They show little effect of the successive campaigns of rebuilding and burial that the fort experienced in the years following the Civil War. The pintle tongues connecting the carriages to the pintles themselves have not been as long-lasting. Most are recognizable as pintle tongues only because of their location underneath the casemate walls, though all the ironwork in the Right Face of the fort, including pintle tongues, traverse rails, and Parrott cannons, were found during the 1950s excavation to be in remarkably good condition.

Tie-Rod & Lintel

When walking into the modern day Sallyport, to the immediate left is a fireplace. The fireplace is sitting on what was once the foundation of the fireplace from the enlisted men's

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[45] *Cullum to Totten, 11 February 1856*. Engineering Records; *1858 Annual Report, 19 August 1858.* Letter. "Engineer Records of Fort Sumter" transcribed letters, 1886 1845, Department of the Interior, National Park Service, Fort Sumter National Monument.

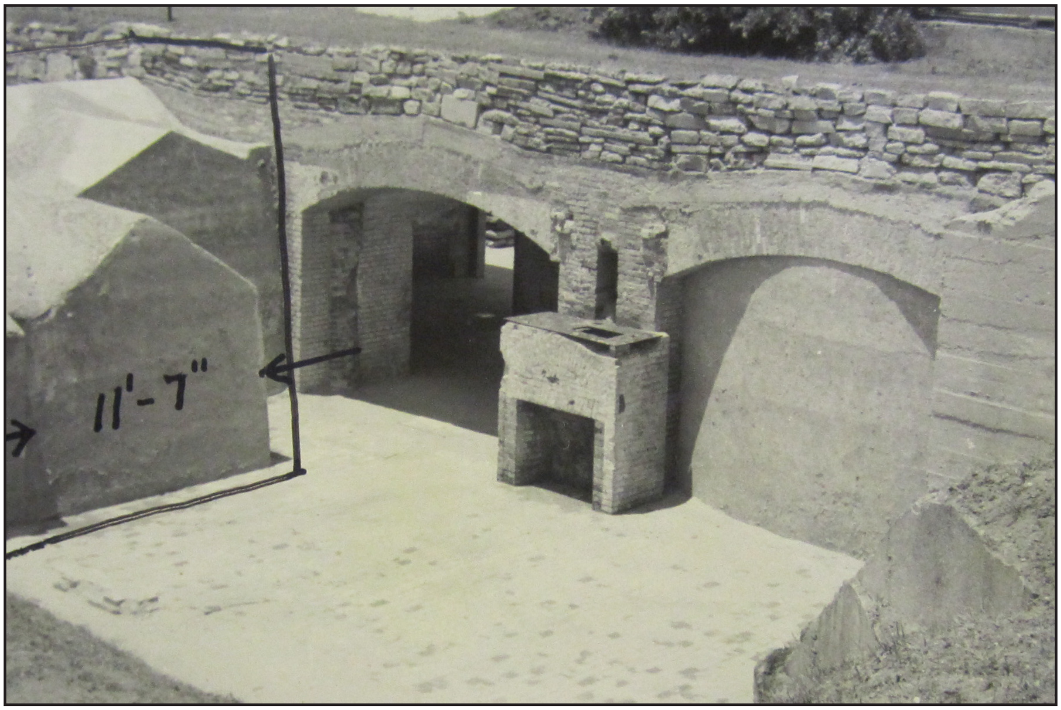

Figure 4.24 1956 Excavation Photo showing recently uncovered fireplace without concrete cap. (courtesy of Fort Sumter National Monument)

Figure 4.25 Left Flank Fireplace after December 2012 conservation work. (photo by author)

barracks along the Left Flank of the fort, and the brick that makes up the chimney is original to the 1850s construction. The engineers and soldiers who occupied the fort had a history of reconstructing buildings and chimneys with salvaged brick on site, thus the date of the brick is not necessarily the best method to date the fireplace itself, nor is the location as the Left Flank of that wall received particularly heavy damage during the Civil War.

During the 1950s excavation, the fireplace was found in much the same condition that it is today. The firebox remains, but the rest has disappeared. The base had a concrete cap placed on top presumably to help prevent moisture from entering the remains of the chimney and degrading it further. The ruins of the chimney have both an iron lintel supporting a simple brick lintel above the firebox and a more complicated brick arch above. The larger brick arch undoubtedly acted as a stronger support for the weight of the brick masonry above, and curiously, a tie-rod is run through the base of the arch. Tie-rods themselves were commonly used in supporting masonry buildings in the Charleston area before the Civil War, but are more commonly associated with the Earthquake of 1886.[46]

If the tie-rod is to be interpreted as a later addition that intended to support the fireplace itself, then there is good evidence for the pre-Civil War original date of construction of the fireplace. Unfortunately, the firebox of the chimney is of a more modern design that did not appear in common building schemes until the late nineteenth century, signaling its post-Civil War construction. The English designed a similar firebox in the early part of the nineteenth century, but the design took time to catch on in the United States. Additionally, the firebrick that is found surrounding the firebox itself differs from the other brick at the fort. The use of the specialized brick to retain heat from a fireplace did not gain popular use until late in the nineteenth century as well. However, as the firebox design was around prior to the start of the Civil War and the Army Corps of Engineers has a history of

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46 In fact, the original plan for the barracks called for having tie-rods run through the barracks as a further means to support the walls of the building. These were replaced when Cullum redesigned the barracks structural design.

incorporating developing designs and technologies into their buildings, the advanced design is not sufficient enough proof that the chimney itself dates after the Civil War.[47]

Since much of the damage was done to the Left Flank of Fort Sumter, it is unlikely that the base of a chimney would be left unscathed during the bombardments; however, that part of the fort was buried in rubble early on, and it is possible that the chimney escaped total demolition and that the Army put the cement cap on the chimney during the 1870s reconstruction as they were building the new Sallyport. As there is no visible soot or ash in the throat of the chimney itself, it is unlikely that this fireplace was used much, if at all.

Documentary evidence is able to shed some light on the origins of this fireplace. During the 1870s reconstruction, Barnes wrote that "In the casemates on either side of the Sallyport casemate, fireplaces were built in the retaining walls that had been built in the rear of the casemates. These casemates could be used for guard rooms."[48] As casemates were notoriously cold and damp places, it is probable that, if guard rooms were to be built, fireplaces would be a natural addition to the room. The few plans that exist document the buildings constructed at the fort and do not appear to utilize the existing casemates. From Barnes' description there would be a twin fireplace on the opposite side of the Sallyport. There is not, nor do the fireplaces orient themselves in such a way that the fireplace would be useable from within the casemates.[49]

Figure 4.26 HABS documentation of Confederate Era fireplace. (courtesty of the Library of Congress)

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[47] John Pickering Putnam, *The Open Fireplace in All Ages* (Ticknor, 1880), 45.

[48] Barnes *Fort Sumter: February 17, 1865*, 32.

[49] "Proposed Ordinance Sergeants Quarters at Fort Sumter, SC", March 28 1879; *Register of Contracts for Engineering Projects, 09/1879 - 10/1887* (Department of the Treasury, 1887 1879), Records of the Accounting Officers of the Department of the Treasury, 1775 - 1978, Record Group 217, National Archives Building, Washington DC.

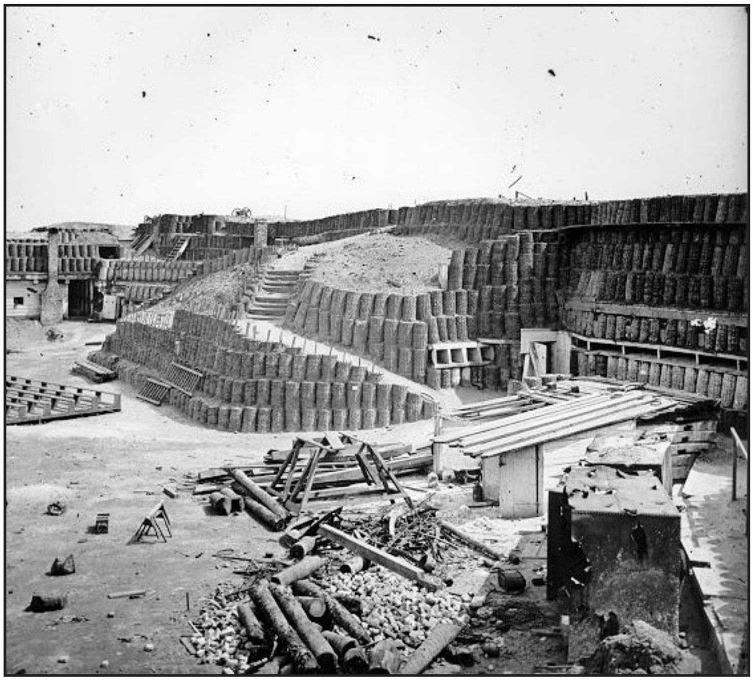

Figure 4.27: 1865 image of interior of Fort Sumter after Union bombardment prior to Second Union Bombardment. Image is of the Gorge Wall, the current fireplace would be buried to the left of the image. (courtesy of Library of Congress)

Figure 4.28 1863 image of interior of Fort Sumter prior to Second Union Bombardment. Note to the far left, a fireplace of similar shape and demensions to the currently exposed fireplace along Gorge Wall. (courtesy of Library of Congress)

Figure 4.29 1956 Excavation Report image detailing fireplace as found. (courtesy of Fort Sumter National Monument)

It is known that the fireplace and chimney existed prior to its burial by the Army in the 1890s to make way for Battery Huger, the Endicott Battery, and until 1955 it was buried and forgotten by the public and Army. When exposed in the 1950s, the tie-rod and lintel appeared to be in very good condition and the park did little with this chimney, choosing to leave it standing along the floor of the original barracks.[50] Over the last sixty years, the tie-rod and lintel have severely corroded and the remaining metal caused the masonry to crack or break apart. Choosing to protect the chimney as whole, the park decided to remove the corroding pieces and replace them with typologically similar replicas (constructed of stainless steel and coated on all surfaces) in December 2012.

Confederate Fireplace Lintel

Along the Gorge Wall sits another, very different, chimney and firebox. While the chimney along the Left Flank is a sophisticated and well thought out design due to the tie-rod, arch, and lintel, the ruins of the chimney along the Gorge Wall consists of a more primitive design and inferior construction. The firebox is a simple box. It is likely that it would have drafted efficiently and undoubtedly would emit large amounts of smoke into the room or area it was intended to heat.[51] Time has caused the fireplace to settle unevenly, showing that the proper foundations were not constructed. Knowing this, it is likely that the chimney and fireplace were built with the intent that they were to be temporary features, not permanent.

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[50] Comstock, *Excavation Report.*

[51] *The Open Fireplace*, 45-48.

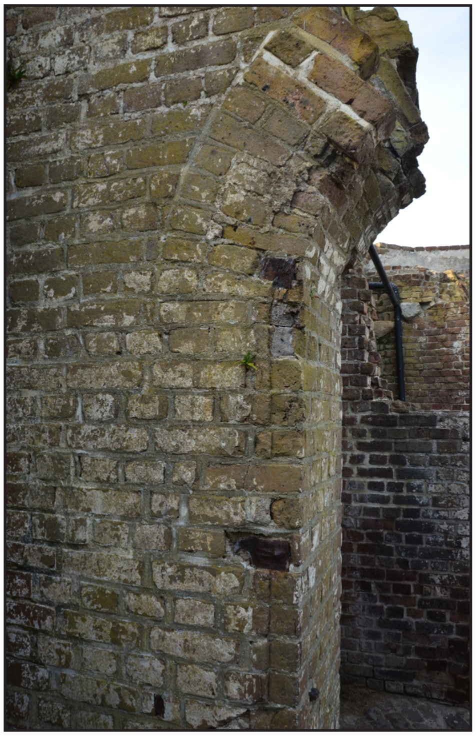

Figure 4.30 (left) Door hardware remanents from original magazine along Gorge Wall

Figure 4.31 (top) Original door tred at base of magazine doors along Gorge Wall.

Photos by author

All knowledge of this chimney must be inferred and taken from photographic evidence as no documentation has been discovered that discusses this chimney prior to the 1950s excavation reports. While the fireplace is in one of the rooms that had been officers' quarters, it is located to the side of the room and does not fit with the original planned fireplace location. This area of the Gorge Wall was destroyed and buried during the Second Union Bombardment and unfortunately all known photographic evidence of the fort during the Confederate occupation exclude this section of the fort. While there is no known mid-nineteenth century image that exists of the remaining fireplace, there is a photograph with a similar fireplace that is located on the opposite end of the Gorge Wall, next to what was the barracks for Confederate soldiers. The image shows a chimney with a similar firebox design that is opened and exposed to the parade ground. Contemporary scholarship attributes the purpose of this fireplace as a way to help warm the soldiers who were working to rebuild the fort. As both the fireplace in the image and the one remaining are of similar

Figure 4.32 Little Gas Piping remains from the Confederate Installation. Photo by author.

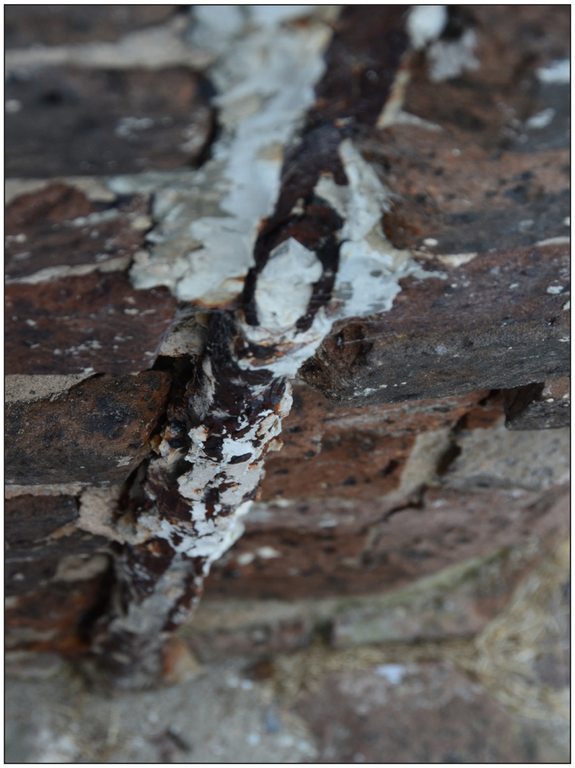

Figure 4.33 Detail of Gas Piping with multiple campaigns attempting to prevent water accumulation in the interior. Photo by author.

construction (primitive firebox, little brick massing to support the vertical weight, and similar dimensions), it is probable that the current existing and exposed chimney had a similar purpose and was buried during the second bombardment as the soldiers attempted to reinforce the powder magazine that was behind the brick wall. [52]

Door Hardware

Unnoticed along the Gorge Wall are the remains of the door hardware that once supported the door to the fort's powder magazine. The hinges were embedded in the brick masonry and an iron door tred still marks the entrance to the remains of the magazine. During construction, Cullum worried about the security and safety implications of the gun powder. He asked Totten for permission to install two iron doors—one in the magazine and one in the ante-room, and connect the rooms with ventilation to protect against fire and

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[52] Johnson, *Defense of Charleston Harbor* 25; Jack E. Boucher, *Historic American Building Survey: Images*, n.d., Library of Congress, Washington D.C., accessed October 2, 2012.

explosion of the powder. As the officers' quarters were finished using wood floors, plaster, and a combustible roof, this was, at least to Cullum, a legitimate worry. He wanted to take every step possible to avoid problems from an enemy barrage should a hot shot light the quarters or magazine on fire.[53]

Totten compromised, allowing for iron doors to be placed in iron castings in the ante-room only, which is what exists today. As these were readily available pieces, it is unlikely that the Corps would have ordered such parts and paid for the shipping to the fort. Since Cullum employed local blacksmiths to finish the parts that were shipped down, it is probable that the doors and castings were manufactured by local blacksmiths, making their origin much more difficult to determine as the fort was burnt soon after completion in the April 1861.[54] In the second bombardment, the magazine was set ablaze and the Confederate soldiers quickly buried the surviving parts of the magazine in cotton bales and sand to provide extra support. After the war, the magazine was abandoned and remained buried until the 1950s excavation.

Gas Piping

Outside of the gorge wall fireplace, there are few remnants of the Confederate occupation of Fort Sumter. After Confederate soldiers took control of Fort Sumter, they found themselves with a fort that had been severely, though not irreparably, damaged by fire. In the following months, soldiers reconstructed the fort and made improvements, such as adding a gas-works to light the stairwells and, presumably, the quarters as well.[55] Unfortunately, the gas-works, along with the rest of the fort, was destroyed during the Union siege. The only remnants of the gas piping that light the fort survive by the ante-room door

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[53] G.W. *Cullum to J. Totten, 17 June 1856,* Letter. "Engineer Records of Fort Sumter" transcribed letters, 1886 1845, Department of the Interior, National Park Service, Fort Sumter National Monument.

[54] *H.G. Wright to G.W. Cullum, 26 June 1856.* Letter. "Engineer Records of Fort Sumter", 1886 1845, Department of the Interior, National Park Service, Fort Sumter National Monument.

[55] Johnson, *Defense of Charleston Harbor*, 116-117.

of the magazine. They are severely corroded despite several attempts made by the park to prevent water from entering the piping.

CHAPTER FIVE
ATMOSPHERIC CORROSIVITY AND THE MICROCLIMATE OF FORT SUMTER

In 1825, Joseph Totten wrote to then Major General Alexander Macomb, the chief of the Army Corps of Engineers, "In a state of war, when to our Merchantmen and Privateers, the dangers of capture increased day to day…it is of great consequence that they should be certain of finding protections in the harbor…not only will this end be attained, but the enemies themselves will have no shelter, and its magnitude and strength should bear proportion to the great value of the objects it was designed to defend."[1] The harbor he was referring to was Charleston Harbor; the protections were the future Fort Sumter. Three tiers high at a height of fifty feet, the intended fortifications, Fort Sumter and Fort Moultrie, at the entrance to the Charleston Harbor were planned to be a highly visible and show of strength for all to see.

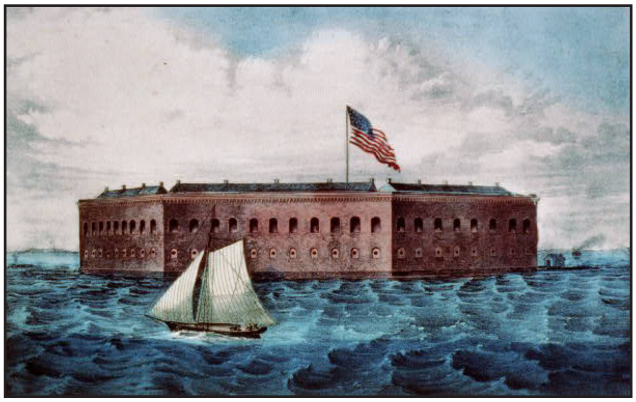
Figure 5.1 1865 Sketch of Fort Sumter showing fort before and after Civil War. (courtesty of the Library of Congress)

Early nineteenth century cannon fire was limited in its range, so engineers needed to build a fort or battery at each side of the entrance to Charleston Harbor. Fort Moultrie already existed and could protect the northern side of the harbor, but Fort Johnson on the western side of the harbor was ineffectual at protecting the rest. This was not a unique problem to the Charleston Harbor. Other bodies of water, like the Delaware River, were able to increase protection by building a fort on an existing island in the harbor. The Charleston Harbor had no such island, but there was a shoal. It was on top of this shoal that Totten and the engineers constructed a man-made island and then, a large masonry fort. For the citizens of Charleston who watched its destruction during the

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[1] *Letters and Reports of Colonel Joseph G. Totten, 1803 - 1864*, bound volume (Washington D.C.: War Department, 1864 1803), Records of the Office of the Chief of Engineers, 1789 - 1999, Record Group 77, National Archives Building, Washington DC, 593.

bombardment in the Civil War, the slow shrinking of the once tall, grand walls of the fort must have been the embodiment of the destruction of their city.

For the visitor standing on the Battery today and looking towards Fort Sumter, there is little resemblance to the fort that Totten surveyed and planned. The placement of Fort Sumter in the middle of the Charleston Harbor still presents its own set of challenges in preservation. Walls that were intended to be covered and capped by roofing systems and arches are now exposed to the harsh marine climate. Metal objects that were originally painted, stuccoed, or enclosed are now continuously subjected to wet/dry cycles and exposure to salts and winds. The masonry walls, while significantly reduced in height, act as both a trap and shelter for the remaining ordnance artifacts. Additionally, the thick brick walls work as both oven and cooler, trapping and retaining both the heat from the sun and coolness of the sea air. While the average visitor is not able to see the destructive qualities of the atmosphere surrounding Fort Sumter, the staff at Fort Sumter National Monument can watch, as certain artifacts corrode to a point of catastrophic failure in a matter of months.

Figure 5.2 1865 Sketch of Charleston Harbor by Robert Sneden. (courtesy of the Library of Congress)

Most iron artifacts were manufactured and installed with the knowledge that they would eventually degrade. Time and historical significance are beginning to demand that iron has its lifespan extended to meet the desires of the preservation community. For decades, scientists, with varying rates of success, have attempted to classify the corrosion rate of historic iron artifacts. The classification problem lies not with the corrosion studies themselves but with the long and unique life-span of the objects in question. To better understand this complex process, tests such as the accelerated aging and coating performance tests on coupons were developed and have proved to be informative for the object that is being studied.[2] Yet, each object and environment has proven itself unique, and no test results are able to fully transfer to other sites and locations with replicating the tests.

Unfortunately for the preservation community, this means that a set of standards (such as those provided by ASTM or REILM) cannot be developed to approach the conservation of historic ferrous materials in a sensitive and cost effective manner. A variety of tests must be undertaken at each site to gain a comprehensive understanding of the location's unique characteristics. Every site has different levels of impurities, humidity, and solar radiation, among other characteristics, which affect the corrosion rate of historic iron. Countries across the globe have spent millions of dollars to better understand why their ferrous metals are corroding and how best to slow this inevitable process. A large part of this research is spent on classifying the aggressivity of the atmosphere in terms of temperature, relative humidity, and airborne impurities. Each location presents its own unique and challenging aspects. The iron pillar in Dehli, thought to be 1,600 years old, still remains standing outdoors with very little corrosion.[3] At the other end of the spectrum, the ironwork at Fort Sumter, while significantly younger than the Dehli pillar and essentially made of the same material (iron), is visibly corroding and breaking down.

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[2] For an overview on some of the applications of these tests, the following sources are excellent starting points: Y. Shashoua and H. Matthiesen, "Protection of Iron and Steel in Large Outdoor Industrial Heritage Objects," *Corrosion Engineering, Science & Technology* 45, no. 5 (October 2010): 357–361; "Measurement of Atmospheric Corrosion Factors," *Measurement of Atmospheric Corrosion Factors*, accessed May 26, 2012, http://corrosion-doctors.org; H. Matthiesen and K. Wonsyld, "In Situ Measurement of Oxygen Consumption to Estimate Corrosion Rates," *Corrosion Engineering, Science & Technology* 45, no. 5 (October 2010): 350–356; L. Marchal, S. Perrin, and G. Santarini, "Study of the Atmospheric Corrosion of Iron by Ageing Historical Artifacts and Contemporary Low-Alloy Steel in a Climatic Chamber: Comparison with Mechanistic Modeling," in *Corrosion of Metallic Heritage Artifacts: Investigation, Conservation and Prediction of Long-term Behavior*, ed. P Dillmann (Cambridge, England: CRC Press ; Woodhead Pub., 2007); C. A Brebbia, "Repairs and Maintenance of Heritage Architecture International Conference on Structural Studies" *Structural Studies, Repairs and Maintenance of Heritage Architecture XI* (Southampton: WIT, 2009).

[3] In most studies of historic iron corrosion the pillar in Delhi figures at least once in the text, but David Scott in *Iron and Steel in Art* discusses it as well as A. Moncmanoca in *Environmental Deterioration of Metals.*

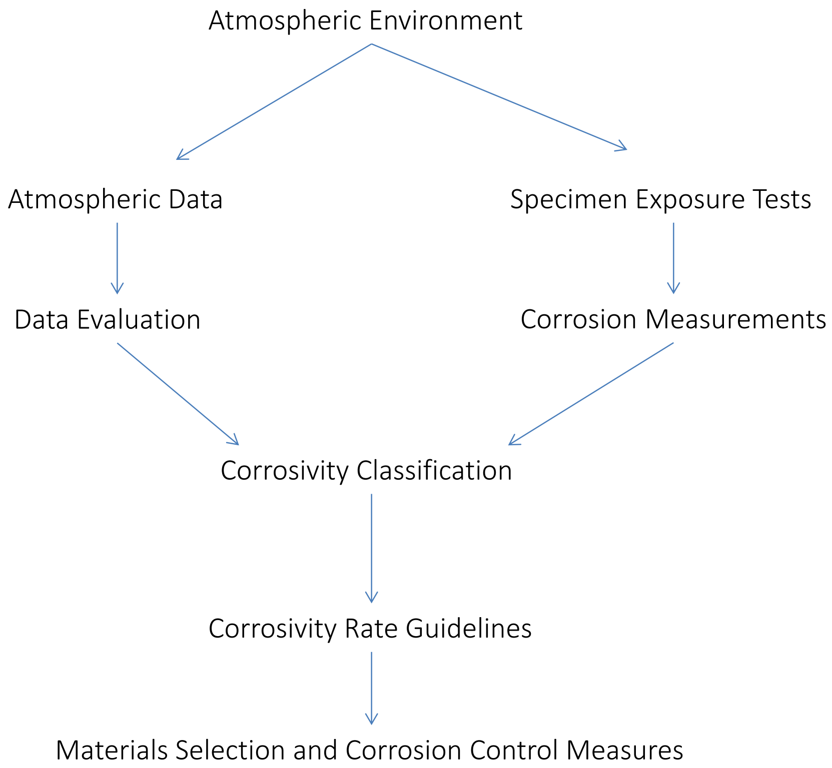

Figure 5.3 Two of the fundamental approaches to atmospheric corrosivity classification (taken from Uhlig's Corrosion Handbook)

Atmospheric corrosion is well understood. It is widely known that exposed metal will corrode rapidly when left unprotected from the atmosphere. Typically, atmospheric corrosivity classifications are approached from two fundamental methods: tracking overall atmospheric data and specimen exposure tests. Overall atmospheric data sheds light on the general environmental patterns and can apply to multiple objects and materials. Specimen exposure tests are designed to track the exact rate of loss of a single material in one environment and results are not easily transferred to other locations or materials. Both tests are considered complimentary and help define the relationship between the substrate and the environment.[4] However, the exact role that the environment plays in the preservation and degradation of historic artifacts is less understood. There is no simple or definitive way to track atmospheric corrosion and the effect of long term exposure on iron. Even the most

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[4] R. Winston Revie, ed., *Uhlig's Corrosion Handbook* (John Wiley & Sons, 2000), 313.

innocent of environmental factors can have serious effects on iron, but without at least a basic understanding of each location's specific characteristics, historic metal can quickly and disastrously corrode.

The agents determining the characteristics of atmospheric systems can be divided into several broad categories: temperature, relative humidity (RH%), and levels of atmospheric contaminants. When exposed to a changing environment, these traits combine to create a thermodynamic process on the substrate that may promote the deterioration of an object. As each site has its own unique characteristics (climate, proximity to industrial zones and/or ocean, human use), it is impossible to classify an environment on a large scale.[5] However, each characteristic is believed to play a role in the progression of an object's corrosion.

Atmospheric corrosion is largely defined by cyclical periods of wetness, when a film of moisture and soluble salts combine to promote the formation of corrosion products. A corrosion product is the product that forms during a chemical reaction of a material with its environment. The type of corrosion product can shed light on the future stability of an object. In the case of metals, the presence of oxygen will trigger the electrochemical reaction of the metal and form iron oxides (corrosion products), more commonly named rust. Essentially, a corrosion product forms in an attempt to reach a stable state that more closely resembles iron ore. Different corrosion products are formed depending on the presence and availability of said counterions, such as oxygen or chlorine within the surrounding materials (granite, brick, or mortar) or atmosphere surrounding the metal.

Without the presence of water, iron is unable to transfer electrons and neutralize.[6] This is not to say that a piece will remain un-corroded if it stays out of contact with climatic changes and condensation. It is currently believed that the relative humidity level of an environment for post-excavation archaeological iron should be at or below 13% RH

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[5] D. Knotkova-Cermakova and K. Barton, "Corrosion Aggressivity of Atmospheres (Derivation and Classification)," in *Atmospheric Corrosion of Metals*, ed. S.W. Dean Jr. and E.C. Rhea, (Denver, CO: ASTM Special Technical Publication 767, 1980), 227.

[6] Knotkova-Cermakova, "Corrosion Aggressivity," 227.

to maintain the stability of the iron, though the appropriate relative humidity level for architectural iron has yet to be tested and agreed upon.[7] As a consistent low RH% is a rare, or non-existent, occurrence in the natural world, architectural conservators should expect to address the corrosivity level of a building's surrounding environment when implementing treatments.

At a glance, Fort Sumter is located in a highly corrosive environment. The high temperatures, direct solar radiation, and its position in the middle of a harbor are significant factors in the corrosivity of the fort's historic iron. These environmental characteristics constitute the many challenges the park faces in the long-term metal conservation of Fort Sumter.

In the harbor and on the mainland are weather stations supported by the National Oceanic and Atmospheric Association (NOAA) that track and log local weather conditions. The data on the mainland is not a comparable data set, because the large masonry walls affect how the airborne salts travel and deposit on and around the fort's structure.[8] Designed to protect soldiers from attack, the masonry walls create a unique microclimate that affects the historic objects in different ways.

Temperature fluctuations

Temperature significantly influences the aggressiveness of rates of corrosion. In sub-arctic or arctic zones, freezing temperatures will freeze the electrolyte film of moisture and decrease the corrosion rate. Warmer temperatures have a tendency to promote aggressive corrosion rates by increasing the probability of wet/dry cycles that promote corrosion. At the same time, warmer temperatures will promote faster drying times, thereby decreasing

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[7] David Watkinson, "Degree of Mineralization: Its Significance for the Stability and Treatment of Excavated Ironwork," *Studies in Conservation* 28, no. 2 (May 1, 1983), 85.

[8] NOAA makes accessible both the results from the station on the Custom House in Charleston, located on East Bay Street as well as stations on Sullivan's Island, and in North Charleston and can be found at http://www.nws.noaa.gov/climate/index.php?wfo=chs.

the time of wetness.[9] Over the course a decade, historic artifacts are more affected through the temperature fluctuations experienced at a site and not the average climatic conditions.

The heat capacity of iron causes the object to retain heat and cold at a different rate than the surrounding atmosphere and changes its dew point. The metal will gradually build and retain heat from the sun as the day progresses. As the temperature lowers in the evening, the metal will retain a warmer temperature and higher dew point than the surrounding materials. Over the course of the evening, the iron will slowly lose its heat and reach a cooler temperature to reflect the ambient surroundings where it begins to collect condensation. The effect is reversed as the temperature begins to rise. The iron will retain its cooler temperature and condensation will form and remain for longer periods of time until the metal can once again reach an equilibrium stage.[10]

In this study Fort Sumter was assumed to be its own microclimate. To test the fort's unique climatic environment, several weather conditions were tracked at the fort for a span of five months and compared to local NOAA stations. A microclimate in the fort would either help or hinder the corrosion processes. The masonry walls could either act as a trap that would allow airborne impurities into the fort but not out; or, the walls could regulate both interior temperature and block the majority of the sea breezes carrying airborne chlorides. Further complicating the process are the multiple microclimates within the fort itself. Just as soldiers in Antebellum America protested having to live in the casemates because of their damp and cold nature, a visitor can feel the difference in temperature and relative humidity as he or she walks through the right face casemate (the most intact casemate). Inside the right face are numerous Antebellum and Civil War artifacts in varying stages of preservation, although the majority of the architectural metal is still largely intact. The Left Face is much more exposed to the elements, and it is believed that the exposure level is causing the pieces to corrode more quickly than the pieces sheltered within the Right Face. As the exposed

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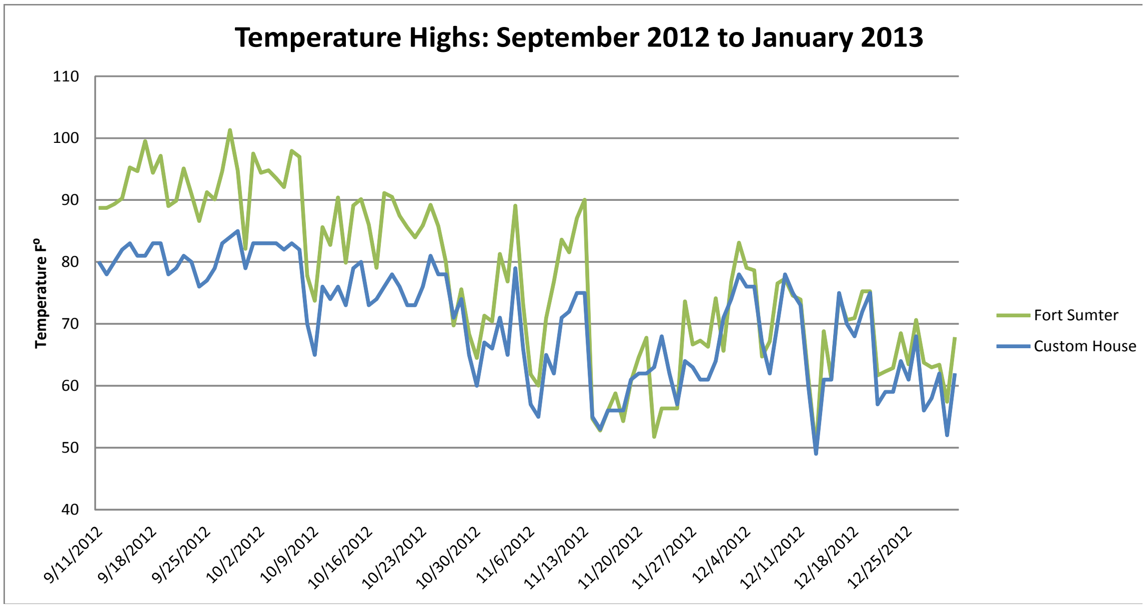
[9] Philip A. Schweitzer, *Atmospheric Degradation and Corrosion Control*, Corrosion Technology 12 (New York: Marcel Dekker, 1999), 9.

[10] "Measurement of Atmospheric Corrosion Factors," *Measurement of Atmospheric Corrosion Factors*, accessed May 26, 2012, http://corrosion-doctors.org.



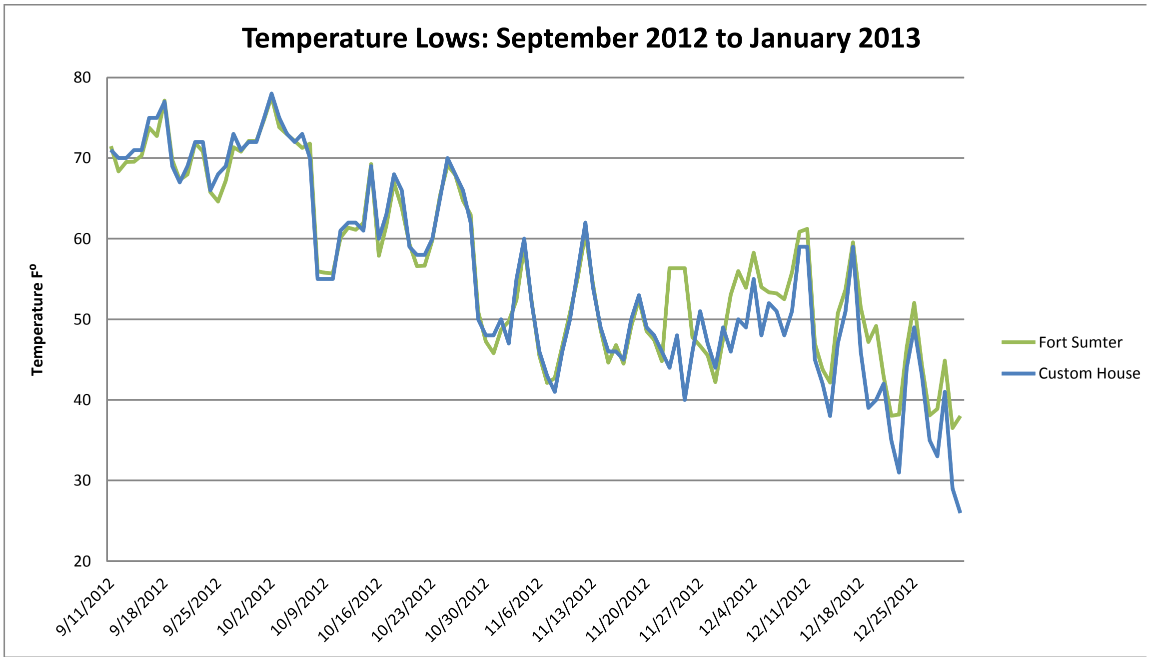


Figure 5.4 & 5.5: Temperature Highs and Lows at Fort Sumter National Monument

pieces at Fort Sumter were in the most danger of catastrophic failure, it was decided, for this study, to attempt to replicate the conditions of the most exposed pieces.

Over the course of six months, temperature, RH%, and the surface relative humidity, were tracked at a station behind one of the remaining officers' quarters' walls along the Gorge Wall. When compared with a NOAA weather station placed on top of the

Custom's House in downtown Charleston, the data confirmed the walls of Fort Sumter acted as a shelter and created a unique microclimate. The interior of the fort experienced temperature highs that were several degrees higher than the surrounding area during the day. Temperatures at Fort Sumter consistently averaged two to seven degrees higher than temperatures on the Charleston peninsula. Temperatures at the fort experienced approximately a twenty degree swing each day; this information can be referenced in Appendix A. The fluctuation shows that the bricks do not efficiently retain enough heat during the day to stabilize the temperatures at night. If the brick did maintain the sun's heat throughout the night, it is possible that the amount and time of condensation would decrease; thereby shortening the time of wetness on the metal. Instead, the temperature at the fort each night regularly returns to the surrounding ambient temperature or drops several degrees lower. Throughout the testing, the minimum temperature was the equivalent or lower than the temperatures recorded on the peninsula of Charleston.

This temperature difference is likely caused by the fact that the fort is enclosed on all sides by brick masonry. As the sun rises, the bricks warm up elevating the temperature of the interior of the fort, but due to their lack of conductivity, they cool just as rapidly and retain the cooler temperature. A possible outcome of such a temperature fluctuation could result in the metal at the fort being forced to undergo more drastic temperature changes throughout the day, thus increasing the possibility for longer or more frequent periods of wetness.

The higher highs likely allow the metal at Fort Sumter to gain a higher temperature during the day and minimize the time of wetness in the evening. However, much of the metal at Fort Sumter is at least partially embedded in brick or stone masonry. Generally, masonry is believed to have a beneficial influence on the metal by protecting it from the atmosphere, but it is believed that the protective advantage of the higher temperature during the day is likely reversed at night as the metal loses its warmth and retains the coolness for a longer period of time because of the connection to the bricks. While it potentially helps to minimize

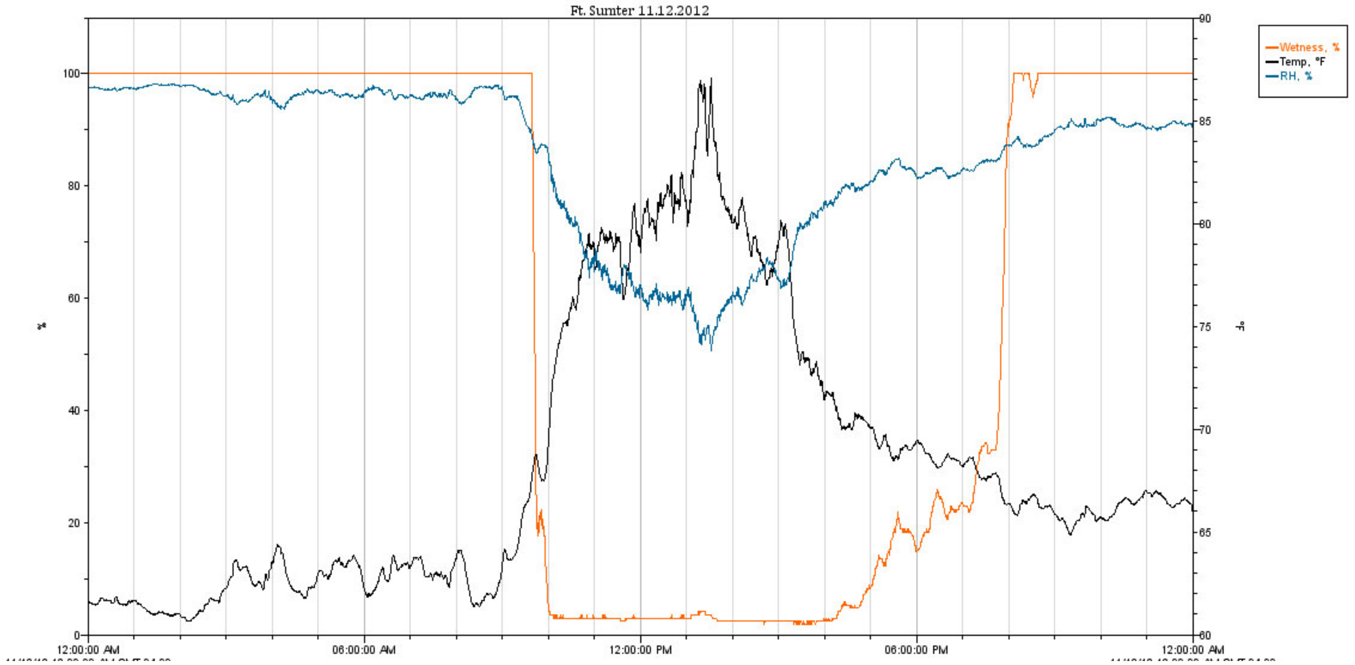


Figure 5.8: November 12, 2012 Chart detailing the temperature, relative humiditiy (%) and surface relative humidity.

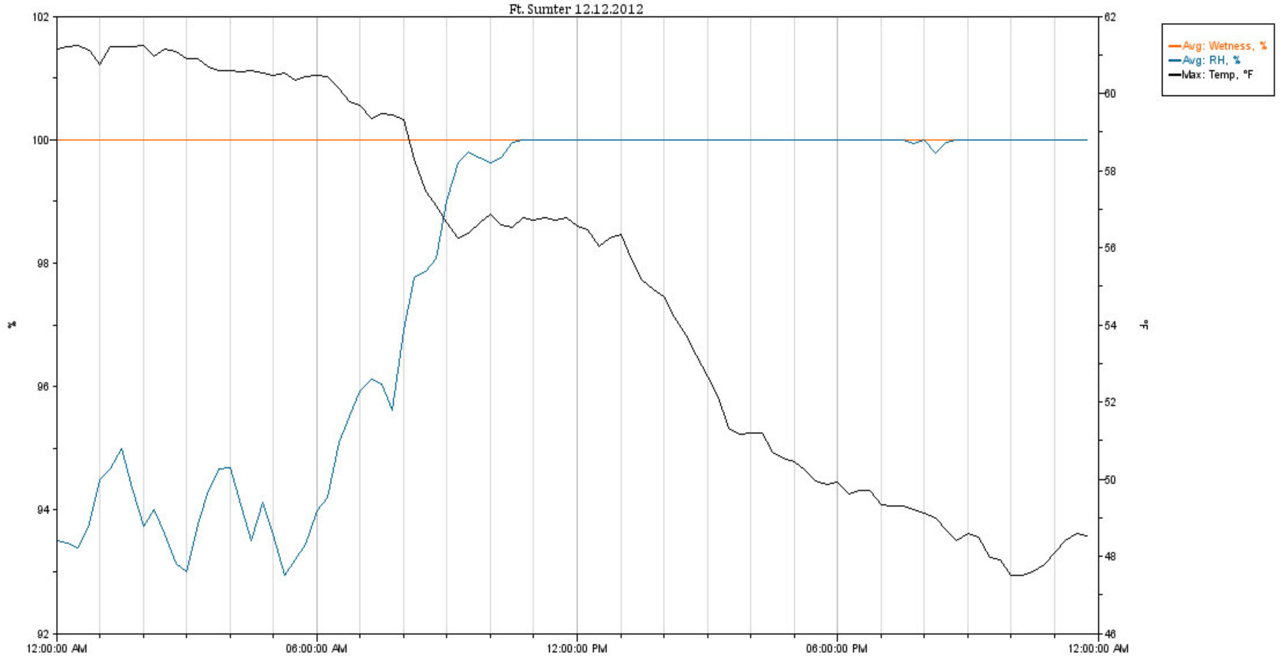


Figure 5.9: December 12, 2012 Chart detailing the temperature, relative humiditiy (%) and surface relative humidity.

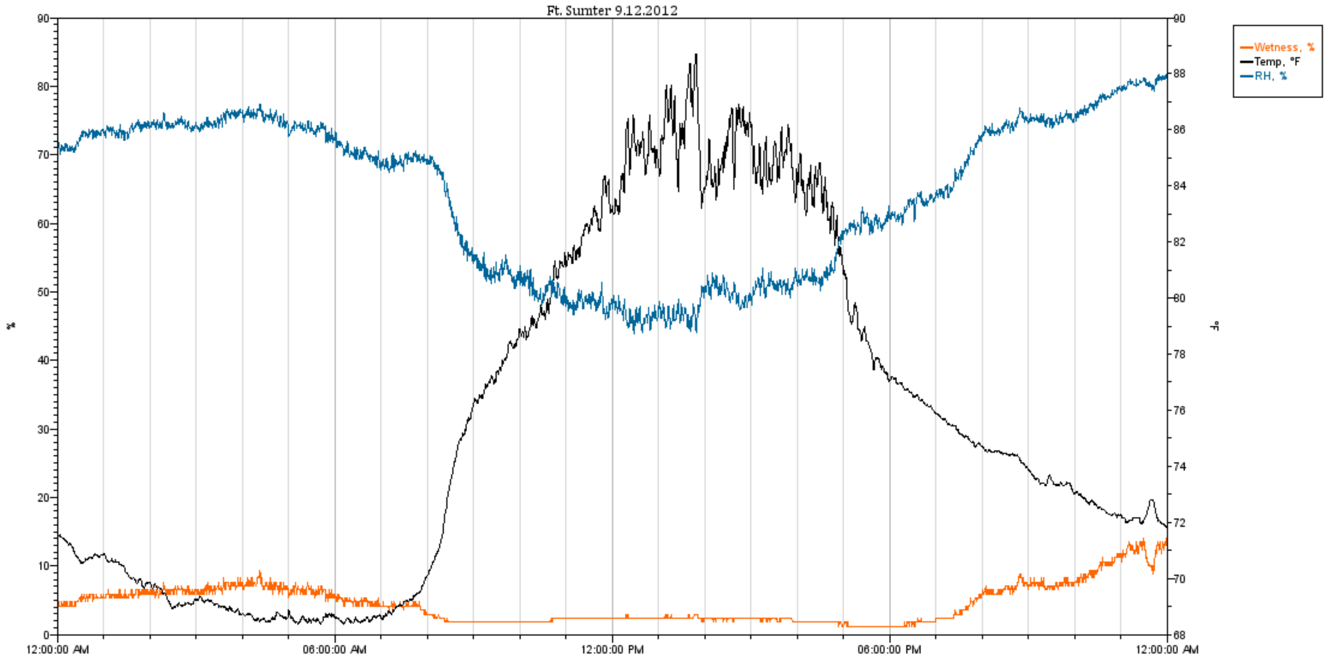


Figure 5.6: September 12, 2012 Chart detailing the temperature, relative humiditiy (%) and surface relative humidity.

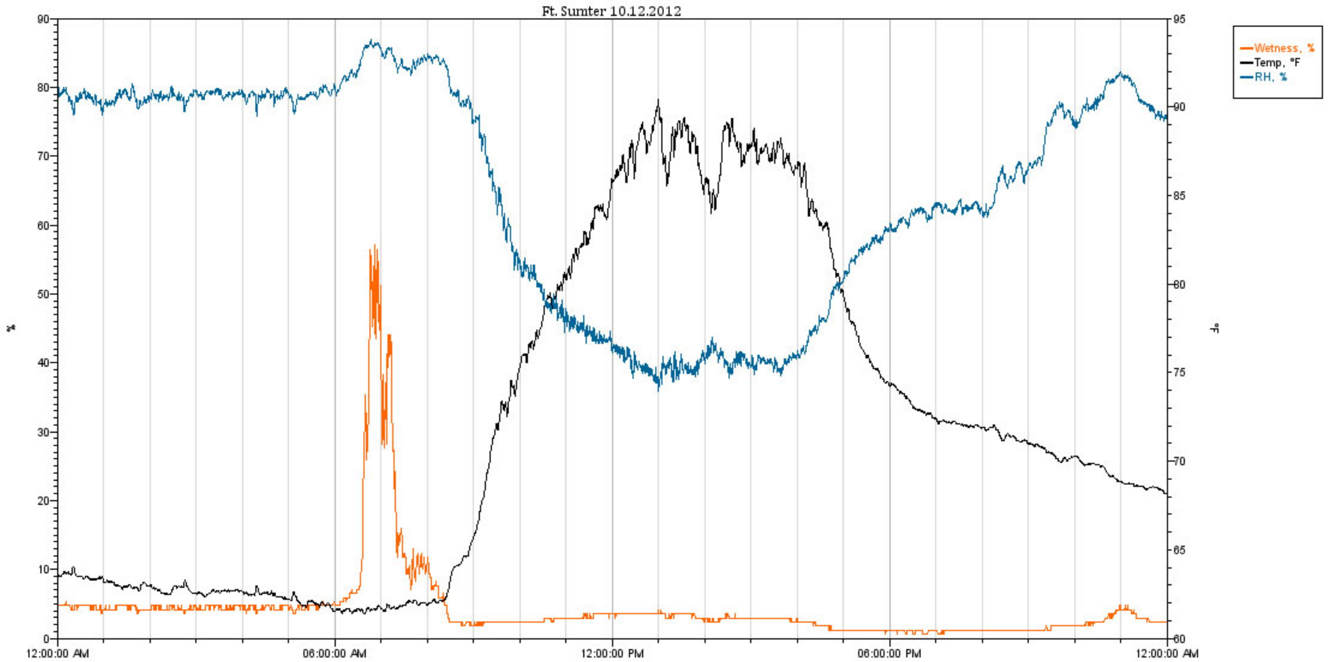


Figure 5.7: October 12, 2012 Chart detailing the temperature, relative humiditiy (%) and surface relative humidity.

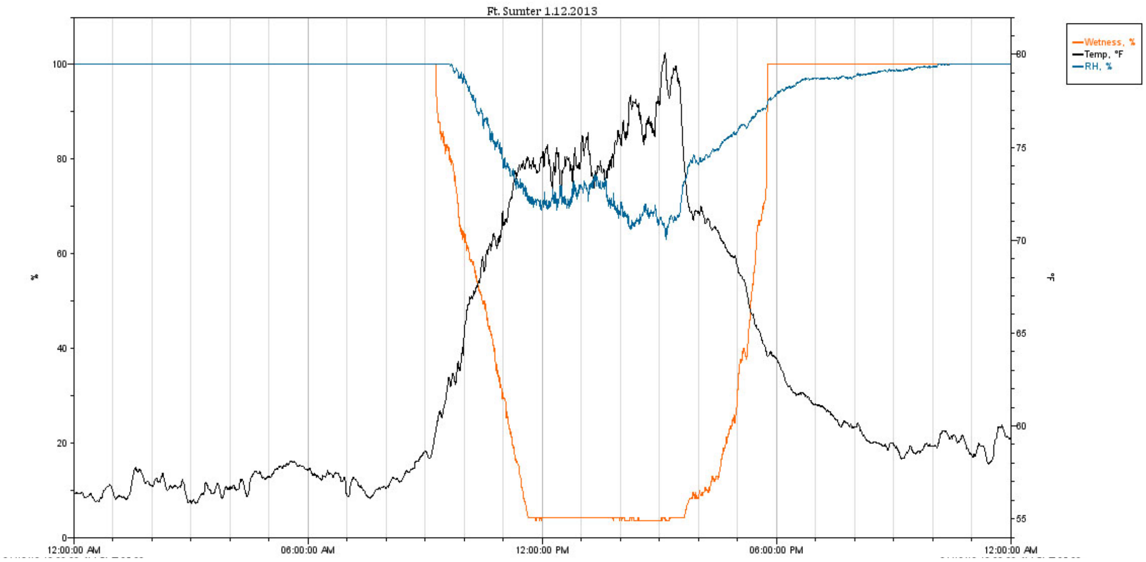


Figure 5.10: January 12, 2013 Chart detailing the temperature, relative humiditiy (%) and surface relative humidity (%)

the exposure of the iron to the direct detrimental atmospheric effects, the masonry itself poses potential problems for embedded iron which will be discussed in Chapter Six.

The brick masonry walls also help regulate the fort's interior temperature. Despite the season, the temperature was shown to rise and fall in a steady fashion. The temperature rapidly increased as the sun rose and began to enter the fort (around 6:30am in the summer and 8:00am in the winter) and then plummeted as the interior of the fort no longer had direct exposure to solar radiation. This change allowed for the ironwork to remain drier and warmer during the evening hours, but it remained cooler and wetter for longer periods into the morning hours. The condensation that formed during the night remained on the ironwork well into the morning hours. First-hand experience has shown that the artifacts that are the most exposed to sunlight, the ones on the western side of the fort, dry more quickly than those without sunlight. Interestingly, the pieces that are the most exposed to solar radiation are the most corroded.

Relative humidity

As previously discussed, a lower humidity level is preferred to stop or slow the formation of a moisture film on an object. Ultimately, this level translates into what is called

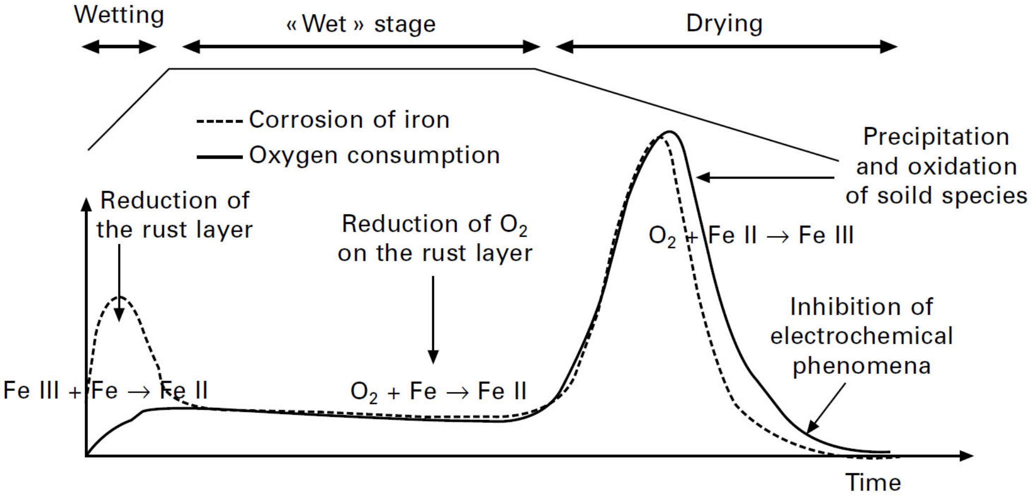


Figure 5.11 The wet-dry cycle as described in L. Marchal, S. Perrin, and G. Santarini, Corrosion of Metallic Heritage Artefacts - Investigation, Conservation and Prediction for Long-Term Behaviour, ed. P Dillmann (Cambridge, England: CRC Press ; Woodhead Pub., 2007), 132.

the Time of Wetness (TOW), or the amount of time that an object is at a level sufficient to promote corrosion. This aqueous phase layer allows a wet and dry cycle to occur which in turn will promote a more aggressive corrosion mechanism to occur. The amount of moisture present on the iron interface also influences the severity of corrosion formation. A thin level of moisture allows for a greater transfusion of oxygen from the atmosphere which contributes to a more rapid formation of corrosion products. A thicker level on the surface would appear to be more detrimental, but often has the result of slowing the oxygen diffusion and thus, slows the process. Pure water in general is a poor conductor as it lacks the other ingredients (soluble salts) necessary to form the electrolytic solution.[11]

The actual time of wetness on an iron object is a trickier subject to quantify. The time of wetness, or the length of time that the metal has a thin layer of condensation, rain, or moisture on the surface determines the amount of time a piece is able to actively corrode. Generally, a 70% humidity level is acknowledged as the critical level of relative humidity exposure, though this level is largely subjective.[12] Corrosion can begin at lower humidity

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[11] P. Novak, "Environmental Deterioration of Metals," in *Environmental Deterioration of Materials*, ed. A. Moncmanova (Boston: WIT Press, 2007); Marchal, "Study of the Atmospheric Corrosion of Iron by Ageing Historical Artifacts," 136; Schweitzer, *Atmospheric Degradation,* 15.

[12] Scott, *Iron and Steel*, 112; Dillmann, *Corrosion of Metallic Heritage*, 132.

levels through the presence of contaminants (e.g. chlorides, or sulfites) on the surface of the metal or the corrosion interface. In addition to these contaminants, the hygroscopic nature of dust, smoke, and other atmospheric pollutants have all been proposed to lower the critical level of exposure.[13]

At Fort Sumter, two different methods were tested to determine which would give the most accurate data of the actual time of wetness on the surface of the metal. The first, more rudimentary method, followed the temperature and relative humidity (%) with the Onset HOBO® Micro Station. The second utilized a moisture residue sensor (HOBO® Leaf Wetness Sensor) to track the amount and length of time a quantifiable level of moisture was present. While the temperature and relative humidity (%) sensors are able to track general atmospheric trends, the moisture residue had the potential to give more specific information as to the conditions of the objects themselves. As the surface temperature of the objects will likely differ from the ambient air temperature, the surface relative humidity will vary depending on the exposure and placement of the metal object.[14] Thus, the time of wetness sensor will potentially give much more descriptive and object specific data.

Each day at the fort the climatic relative humidity level reached above the critical level (70%), and for 45 of the 126 days that data was collected at the site, the relative humidity level never dropped below 60%. (Appendix B) One day each month, the twelfth, was chosen to further investigate the amount of time the atmospheric humidity levels were at or below 60%. During the warmer months of September and October, the RH% levels would predictably dip below 60% for approximately eight hours during the hottest part of the day and spike again as the night cooled the surrounding air. The cooler months of November, December, and January showed that the humidity level never dropped below the 60% mark, but as two of the days experienced rain, this is to be expected.

In the scope of this study, the summer months at Fort Sumter appear to be the time of year that promotes the least amount of atmospheric corrosion based on RH% and

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[13] Scott, *Iron and Steel,* 112.

[14] Dean SW, ed., *Atmospheric Corrosion of Metals: A symposium* (ASM International, 1982), 277.

TOW. The atmospheric relative humidity would often spike during the evening and night hours leaving a noticeable moisture film in the morning but would evaporate as the day progressed. As cooler weather came, it became common for the relative humidity levels to rarely dip below 70%. Thus, it appears as if the atmospheric conditions during the winter will be consistently at or above the critical level of relative humidity for the exposed objects.

The time of wetness sensor was placed in an exposed position to simulate the fireplace lintels and to track the surface relative humidity level of the object. It was anticipated that the sensor would accumulate atmospheric contaminants on the surface as well as gain and lose heat in a similar fashion to the iron, thereby reflecting the actual surface relative humidity of the fireplace lintels. Recent scholarship has discussed the possibility that a succession of wet and dry cycles have a larger influence on the level of oxygen consumption during the atmospheric corrosion of iron than a consistently damp object. During the cycle, the oxygen consumption changes. It is accepted that corrosion happens at a higher rate when there is a thinner layer of moisture as it promotes greater diffusion of oxygen from the atmosphere to the surface of the metal. Rarely did the sensor read at 0% moisture residue, but it was more common for the levels of moisture to dip down during the day and spike again at night when dew and condensation likely form.

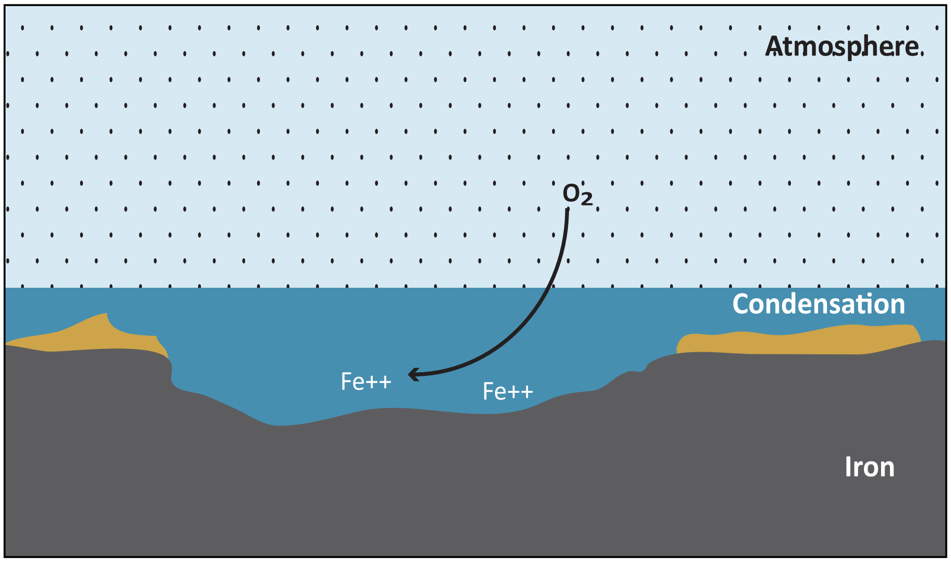

Figure 5.12 Schematic drawing illustrating effect of condensation on iron object (drawn by author).

Interestingly, even in the warmer months, when the RH% level was below 60% the Time of Wetness Sensor still recorded small but present levels of moisture. This shows that even though the humidity level is lower, a thin, invisible film is still able to form on the objects.

Wind direction

The wind speed and direction will dictate the airborne salt levels at different locations. In larger terms, airborne salts, governed by the wind direction and air currents that travel from the ocean will influence inland salt levels. Essentially, as chlorides and other salts from the ocean become airborne and travel on the wind, the wind will transect with objects. As anybody who has taken a walk on a beach during a windy day and had the subsequent salt crust left on clothes, skin, and hair knows, the wind will intersect and move around the obstacle leaving particles of soluble salts on the surface. Those obstacles that are closest to the ocean have the highest level of airborne chlorides while distance and other obstacles progressively lessen the impact of airborne chlorides.[15]

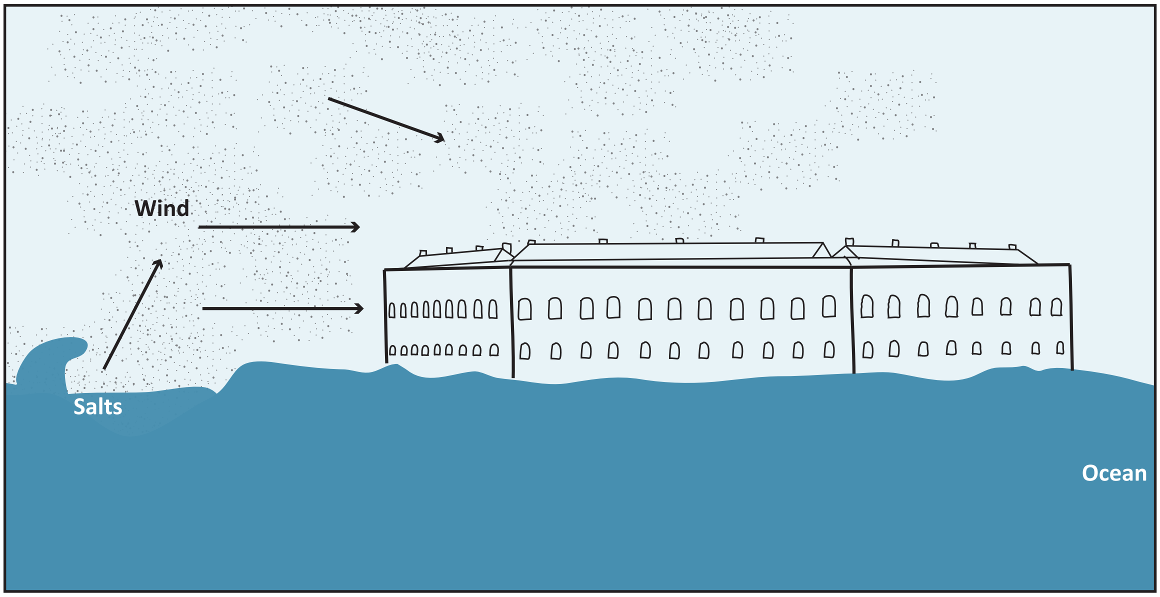

Figure 5.13 Schematic showing airborne chloride dispersal at Fort Sumter (drawn by author).

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[15] John R Duncan and Julie A. Ballance, "Marine Salts Contribution to Atmospheric Corrosion," in *Degradation of Metals in the Atmosphere: A Symposium Sponsored by ASTM Committee G-1 on Corrosion of Metals, Philadelphia, PA, 12-13 May 1986*, ed. S. W Dean and T. S Lee (Philadelphia: ASTM, 1987), 316; Nattakorn Bongochgetsakul, Sachie Kokubo, and Seigo Nasu, "Measurement of Airborne Chloride Particle Sizes Distribution for Infrastructures Maintenance," *Kochi University of Technology*.

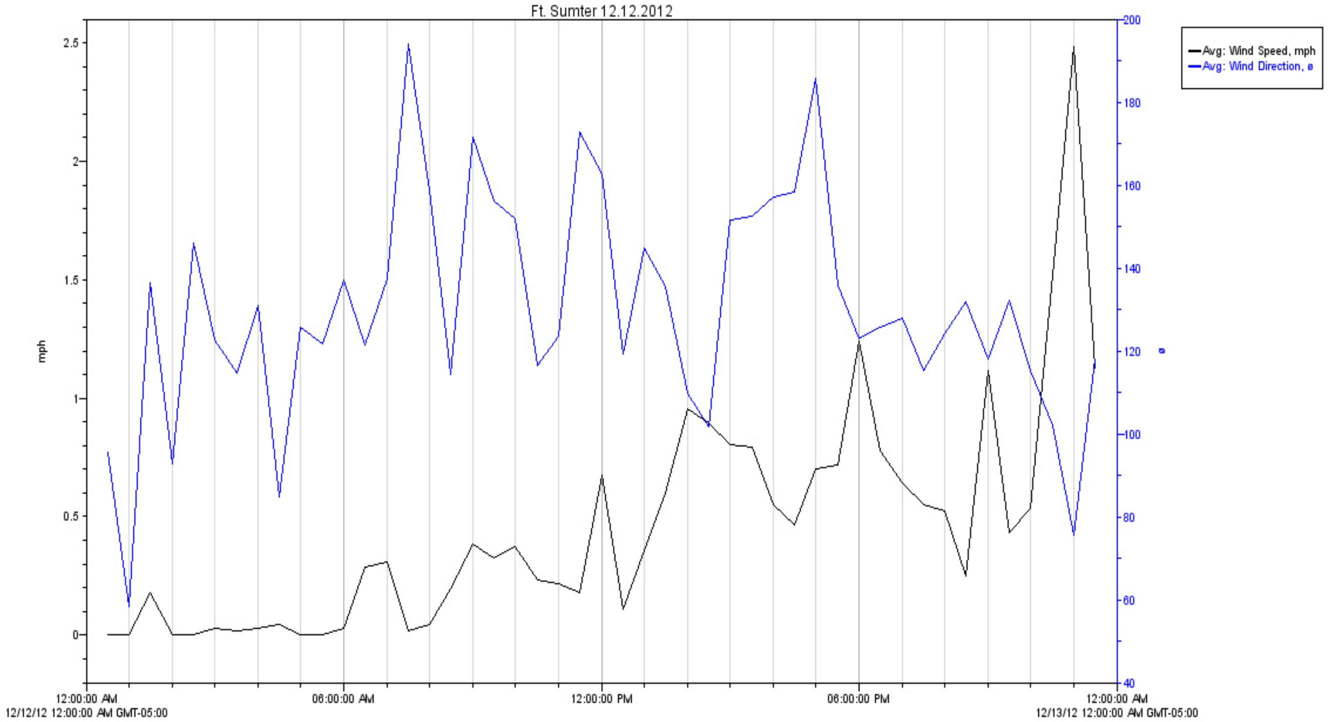

Figure 5.16 November 2012 Wind Speed and Direction at Fort Sumte National Monument.

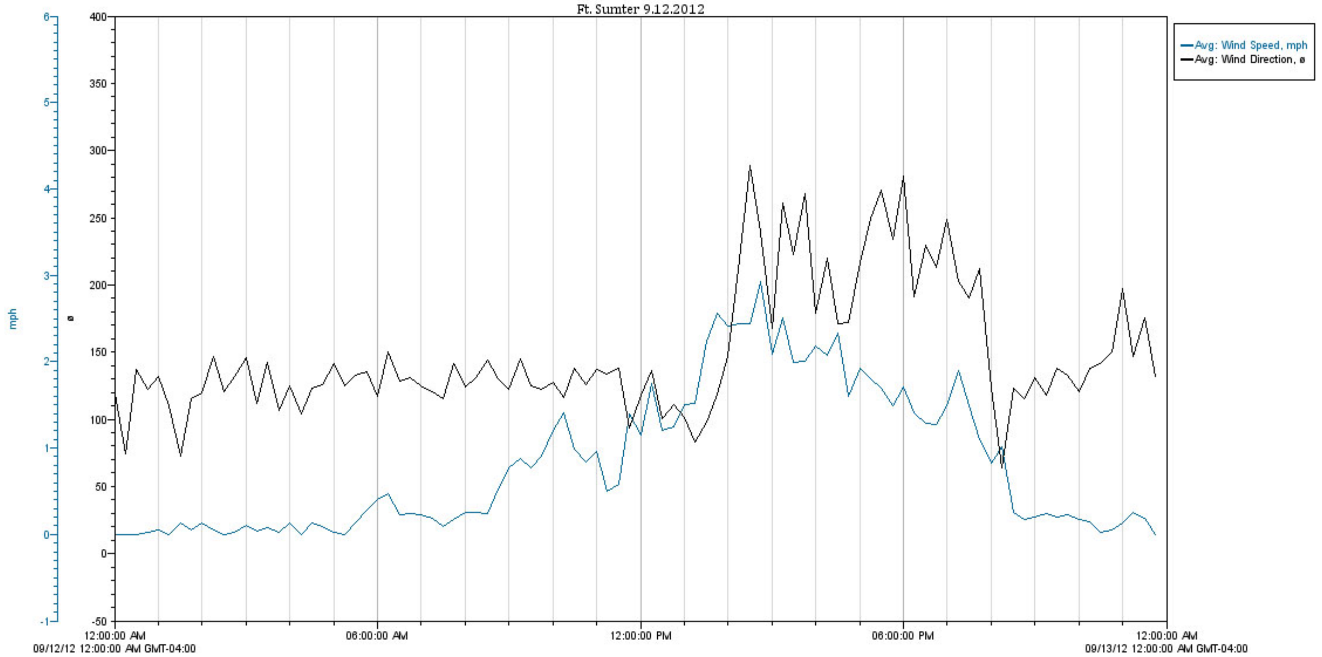

Figure 5.14 September 2012 Wind Speed and Direction at Fort Sumte National Monument.

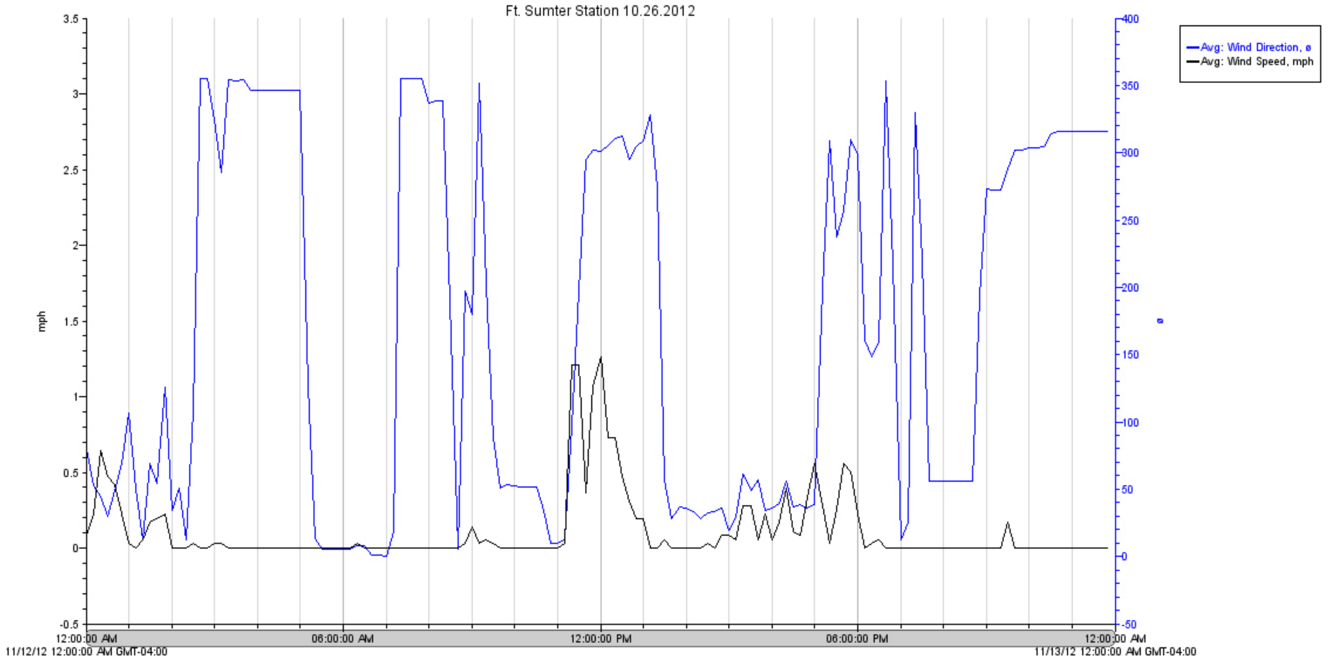

Figure 5.17 December 2012 Wind Speed and Direction at Fort Sumte National Monument.

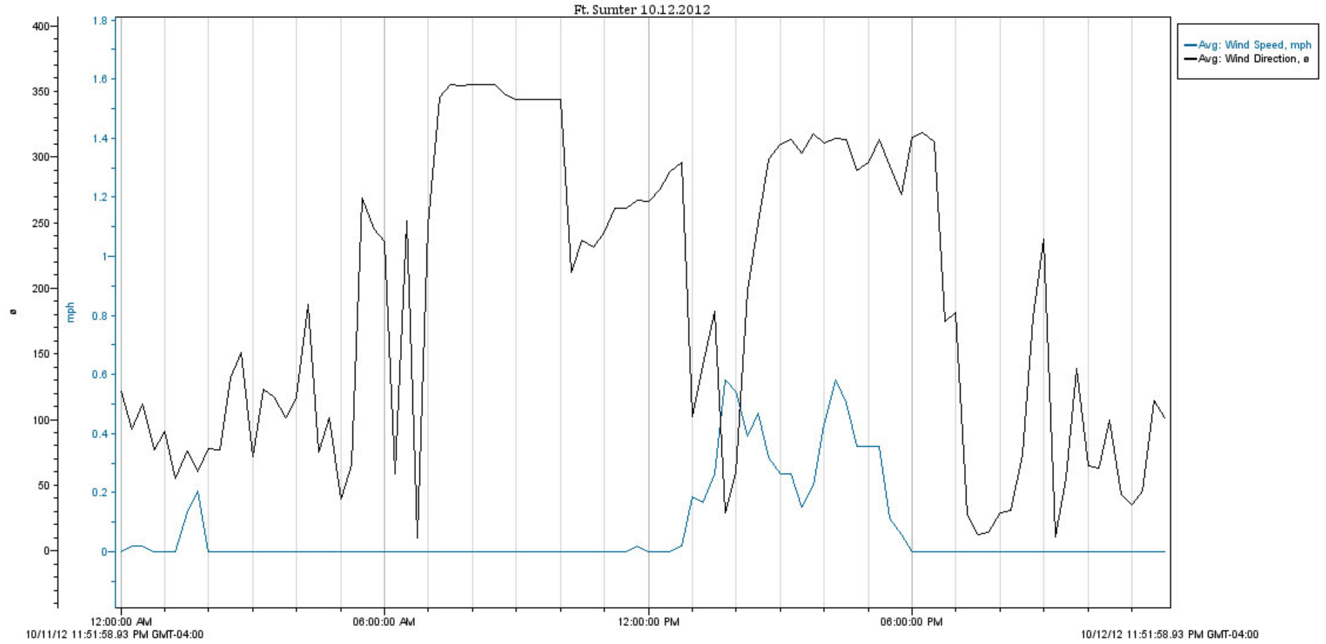

Figure 5.15 October 2012 Wind Speed and Direction at Fort Sumte National Monument.

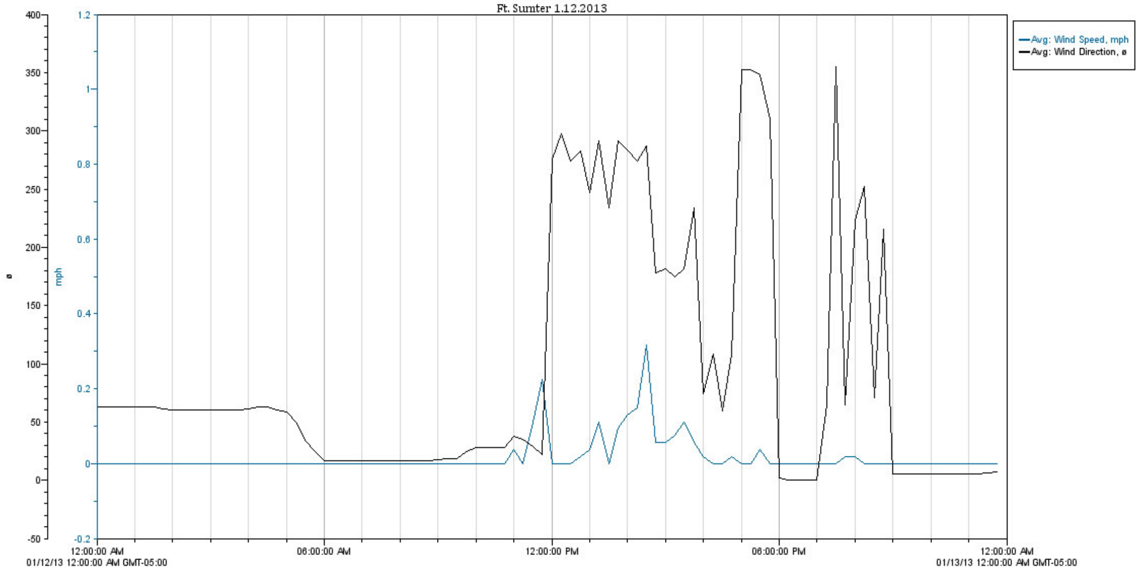

Figure 5.18 January Wind and Speed at Fort Sumter National Monument.

For the architectural conservator, wind plays an important role in predicting the lifespan of heritage artifacts that are susceptible to potential corrosion or damage accelerated by airborne salts. Wind, if it comes predominantly from one particular direction, can significantly influence the rate of atmospheric corrosion through the deposition of airborne contaminants. Those objects that are sheltered from the predominate wind direction will likely not suffer from the same effects.

Fort Sumter's position in the Charleston Harbor makes this a well-placed obstacle in airborne chlorides' travels inland. Recent studies prove that the fort's scarp wall is suffering from the effects of wind borne salts in the cryptoflorescence found on the bricks.[16] Inside the fort, it is less clear how the wind is affecting the artifacts. The high walls mean that the wind must intersect with the exterior wall and then come down and over the top of the walls. Therefore, most of the wind driven chlorides will be deposited on the exterior scarp wall and not on the interior pieces. The remaining wind, if it comes in a dominate direction, will deposit the remaining chlorides on the surface of the fort.

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[16] Denis Brosnan, "Characterization and Forensic Studies of Construction Materials for Fort Sumter National Monument," January 11, 2010, Fort Sumter National Monument.

At the beginning of this study, it was unknown if the high exterior walls would significantly affect the wind patterns inside the fort. Depending on the predominant wind patterns, the wind would either flow into and out of the fort in one particular direction or the walls and interior obstacles would cause the wind speed and direction to vary around the fort. The anemometer sensors were placed in a way to replicate the position of the iron objects of interest, and significant influence from the surrounding masonry walls was immediately noted. The wind predominately came over the left shoulder angle in a north-westerly current. However, the casemates and Battery Huger provided enough of a barrier that the wind rarely blew in a consistent speed or pattern. Most often, the actual wind speed at the test site was significantly less than the wind speed outside the fort itself. Together, the wind speed and direction creates an inconsistent pattern. If salts are being transported over the walls of the fort, then there few ways to successfully track their impact at the fort due to the interior wind variability. In another location, this test would likely prove quite useful in tracking the vulnerability of a site's artifacts.

Airborne chlorides

Impurities and contaminants in the atmosphere may influence the rate of corrosion of iron artifacts. These impurities vary depending on location. Marine salts, such as chlorides, have a well-known effect in promoting rapid and destructive iron corrosion. As the distance from the ocean increases, airborne chlorides in the atmosphere are known to decrease with mileage, though the rate of decrease largely depends on wind patterns and various other factors. A continual prevalent wind inland will tend to carry marine salts further inland than if the wind blew away from the shore.[17] Sulfur Dioxide from manufacturing emissions is another known influence in industrial environments

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[17] John R Duncan and Julie A. Ballance, "Marine Salts Contribution to Atmospheric Corrosion," in *Degradation of Metals in the Atmosphere : A Symposium Sponsored by ASTM Committee G-1 on Corrosion of Metals, Philadelphia, PA, 12-13 May 1986*, ed. S. W Dean and T. S Lee (Philadelphia: ASTM, 1987); Barbara Lubelli, Rob P.J. van Hees, and Caspar J.W.P. Groot, "The Role of Sea Salts in the Occurrence of Different Damage Mechanisms and Decay Patterns on Brick Masonry," *Construction and Building Materials* 18, no. 2 (March 2004): 119–124, doi:10.1016/j.conbuildmat.2003.08.017.

and, when combined with moisture, may have the same effect that chlorides have in the marine environment on atmospheric corrosion. Again, the detrimental level of this pollutant decreases with distances from the industrial sources.

Previous scholarship has classified the aggressivity of different environments and combined them into five main categories: rural, urban, industrial, marine, and indoor.[18] Each environment has different levels of corrosivity because of the levels and types of contaminants in their respective atmospheres. Understandably, rural environments are classified as the least corrosive of exterior climates. Depending on the climate (artic, temperate, tropical), a rural tropical environment can be more corrosive than an artic industrial. Previously run experiments have roughly classified the rate of iron loss in the different environments and can be seen in table 5.1, but it should be noted that the rates of corrosion are the most accurate for the early years of exposure, and long-term tests have demonstrated that the rate of corrosion drops off with the amount of long-term exposure due to a passive layer forming on the metal (commonly referred to as rust), thereby protecting much of the iron from rapid corrosion.[19]

Enviromental Corrosion rate µm/year	
rural	4-65
urban	23-71
industrial	26-175
marine	26-104

Table 5.1 Enviromental Corrosion Rates (from Scott, Iron and Steel in Art, *109).*

Fort Sumter, because of its location in the middle of the Charleston Harbor, is generally classified as being in a highly corrosive environment. Corrosivity maps of the United States tend to classify South Carolina as being in a mildly corrosive region. The map, while helpful in giving a general understanding of the overall corrosive level of a regional atmosphere, was compiled using corrosion levels on automobiles, and does not account for airborne salts. It is not able to accurately define the corrosive level of the atmosphere in regards to the corrosivity of heritage objects.[20] Obviously, the fort faces a much high

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[18] Scott, 52.

[19] Philip A. Schweitzer, *Atmospheric Degradation and Corrosion Control*, Corrosion Technology 12 (New York: Marcel Dekker, 1999), 56; David A Scott and Gerhard Eggert, *Iron and Steel in Art : Corrosion, Colorants, Conservation* (London: Archetype, 2009), 109.

[20] *Uhlig's Corrosion Handbook*, 306.

corrosion level than iron pieces that are further inland, but at the start of this project it was unsure as to the exact level of airborne impurities at the site due to the relatively sheltered position of the metal through the casemate wall's protection.

<u>'Wet Candle' Method</u>

ASTM standards have long classified the 'wet candle' method as a simple and low-tech method to calculate the long-term exposure of airborne chlorides. In the ideal situation, this method is designed to provide the exact level of airborne contaminants and salts which is then expected to help classify the aggressivity of the atmosphere.[21] For this study, the results of this experiment were inconclusive, showing low to no levels of atmospheric chlorides within the test solution. The 'wet candle' method has been successfully employed in many applications, but for the purposes of this study, it proved ineffective. While there are many possibilities for the failure of this test, one possibility lies with the placement of the experiment. The test was set up to be both out of the line of sight of the normal visitor, as well as to replicate the conditions of the lintels and tie-rod at the fort. The relatively sheltered nature of gorge wall caused the test to not receive the level of chlorides that the brick masonry on the exterior experiences. There, the effect of the salt intrusion, through

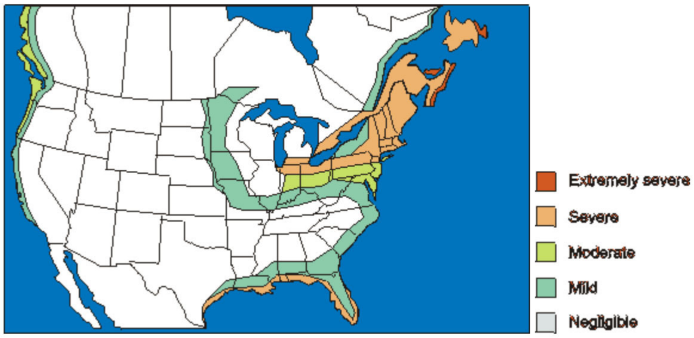

Figure 5.19: Map showing general atmospheric corrosivity. (from Handbook of Corrosion Engineering)

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[21] "ASTM G140-02 Standard Test Method for Determining Atmospheric Chloride Deposition Rate by Wet Candle Method" (ASTM International, 2008), http://www.astm.org.

cryptoflorescence, is easily seen by the naked eye. As the wind carrying the chlorides must travel over the tops of the fort walls and then down to the objects, the walls likely are serving as a protective shield for the iron. The other, likelier cause of this test's failure is human error. The test was created to replicate the conditions of the artifacts themselves, not the general atmospheric chloride levels. As it was only deployed and tested for a period of two months, it is probable that test did not have enough time to collect the level of soluble salts that are currently on the objects themselves. Likely, if the test was left exposed for a longer period of time, more salts would appear in the test.

X-ray Fluorescence Spectroscopy

While the 'wet candle' method is a simple, easy to replicate and inexpensive test to track the corrosivity of the atmosphere, time restraints likely will prevent this test from being useful for the majority of architectural conservators. In many cases, exposure of the test system has to be carried out over a period of several months and results are not always conclusive. On the other hand, new technologies are able to solve this problem. Portable X-Ray Fluorescence (XRF) spectroscopy is able to show the superficial chloride levels present on historic metal. While no method (outside of complete digestion) can be expected to give completely accurate results, XRF is able to provide a quick qualitative and semi-quantitative analysis with minimal set up. Additionally, all the analyses can be run in a matter of hours, not months, and is non-invasive allowing for minimal intervention and a smaller time-commitment.

At Fort Sumter, the six pieces chosen for further study were examined using XRF. Multiple tests were run for each piece in order to achieve an average chloride level for each object. For two pieces, XRF analysis was also carried out on the surrounding masonry in order to compare the iron and masonry chloride levels.

CHAPTER SIX
THE SURROUNDING MATERIALS' INFLUENCE ON MASONRY AT ITS ROLE IN THE CORROSION OF HISTORIC IRON AT FORT SUMTER

As the Union Siege of Fort Sumter progressed during the Civil War, the casemate walls threatened to collapse from the strength and force of the newly developed rifled cannons. In response, Confederate troops worked almost continually during the Union bombardment to reinforce the walls. Sand, concrete, and cotton bales were used to backfill and reinforce the lower casemate walls, in the process burying previously used living quarters and casemates. Bricks were cleaned, reused, and scattered across the fort as needed. By the war's end, both barracks, the officer's quarters, and the second tier casemates were demolished. After the war, there was a concerted clean-up effort to ready the fort for a flag raising ceremony, but little was done to rebuild until 1868 when then Major Quincy Gilmore suggested a plan to reconstruct Fort Sumter. Until this time, the fort remained largely a buried ruin.[1]

The end of the nineteenth century saw many changes at Fort Sumter. The Sallyport was moved from the Gorge Wall to the Left Flank. Workers began reinforcing the fort's foundations and casemate piers. A storm ripped through the area in 1874, wetting a shack containing lime and causing the lime to slake and set fire to the fort.[2] By 1892, when the decision was made to bury the original Parade Ground during the construction of Battery Huger, there was little visible original material left exposed. The fort was filled with soil. The remnants of the original Fort Sumter were left buried for the next sixty years until the National Park Service took over stewardship of the site and made the decision to excavate and expose the surviving ruins of the fort at which the first shots of the Civil War were directed.

Utilizing both mechanical and hand digging, the park worked over the course of five years (1951-1956) to expose the original parade ground and casemate walls. This process

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[1] Frank Barnes, *Fort Sumter: December 26, 1860* (Fort Sumter National Monument: Department of the Interior: National Park Service, 1950), 5.

[2] John Babington, *Fort Sumter: 1876* (Fort Sumter National Monument: United States Department of the Interior, National Park Service, 1954), 35.

6.1: *Iron fireplace basket found in ruins of Officer's Quarters during the 1950s excavations (courtesy of Fort Sumter National Monument)*

was often slowed by workers as they encountered 1870s reinforcements and armaments as well as rubble. As workers dug through the first three to four feet of sand and earth, they encountered a layer that contained large amounts of broken bricks, stone, old iron, and other unidentifiable rubble.[3] Wood door surrounds, remnants of original flooring, and masonry were all recognizable and recoverable, but the majority of iron that was found was described as "often nothing more than a rusty mess."[4] Decorative and easy-to-remove metalwork, like the iron basket fire grate found in the officers' quarters' parlor, was taken to the park's collection center. Remaining ironwork, such as the pintles, traverse rails, and lintels were cleaned, painted and left in place.[5]

The excavators of Fort Sumter discovered that architectural iron cannot always be easily removed and treated as an individual piece. An exposed iron gate is embedded and attached to stone, brick or timber. A beam is an integral part of the structural system. Door lintels and hardware are embedded in historic masonry. It is at these connection points where iron often fails first. Unfortunately, for logistical and ethical reasons, it is not usually feasible for conservators to remove architectural iron from its surrounding materials and treat it separately without causing irreparable damage to the building as a whole.

Corrosion is a dynamic process in which many factors play a role. In order to have the greatest chance at a successful conservation treatment, all aspects of the corrosion process should be studied. For the architectural conservator, this includes not just the

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[3] Rock Comstock, Jr., *Excavation Report: Fort Sumter National Monument, June 17-30, 1955* (Fort Sumter National Monument: United States Department of the Interior, National Park Service, 1955), 10.

[4] Comstock, *Excavation Report,* 7.

[5] Horace Sheely, *Excavation Report: Fort Sumter National Monument, May 7-June 21, 1956* (Fort Sumter National Monument: United States Department of the Interior, National Park Service, 1956), 5.

coating layers and the iron itself, but also the brick and mortar surrounding the historic iron. Because iron will not patinate, or form a protective oxidation layer naturally, the surrounding context is believed to play a large role in the corrosion process. This is one of the least understood and studied aspects in architectural conservation.[6]

Future research will undoubtedly focus more on the interplay between the two materials. Historically, there has been little motivation to answer the question of how best to conserve metal in masonry. Scholarship and practice commonly views iron as the culprit during the interaction between metal and masonry. With this view, it is the corroding metal that damages historic masonry and stains artifacts. While this inclination perhaps reflects the preservation community's desire to focus on craftsmanship, it is becoming increasingly difficult today to maintain the authenticity and integrity of a structure without acknowledging iron and masonry as a complementary, not antagonistic, system.

A simple visual assessment shows that the surrounding material, whether it is masonry or timber, can either have a beneficial or hostile effect on historic iron. Degradation results from the composition of the materials themselves. Porosity, the presence and amount of soluble salts, freeze-thaw cycles, thermal expansion and strength tests have proven to be useful methods for studying the internal composition and predicting rate of wear for masonry buildings. It is well-understood that the size and shape of pores in brick will affect the bricks' ability to withstand salt intrusion and freeze-thaw cycles. Less studied is the effect that the masonry has on structural metal. As the corrosion mechanism of iron depends on contact from an electrolyte, further investigations into the distance and time of saturation of historic brick would illuminate the exact impact masonry has on iron.

Porosity of the surrounding material plays an important role in the corrosion process of embedded metal. Pores act as a conduit for transporting water and soluble salts which are an important trigger of the corrosion process. In modern construction, reinforced concrete made with Portland cement, if a good quality, is a fairly impermeable material

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[6] Considerable work has been done to study composite materials in the archaeological conservation community. This study looks at the interplay and conservation needs between radically different materials and the best and most appropriate way to approach a conservation treatment.

that can encapsulate the embedded rebar and protect it from the destructive forces of the corrosion process—oxygen, moisture, and soluble salts. Brick and mortar, on the other hand, were traditionally made with sand, shell and clays that came from areas contaminated with soluble salts. The manufacturing process often required the addition of water to increase the plasticity, or workability, of the clay. Additionally, the process of hand-molding bricks meant that there was a greater chance for a high level of porosity in the finish product, allowing for greater water absorption.[7] Rising damp, airborne salts and floods can all serve as additional ways to reintroduce and alter the soluble salt content of historic brick and mortar. The length of time of saturation and rate of evaporation undoubtedly play a role in the speed and rate of corrosion of embedded architectural iron. These have not been sufficiently studied to provide useful and beneficial data in this project. For this reason, the porosity and long-term diffusion rates will be examined.

Composition of traditional surrounding materials of metal

Brick porosity and cryptoflorescence have been the subject of many studies by material scientists and architectural conservators in order to understand the long-term conservation needs of historic masonry buildings. These studies have a tendency to focus on damage caused by the salt content during freeze/thaw cycles and spalling and cracking of brick due to moisture infiltration.[8] As these are highly visible signs of decay, it is understandable that special focus has been placed on studying how brick degrades

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[7] John Warren, *Conservation of Brick*, Butterworth-Heinemann Series in Conservation and Museology (Oxford ; Boston: Butterworth Heinemann, 1999), 27.

[8] For more information on brick porosity studies, the following sources provide a helpful guide. John Warren, *Conservation of Brick*, Butterworth-Heinemann Series in Conservation and Museology (Oxford ; Boston: Butterworth Heinemann, 1999); S Fitz et al., *Conservation of Historic Brick Structures: Case Studies and Reports of Research* (Shaftesbury, Dorset: Donhead, 1998); David Watt, “Investigating the Effects of Site and Environmental Conditions on a Historic Building and Its Contents,” *Structural Survey* 19, no. 1 (2001): 46–57; J.A. Larbi, “Microscopy Applied to the Diagnosis of the Deterioration of Brick Masonry,” *Construction and Building Materials* 18 (2004): 299–307; Alison Henry and John Stewart, *Practical Building Conservation: Mortars, Renders, and Plasters*, English Heritage (Burlington: Ashgate, 2009); Barbara Lubelli, Rob P.J. van Hees, and Caspar J.W.P. Groot, “The Role of Sea Salts in the Occurrence of Different Damage Mechanisms and Decay Patterns on Brick Masonry,” *Construction and Building Materials* 18, no. 2 (March 2004): 119–124.

overtime. The porosity and subsequent permeability of historic masonry act as the mechanism that allows for the diffusion of salts into the core of the brick or stone masonry. These problems, while traditionally applied only to masonry conservation, can also exacerbate the corrosion of embedded iron within structures.

Moisture Infiltration of Masonry

As is the case of many other causes of material degradation, water and its ability to be transported to the core of a masonry structure is one of the largest factors in masonry deterioration. Research has demonstrated that moisture can be absorbed into masonry either as a liquid or as a vapor. If a liquid, absorption happens in three primary forms: capillary action, diffusion, or osmosis.[9] For architectural conservators, capillary action is a common manifestation of water absorption and often seen in the form of rising damp. High water content in the soil surrounding a structure will cause the masonry foundations to become saturated and draw water up from the ground as the water travels to the drier areas. Capillary action works because of the amount and distribution of pores within the material, or the material's porosity.

Porosity is known to have significant consequences for masonry, but the effects of prolonged exposure to a constant moisture level can also be disastrous to historic metal. This is believed to be the most direct method of water transport and can lead to high amounts of water absorption in the masonry. Higher saturation levels increase the likelihood that the surrounding masonry will create a hostile and aggressive setting for the embedded iron. Often cramps or clamps that act as anchors for masonry will corrode first causing cracking and spalling of the stone or brick. The masonry's porosity or small, unseen fractures in the mortar are enough to begin the corrosion process. As the clamp corrodes, the expansive corrosion product causes the masonry to split, allowing for the larger levels of oxygen, water, and soluble salts to contact the iron, and accelerate the corrosion mechanism.

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[9] Ernesto Borrelli, "Porosity," in *ICCROM ARC: Laboratory Handbook* (Rome, Italy: International Centre for the Study of the Preservation and Restoration of Cultural Property, 1999), 6.

Diffusion and osmosis have less dramatic effects on embedded iron, but each still has equal ability to create an aggressive environment. Absorption through diffusion occurs when masonry is submerged in water and the higher water content will naturally travel to the lower concentration in order to equilibrate. Osmosis, in brick, occurs when salts present in water form electrically charged particles that attract more water.[10]

As a vapor, water can be transmitted through condensation, diffusion, or through hygroscopic absorption. Condensation primarily acts in a superficial manner as the masonry becomes wet and dries in a cyclical manner. On the other hand, hygroscopic absorption occurs when the temperature is above the dew point and the presence of soluble salts in the masonry itself attract water in the atmosphere, much like osmosis in water. With this in mind, it is possible that hygroscopic absorption, which can absorb water under even average relative humidity levels, will promote more water absorption for a longer period of time without being visibly seen. Through this action, water can potentially be absorbed into porous masonry at almost all times during the course of the day when the temperature is above the dew point.[11]

The internal structure of masonry creates a pattern of pores that serve as water's highways to the core of the brick or stone. Excessive loads placed on the stone or brick can cause micro-fractures that act as continuous channels that transport soluble salts and moisture deep into the interior of the brick. Pores come in various shapes and can be classified either by their cross-sectional shape (spherical, cylindrical, or elongated) or their origin (basic, dissolution, fracture, or shrinkage). The formation of the shape and structure of the pores is attributed to the manufacturing or curing process.[12]

Stone can be classified by its pore structure as a way to determine the rate and amount of potential water penetration. In addition to the percent of pores, or the porosity,

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[10] Borrelli, "Porosity", 6.

[11] Borrelli, "Porosity", 6.

[12] B. Fitzner, "Porosity Properties and Weathering Behavior of Natural Stones-Methodology and Examples," in *Papers Collection of the Second Course "Stone Material in Monuments: Diagnosis and Conservation", Heraklion-Crete, 24-30 May 1993* (Scuola Universitaria C.U.M. Bari, Italy: Conservazione dei Monumenti, 1993), 44.

stones and brick can be classified as having micropores, which are generally considered impermeable, and the larger macropores. Typically, pores seen in naturally formed stones are basic, dissolution or fracture pores, meaning that pores are formed naturally or through the stress of loads. The pore structure for brick is less easily defined. The manufacturing methods, clays, and temperatures contribute to a higher porosity in brick than in most natural stone. Shrinkage pores commonly appear in manufactured brick and mortar due to the contraction of the components during the curing process.[13] Mortars have a similarly high porosity. Lime/sand mortars often exhibit the highest porosity.[14] Natural cements, such as Rosendale or Pozzolan, exhibit less porosity, while Portland cement has the least porosity, making it roughly equivalent to stone. Portland cement is held in low esteem by the historic preservation community due to its incompatibility with historic lime mortars, though few studies have tracked the actual porosity and diffusion rates of historic Portland cement mortar and its effect on surround building components.

Salt Intrusion in Masonry

Without the transport of soluble salts, primarily chlorides, pores and water absorption would unlikely cause the damage that they are known to do. Chlorides, often in the form of sea salt, encounter the surface of a brick and can be transported into the

Rock Type	**Genesis**	**Geological formation**		**% porosity**	**Predominant Pore Type**
		Pressure	*temperature*	*(average value)*	*pore type*
basalt	igneous	low	very high	1-3	macro
granite	igneous	high	very high	1-4	micro
tuff	igneous	low	high	20-30	micro
gneiss	metamorphic	high	high	.4-2	micro
marble	metamorphic	high	high	.2-.3	micro
slate	metamorphic	high	medium-high	.1-1	micro
coral stone	sedimentary	low	low	40-50	macro
limestone	sedimentary	low	low	15-20	micro/macro
sandstone	sedimentary	low	low	10-15	macro

Table 6.1 Graph detailing average porosity % and pore type of common stone types. (from ICCROM handbook)

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[13] Borrelli, “Porosity”, 4

[14] P. Manita and T.C. Triantafillou, “Influence of the Design Materials on the Mechanical and Physical Properties of Repair Mortars of Historic Buildings,” *Materials and Structures* (March 26, 2011).

masonry through the absorption of water. While chlorides penetrate masonry through flooding, sea spray or rising damp, water evaporates at different levels leaving residual salts in the structure. Typically, damage due to salt intrusion is seen through the blistering of brick, or powdering caused by cycles of chloride crystallization and thermal expansion.[15] Prolonged saturation times can however allow water to move upwards through pores by capillary action. As the water moves, moisture travels upwards and to the center of the brick. When the water retreats, salts are deposited on the exterior of the brick where they will have a relatively harmless role. As the water moves upward through the masonry, it will eventually disperse in the core of the brick itself, leaving the soluble salt to crystallize in the pores. The crystallization of salts is generally identified as the cause of brick spalling and flaking.[16] It is the addition of salts that allows for the formation of an electrolyte, which may promote corrosion. Salt crystallization may cause brick to spall, but it is possible that the transport of salts through pores and micro-fractures in the masonry contributes to larger concentrations of chlorides that accelerate the corrosion process of embedded metal.

Types of corrosion associated with masonry

Corrosion is generally classified as uniform, pitting, galvanic, stress-cracking, erosion, or crevice corrosion. Certain corrosion classifications have causes that are more directly tied to the surrounding masonry than others, although it is not uncommon for a single piece of historic iron to exhibit several of these types of corrosion. Unlike general atmospheric corrosion, which promotes the more or less continuous superficial formation of corrosion products, corrosion that is primarily influenced by the surrounding materials in its immediate context is identifiable through the intensity of isolated, localized corrosion.

A common type of corrosion associated with artifacts embedded in historic masonry is crevice corrosion. This manner of corrosion occurs when pockets of moisture get trapped

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[15] Barbara Lubelli, Rob P.J. van Hees, and Caspar J.W.P. Groot, "The Role of Sea Salts in the Occurrence of Different Damage Mechanisms and Decay Patterns on Brick Masonry," *Construction and Building Materials* 18, no. 2 (March 2004): 119.

[16] Warren, *Conservation of Brick*, 188.

Type of Corrosion	Metalwork Affected	Description	Means of Failure
Uniform	most common form, affects all metals	electrochemical reaction which proceeds in a uniform patten over the exposed surface	metal thins and fails
Pitting	common in cast iron	localized corrosion that forms in pits, most pits are deeper than in wide	corrosion can cause failure, even through only small percentage of iron is lost
Galvanic	occurs at intersection of two metals	the less noble metal will corode while more noble is protected	relative area of cathode/anode will determine degree of corrosion
Crevice	found in bolt holes, joints, rivets, and under surface deposits	depleted oxygen levels in crevice can initiate corrosion	can cause localized corrosion and failure even through only small percentage of iron is lost
Stress Cracking	most forms	caused by tensile stresses from either internal or external forces	not common for old iron

Table 6.2 Types of corosion commonly seen in architecture. (from Practical Building Conservation: Metals, 31-32)

in a restricted location. An electrochemical corrosion cell is formed when the electrolyte in the crevice becomes oxygen-depleted and then reacts with the oxygen-rich environment. The oxygen-rich area then acts as the cathode while the iron in the crevice becomes the anode and corrodes.[17] In architecture, crevice corrosion is regularly found at the junction of two metal pieces (connections in a gate or fence) or at the intersection of the metal and its embedded material.

Stress corrosion is less seen in historic iron. Caused by excessive tensile loads and the subsequent weakening of the material, stress corrosion often appears in the form of cracking at points of stress. This type of corrosion will typically occur early in the service life of iron and is replaced. Thus, it usually falls out of the purview of historic metal conservation and is not a problem for conservators. However, there are occasions where

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[17] J. R. Davis, ed., *Corrosion: Understanding the Basics* (Materials Park, Ohio: ASM International, 2000), 107.

otherwise unexplained cracking appears in historic iron. These cracks are possibly formed when the historic iron is surrounded by a material that is stronger than the iron itself. If the surrounding material is strong and dense enough to withstand the expansive forces of iron corrosion, then the internal stresses or loads will likely cause the metal itself to fail or crack along the stress lines.[18]

Because few pieces of architectural iron are buried and considered important enough to conserve, architectural conservators seldom discuss soil corrosion. This indistinct form of corrosion is not easily tracked. In the case of Fort Sumter, the sixty years that the historic iron was buried undoubtedly had a significant influence on its current condition. As many of the pieces the Park Service found during excavation were considered unidentifiable, a comprehensive assessment of the condition of the remaining objects would not be complete without understanding the effects of the burial.

In most situations, iron is able to maintain a high level of stability when buried. However, if soluble salts are present in the soil, a corrosive environment can be created. Backfilled soils are known to form a partially aerated soil that can trap soluble salts and create a galvanic current that flows from partially-aerated to a well-aerated soil. This causes one part of the object to form the anode and corrode, while the other acts as the cathode. Thankfully, not all soils form the galvanic current. Coarse soils, such as gravel and sand drain well and typically have the same low corrosivity as the atmosphere. That is to say, while they can promote corrosion, it will progress at a slower and steadier rate than other soils. Clay and silt, with their finer texture and higher water retention rate, can promote the highest corrosion rate. Typically, corrosion from soil conditions will result in pits across the surface in a fashion similar to pitting.[19]

This process can be applied to help understand the corrosion mechanism of embedded architectural iron. Mortar and bricks, through their varying porosity and water retention levels, will induce galvanic and crevice corrosion in similar manner to buried

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[18] English Heritage, *Practical Building Conservation. Metals and glass.* (Farnham: Ashgate, 2009).

[19] *Corrosion: Understanding the Basics*, 105, 211.

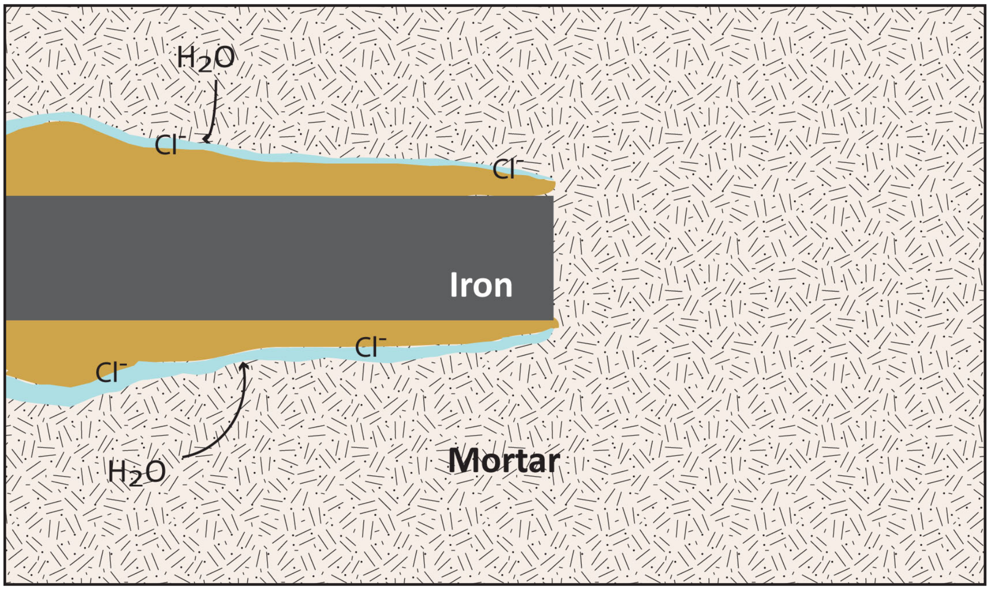


Figure 6.2 Shematic drawing detailing crevice corrosion (drawn by author).

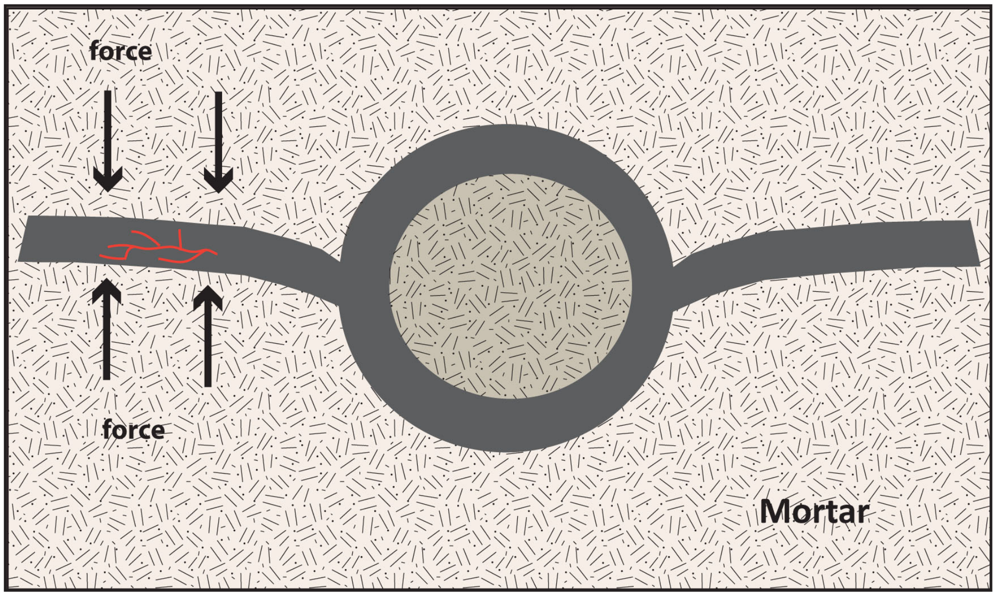


Figure 6.3 Schematic drawing detailing forces creating stress corrosion cracking (drawn by author)

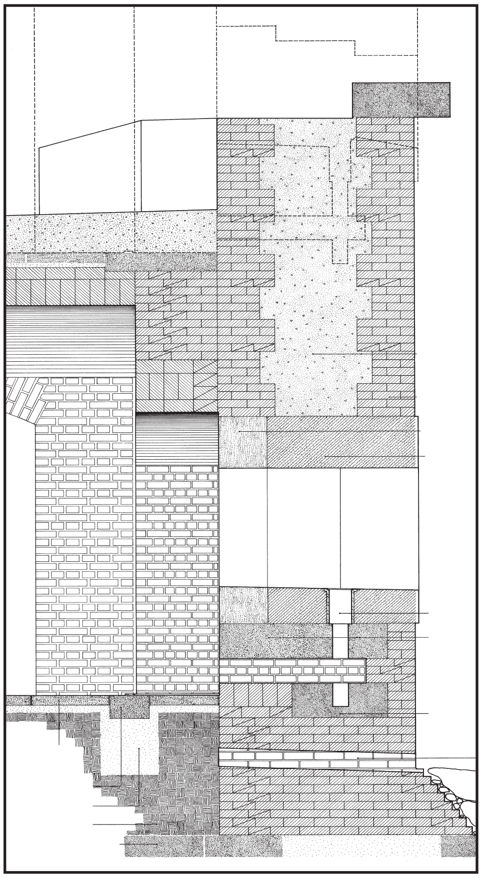
iron. In the case of buried iron, it can be expected that the iron will eventually reach a state of equilibrium and stabilize. Unfortunately, with architectural embedded iron, the iron is not able to reach a state of equilibrium due to the continually changing environment—wind, rain, freeze/thaw—that affect the masonry. The result is the creation of an ongoing corrosion cell that will continue until the embedded iron is completely consumed by corrosion products or is removed from its original location.

It would be detrimental when analyzing the causes of iron corrosion to discount the past treatments and materials used, as the effects of these will likely remain apparent on the surface of the historic object. For example, historic iron that was originally pointed in a porous, permeable mortar will continue to bear signs of the effect of the primary material. Unless all the preexisting mortar is removed and the embedded iron is rinsed to remove soluble salts, a higher chloride content along the interface of the mortar and iron will often be maintained during a repointing campaign and continue to promote corrosion. It should be noted that it is possible that a well-meaning repointing campaign to replace a dense, hard mortar with a sacrificial lime-based mortar can expose and reactivate a previously passive corrosion mechanism by allowing for greater permeability. Though in the same way, a dense impermeable mortar can also cause bricks to crack and allow for the ingress of moisture which will also reactivate the corrosion mechanism.

Surrounding masonry and Fort Sumter

Clemson University's National Brick Institute has recently performed a study characterizing the Fort's historic and restoration materials. The study identified and characterized the wear processes of the masonry at Fort Sumter. Porosity, compressive strength, water absorption, and the soluble salt content were studied to develop a comprehensive understanding of the properties of the fort's unique masonry. Though the studies primarily focused on the exterior brick masonry, the study was able to contribute to the understanding of the interior brick of the fort and the possible role it has on the corrosion of the historic iron at Fort Sumter.

On the surface, Fort Sumter appears to be a solid masonry fort. However, the Historic American Building Survey's (HABS) cross section shows that the exterior scarp wall and the interior casemates line a solid core that was made with an oyster shell and rubble aggregate concrete. Analysis showed that the bricks used in Fort Sumter were made in various campaigns and can be classified into five groups.[20] War, successive rebuilding, and lack of resources forced both the Confederate and Federal Armies to reuse the materials at the fort; thus, the interior bricks used in later rebuilding campaigns have no clear point of origin.


6.4 HABS drawing detailing masonry exterior and interior walls with a concrete core. (courtesy of the Library of Congress)

There is some speculation that in addition to cleaning and reusing existing brick, newer brick was brought to the fort as needed for a specialized purpose. For example, yellow firebrick is found in the remnants of the two fireplaces located along the Left Flank. As the fireplaces themselves are not original to the barracks, it is likely that the firebrick was brought to reconfigure the newly constructed fireplaces for greater efficiency. Firebrick was not an uncommon material in Antebellum America. The officers' quarters show evidence of having a much higher quality pressed brick lining their fireboxes. Typically, these bricks were made with stiffer clay and then pressed into molds under high pressure. The result was a much harder and consistent brick than locally manufactured, hand-made brick.[21] The yellow firebrick does not match any other brick at the fort and is not

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[20] Denis Brosnan, "Characterization and Forensic Studies of Construction Materials for Fort Sumter National Monument," January 11, 2010, Fort Sumter National Monument, 219.

[21] Calder Loth, "Notes on the Evolution of Virginia Brickwork from the Seventeenth Century to the Late Nineteenth Century," *Association of Preservation Technology* 6, no. 2 (1974), 118.

found in large quantities in the brick remnant piles that remain at Fort Sumter. It is far more likely that these bricks were brought in during the late nineteenth century to line the newly constructed fireplaces.

Most of the bricks at Fort Sumter and all brick used in its casemate and scarp walls are classified as "Charleston Grey" brick, meaning that the brick was likely manufactured in the Charleston area from local clays. The color refers to the color of the clay prior to firing.[22] At the time of Fort Sumter's construction, brickyards were common in local plantations in the Lowcountry. Typically, bricks had a lower firing temperature and a lower density than more modern bricks.[23] The overall porosity of bricks at Fort Sumter is high, ranging from 28-33%, a significantly higher porosity level than most natural stone.[24] Due to the location of the fort on a former shoal and the cyclical rise and fall of tides, the overall porosity likely contributes highly to the problems associated with rising damp and salt crystallization along the exterior scarp wall. It is believed that the historic iron on the interior of the fort is relatively protected from salt intrusion due to rising damp because the inner core of concrete acts as a filter and barrier.

As mortar is generally accepted to be the sacrificial building layer, it is not surprising that studies found that the mortar has the highest porosity of all building material at Fort Sumter. In addition, the mortar also showed the highest level of soluble salts. This is likely due to the rebuilding campaigns when all supplies had to be transported to the site via boat. It is commonly believed that water used to wet the mortar came from the harbor, thus leaving a higher salt content in the material as it cured.

The original Rosendale mortars used at Fort Sumter have an average porosity between 24-44%.[25] Unlike lime and sand mortars which would have a lighter density and high lime and soluble salt content, Rosendale mortars were traditionally denser and came

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[22] Brosnan, Characterization and Forensic Studies, 225.

[23] Lucy B Wayne, "'Burning Brick and Making a Large Fortune at It Too': Landscape Archaeology and Lowcountry Brickmaking," in *Carolina's Historical Landscapes: Archaeological Perspectives*, ed. Linda F. Stine et al. (Knoxville, TN: The University of Tennessee, 1997), 104

[24] Brosnan, "Characterization and Forensic Studies", 230.

[25] Brosnan, "Characterization and Forensic Studies", 243.

Figure 6.5: Yellow firebrick at Fort Sumter. Likely, this firebrick was brought to the fort at a later date after the Civil War. (photo by author)

Figure 6.6 Finer quality extruded brick found in the area around the Officer's Quarters. (photo by author)

Figure 6.7 Locally-made Charleston grey brick that is common through the fort. (photo by author)

from the burning of a marl layer in Rosendale, New York. Marl, a lime-rich mud, was a well-known component in natural cements in the nineteenth century and widely used for large-scale construction projects such as the US Capitol, the Brooklyn Bridge, and the pedestal of the Statue of Liberty. More efficient than traditional lime and sand mortars, mortar made with Rosendale Cement dried faster and set harder than lime mortars. Until the emergence of Portland cement in the late nineteenth century, Rosendale cement was one of the highest qualities available.[26]

The majority of the bricks tested during the National Brick Institute study came from either the stockpile (to minimize invasive studies) or from the exterior walls. While the porosity studies are applicable to the interior of the fort's brick, the soluble salt levels and water absorption are less useful. The soluble salt levels and water absorption levels are high in the brick samples that came from the exterior walls of the fort. On the other hand, the chloride levels in the brick from the stockpile is significantly less, making it difficult to draw assumptions of the soluble salt content of the brick in the interior of the fort.[27] It is suspected that the walls of the fort block much of the salts from entering the interior of the fort. If this is the case, the chloride levels in the brick and mortar in the interior of the fort would be significantly less than the exterior levels. Further studies would help to further answer this question.

Rising damp is not a visible problem for the metal objects, although the initial rate of absorption (IRA) of water in the historic brick is significantly higher than the average absorption rate for modern brick. The IRA for modern brick averages between five to thirty grams per minute (5-30 g/min). At Fort Sumter, the highest absorption rate of the bricks reached 331.8 g/min, though the average rate remained around 120 g/min.[28] Unfortunately, tracking the initial rate of absorption in historic brick does little to define the depth and time of water infiltrations. However, the study shows that the bricks' high absorption rate

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[26] Dietrich Werner and Kurtis Burmeister, "An Overview of the History and Economic Geology of the Natural Cement Industry at Rosendale, Ulster, County, New York," *Journal of ASTM International* 4, no. 6 (2007), 2-4.

[27] Brosnan, "Characterization and Forensic Studies," 230.

[28] Brosnan, "Characterization and Forensic Studies", 239-240.

Standard Properities	Specimen 1	Specimen 2	Specimen 13	Specimen 31	Specimen 32	Others
Location	unknown	Left Face near Left Shoulder Angle, at mid-tide elevation	Loose from stockpile	Gorge Wall, ocean end, 15’ above esplanade, 20’ from angle	Loose on Esplanade	Loose from Stockpile
Cold Water Absorption %	15.30%	18.60%	21.60%	19.60%	14.70%	11.0-15.3 %
Boiling Water Absorption %	21.00%	24.40%	22.30%	25.00%	19.50%	19.0 -23.4 %
Moisture Expansion Coefficient, in/in			1.07 X exp (-4)			
Thermal Expansion Coefficient, C^{-1} (F^{-1})			12.2-13.5 X exp (-6); [6.8-7.5 X exp(-6)]		6.3 X exp (-6) [3.5 X exp (-6)]	
Apparent Porosity %	34.20%	36.80%	35.90%	38.00%	32.80%	

Table 6.3 Physical properities of bricks tested at Fort Sumter. From Dr. Brosnan “Characterization of Brick”

	Specimen 3	Specimen 5	Specimen 6	Specimen 11	Specimen 16
Location	Left Face exterior near Left Shoulder Angle, at mid-tide elevation	Left Flank exterior 28’ to the right of the Sallyport right side casing, 20” above ground level	Sallyport vault pointing	Right Flank exterior 38’ from USGS marker, 100” from top of wall	Right Face Casemate A18 Vault
Type of Mortar	submerged bedding	bedding	pointing	bedding	officer’s quarters foundation
Apparent Porosity, %	24.30%	44.10%	43.10%	31.60%	22.70%
Mix (cement:lime:sand)	ND	1:2:4	1:2.5:.25	1:4:9	1:1.5:2-3
Soluble Salts (ppm of solid)					
Na	2066	839	2092	149	851
Cl	5801	1232	2706	148	7406

Table 6.4 Physical properities of historic mortar at Fort Sumter. From Dr. Brosnan “Characterization of Brick”

likely increases the probability of frequent wetting of the embedded metal thereby creating a dynamic system that promotes greater corrosion rates.

In an attempt to minimize invasive and destructive studies, the brick and mortar in the interior of the fort were not subjected to destructive studies in this project to determine soluble salt levels. Instead, portable X-ray fluorescence (XRF) was used to look at the superficial chloride levels on the brick rubble cement and the brick. The results showed that there were significant levels of chlorides on the surface, although the levels found on the mortar and rubble cement were not in a greater concentration than what was found on the metal. Nonetheless, this indicates the possibility that destructive chlorides can continue to be transported into the interior of the brick through capillary action.

As the US Army, and later the National Park Service began their successive campaigns to stabilize and rebuild the fort, Portland cement was used during reconstruction because of its strength and availability.[29] The differences in permeability and density between the historic masonry and the Portland cement have proved to be destructive to the fort's brick.[30] The stresses caused by varying levels of thermal expansion are further damaging the fort causing erosion, blistering and spalling of the brick. The Park Service has reverted to the use of the original Rosendale cement in order to minimize damage caused by the harder and less permeable Portland cement based mortars. The use of the original Rosendale cement allows for the thermal expansion of the brick and mortar to function in the manner that Joseph Totten intended when he performed his brick and mortar studies.[31]

While Portland cement is known for making a mortar that is harmful to soft historic bricks, the small pores size and relative imperviousness of the cement potentially help protect the embedded metal by preventing further intrusion of soluble salts. This indicates the possibility that future ingress of soluble salts is minimized. It is possible that future

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[29] Brosnan, "Characterization and Forensic Studies", 219-221.

[30] Another common destructive force in the interplay between modern Portland cement and historic brick, the freeze/thaw cycle, is of little concern for Fort Sumter due to its location in a warmer climate and thus not discussed.

[31] Ann Johnson, "Material Experiments: Environment and Engineering Institutions in the Early American Republic," *Osiris* 24, no. 1 (January 1, 2009): 53–74.

repointing campaigns with historically sensitive, yet less dense, Rosendale cement will enable the transport of new quantities of soluble salts to the interface of the embedded iron and reactivate a formerly passive corrosion mechanism.

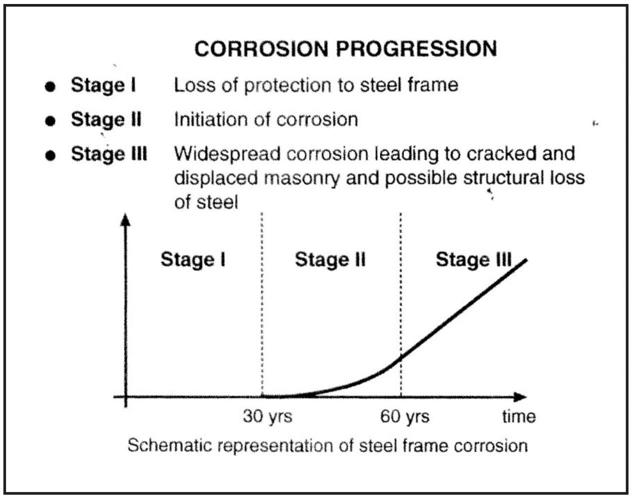

*Figure 6.8 graph predicting the overall corrosion and eventual loss of steel embedded in concrete. (*taken from Corrosion in Masonry Clad-Buildings)

Corrosion of embedded iron at Fort Sumter

The historic iron at Fort Sumter can be divided into two different categories of surrounding material. Primarily, the fireplace lintels, tie-rod, door hardware, and shells are all embedded in brick and mortar. Secondly, the traverse rails and pintles are embedded in imported granite and the corrosion on these pieces shows significantly less influence from the granite than those objects that are surrounded by brick and mortar. There are undoubtedly multiple potential reasons for why each object is corroding, but the visible influence from the surrounding materials can be determined with certainty.

The survey of the historic Civil War era metal showed that both fireplace lintels and the tie-rod were significantly affected by either the surrounding material or atmosphere. There was general corrosion over the exposed surface of the iron that appears to be in a relatively stable state. At the interface of the metal and mortar supporting the lintels, the corrosion had reached such an advanced state that there was little metallic iron remaining in the juncture. In fact, during the course of this study, the lintel along the Left Flank failed and collapsed. The differential exposure between shallowly embedded metal and the exposed portion is likely causing a higher concentration of chloride levels at the metal interface and the high humidity levels at the fort are causing the lintel to have a near constant electrolytic film. Additionally, the corrosion process is likely exacerbated as

Figure 6.9 Detail of the Left Flank fireplace lintel showing remaining metal core and remaining corrosion after failure of lintel. (photo by author)

Figure 6.10 Interior detail of the Left Flank fireplace tie-rod showing remaining metal core and remaining corrosion. (photo by author)

Object	Date of Installation	Location	Casemate	Type of Metal	Surrounding Materials	Assumed Porosity	Type of Corrosion
Tie-rod	1870-1880	Left Flank	n/a	wrought	brick/mortar	High	crevice, general
Lintel	1870-1880	Left Flank		rolled wrought	brick/mortar	High	crevice, general
Clip	unknown	Left Face	B-1	wrought	brick/mortar	High	general, pitting
Shell	1860	Left Face	A-8	cast	brick/mortar	High	general, pitting
Shell	1860	Left Face	A-11	cast	brick/mortar	High	general
Pipe	unknown	Left Face	A-12	cast	brick/mortar	High	general
Shell	1860	Left Face	A-12	cast	brick/mortar	High	general, pitting
Door Tred	1850	Gorge Wall		cast	brick/mortar	High	general
Lintel	1860	Gorge Wall	n/a	rolled wrought	brick/mortar	High	crevice, general
Pintle Tongue	1850	Left Flank	A-13	cast	brick/mortar, concrete (brick rubble)	High	general, pitting
Door Hardware	1850	Salient Angle	A-13/B-2	cast	brick/mortar, concrete (modern)	High	general
Pintle	1850	Left Flank	A-4	cast	concrete (brick rubble), granite	Low	pitting, stress cracking
Pintle	1850	Left Flank	A-5	cast	concrete (brick rubble), granite	Low	general, pitting, stress cracking
Pintle & Pintle Tongue	1850	Left Face	A-11	cast	concrete (brick rubble), granite	Low	general, stress cracking
Pintle & Pintle Tongue	1850	Salient Angle	B1-2	cast	concrete (brick rubble), granite	Low	general, pitting
Pintle & Pintle Tongue	1850	Salient Angle	C-4	cast	concrete (brick rubble), granite	Low	general
Pintle & Pintle Tongue	1850	Right Face	B1-3	cast	concrete (brick rubble), granite	Low	general
Pintle & Pintle Tongue	1850	Right Face	A-14	cast	concrete (brick rubble), granite	Low	general, stress cracking
Pintle & Pintle Tongue	1850	Right Face	A-15	cast	concrete (brick rubble), granite	Low	general, pitting
Pintle & Pintle Tongue	1850	Right Face	A-16	cast	concrete (brick rubble), granite	Low	general, pitting
Pintle & Pintle Tongue	1850	Right Face		cast	concrete (brick rubble), granite	Low	general, pitting
Pintle & Pintle Tongue	1850	Right Face	A-18	cast	concrete (brick rubble), granite	Low	general, pitting, stress cracking
Pintle & Pintle Tongue	1850	Right Face	A-19	cast	concrete (brick rubble), granite	Low	general
Pintle & Pintle Tongue	1850	Right Face	A-20	cast	concrete (brick rubble), granite	Low	general, pitting
Pintle & Pintle Tongue	1850	Right Face	B1-3	cast	concrete (brick rubble), granite	Low	general, pitting
Damper/Cap	1870-1880	Left Flank		cast	concrete (modern)	Low	crevice, general
Shutter Pins	unknown	Left Face	A-7	wrought	sandstone	medium	crevice, erosion, general

Table 6.5 Embedded iron objects at Fort Sumter, material, location, and type of corrosion

the corrosion product is not able to be washed or worn away due to the brick and mortar confining the iron.

In a similar fashion, the tie-rod embedded in the fireplace along the Left Flank of the fort is largely surrounded by brick. The tie-rod is deeply embedded in the sides of the fireplace, but it is exposed inside of the flue of the chimney. Thus, outside of the plates serving as anchors, the tie-rod receives no washing from rain. The firebox which is separate from the casemate walls and has its own foundation shows little evidence that moisture is transported to the metal through rising damp. Similar to the fireplace lintels, the mortar prevented the corrosion product from separating from the iron, and the resulting expansion was forcing bricks to crack. Over the span of four months (August-December), visual observations indicated that the tie-rod was degrading to such a point that the fireplace was in danger of overall structural failure and collapse. Corrosion was occurring along the slag lines of the wrought iron bar, and fragments of the now severely mineralized artifact were visibly accumulating on the base of the firebox. In November 2012, the decision was made to consolidate and remove the tie-rod from the fireplace and replace it with a stainless steel replica. This work was carried out in December 2012, and included a program of realignment and repointing of the bricks shifted by the expansive corrosion. The process of which can be seen in Chapter Eight.

The high porosity of the brick and mortar and their rate of absorption allow moisture to easily reach the embedded iron. The resulting increase in the time of wetness and differential oxygen levels between the embedded and exposed portion likely encourage a more aggressive corrosion. Additionally,

Figure 6.11 Cracking of the Left Flank fireplace due to the expansive corrosion of the tie-rod. (photo by author)

the initial high soluble salt content of the mortar is able to be transported through the brick and mortar to the embedded metal by the movement of water. Based on this, these causes likely create an extremely aggressive environment that promotes the rapid corrosion of the historic iron at the junction of the embedded to exposed iron.


Figure 6.12 Granite Lintel over pintle tongue in Right Face. (photo by Author)

In contrast, the pintles are surrounded by granite and rubble concrete and show significantly less loss of material than the pieces that were predominantly surrounded by brick and mortar. Totten, knowing the stress and strain that the pintles would be under during the successive firing of the cannons that they served to anchor, designed a pintle and pintle tongue system that was embedded in the masonry walls of the fort. Surrounding the cast iron pintle is a large granite lintel, a granite base, and an exterior concrete and rubble casing that was stuccoed.[32] Granite, being a largely impervious rock, is helping protect the cast-iron pintle from the influence of salt intrusion. There is no visible cracking of the granite, meaning that oxide jacking is not known to be occurring. The corrosion appears to be more influenced by the permeable rubble concrete and the exposure level of the pintle tongues.

Many of the pintles, while corroded, are not showing the same degradation symptoms by the surrounding material as the fireplace lintels and tie-rod. There is spalling at the interface of the rubble cement and iron but no signs of catastrophic failure of the metal itself. However, the cast-iron pintles are showing signs of stress cracking because of the strength of the surrounding cement. It is believed that as the corrosion products expand

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[32] Joseph Totten to J.D. Kurtz, September 2, 1851 "Engineer Records of Fort Sumter," 1845-1886, Department of the Interior, National Park Service, Fort Sumter National Monument.

in the pintle, the strength of the surrounding granite and rubble concrete are causing the metal to create tensile stresses within itself that are sufficient enough to crack the metal.[33]

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[33] P. Novak, "Environmental Deterioration of Metals," in *Environmental Deterioration of Materials*, ed. A. Moncmanova (Boston: WIT Press, 2007).

(top) Figure 6.13 Brick rubble cement around pintle in Left Flank embrasure. (photo by author)

(bottom) Figure 6.14 Pintle and pintle tongue in Right Face with evidence of staining on top of granite lintel, but no cracking. (photo by author)

CHAPTER SEVEN
THE INTERNAL STRUCTURE OF IRON AND ITS ROLE IN CORROSION

When the National Park Service took over responsibility of the overall management of Fort Sumter in 1949, the superintendent of the park, William Luckett, found himself in charge of a buried fort. Army engineers had buried the original parade ground at the turn of the century and Battery Huger and several smaller structures (two small observation towers, a house, and various other buildings) had been erected on the new surface. From the beginning, Luckett wanted to excavate and expose the historic Fort Sumter. With no boat to ferry people to and from the site and only a superintendent, clerk and historian as staff, there was little hope to accomplish the work without outside assistance.

The local community stepped in to help the Park Service transform the old fort into a National Park. The mayor of Charleston helped Luckett acquire a boat to transport the staff. The local Coast Guard stepped in and "undertook another mercy mission" to repair and stabilize the parts of the fort that were considered hazardous to visitors.[1] Over the next seven years, the Park Service slowly acquired the money needed to begin excavation and the process of revealing what remained of the original fort.

By the time the National Park Service began excavating the fort much of the original structural iron had been scrapped and removed from the site in order to facilitate the construction of Battery Huger. Theoretically the excavation should have progressed smoothly (as Fort Sumter had been cleaned and had significant debris removed after the Civil War). Nevertheless, removal or fill work was hindered by several factors. For example, workers initially had occasionally dynamite through the 1870s and 1880s gun emplacement campaigns to reach the original structure. Throughout this process, there were few options to help ease the removal and disposal of the dirt and debris excavated. The original plan was to dump the majority of the debris over the casemate walls and allow the tide to dispose of the dirt, but this proved to be a slow and largely ineffective method of removal. The debris

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[1] William Luckett, *Report on Activities at Fort Sumter National Monument During the Past 10 Months* (Charleston, SC: United States Department of the Interior, National Park Service, April 20, 1950), Fort Sumter National Monument.

itself constantly slowed progress as workers had to sift through brick from the collapsed barracks and officers' quarters, shells, mortar balls, remains of rifles, and shrapnel.[2]

When excavating the south-western portion of the Gorge Wall, Horace Sheely described the majority of the iron fragments found as "twisted metal and molten masses of metal." The gorge wall received particularly heavy fire during the war and a fire in the magazine caused this area to be buried early in the war. When reconstruction began in the 1870s, the US Army largely left the Gorge Wall unexcavated due to its structural instability. Excavators found a considerable number of objects and artifacts along the Gorge Wall area during the 1950s excavations, but many of these pieces were considered unidentifiable and discarded.[3] Nevertheless, workers were able to discover and identify other remaining iron features. The fireplace basket and grates from the officer quarters, though badly corroded, were discovered to be intact and in place underneath a concrete foundation for a 1870s gun placement.

Elsewhere in the fort, the remaining iron objects found were in considerably better condition. Previous reconstruction campaigns caused much of the original barracks material to be removed from the fort before the Parade Ground was buried at the turn of the century. Along the Left Flank, T-iron rails and stanchions were found close to the remaining fireplace as well as a large iron sheet that was presumed to come from the fireplace.[4] Photographs show that these remaining pieces were in considerably better condition than the iron fragments found along the Gorge Wall.

Iron objects recovered during the excavation of the Fort were classified either as an "unidentifiable rusty mess" and discarded, or as artifacts that could be cataloged and exhibited.[5] While this sorting method helped the park differentiate what would be saved and

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[2] Horace Sheely, *Excavation Report: Fort Sumter National Monument, May 7-June 21, 1956* (Fort Sumter National Monument: United States Department of the Interior, National Park Service, 1956).

[3] Sheely, *Excavation Reports*.

[4] Horace Sheely, "Excavation Report: Fort Sumter National Monument March 27- May 28, 1957" (United States Department of the Interior, National Park Service, 1957), Fort Sumter National Monument.

[5] Rock Comstock, Jr., *Excavation Report: Fort Sumter National Monument, June 17-30, 1955* (Fort Sumter National Monument: United States Department of the Interior, National Park Service, 1955).

Figure 7.1 Fireplace basket underneath concrete foundations during the 1950s excavations. (courtesy of Fort Sumter National Monument)

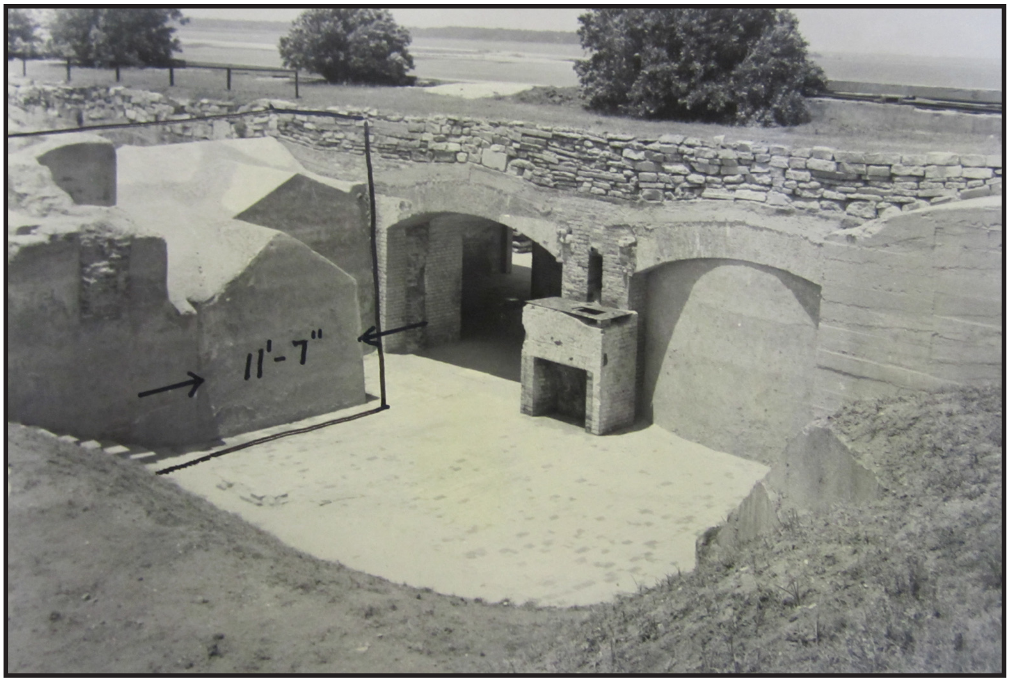

Figure 7.2 Left Flank fireplace in signficantly better condition than the ruins found along the Gorge Wall (courtesy of Fort Sumter National Monument)

what could not in a cost-effective manner, the true differences in the metal are much more complex. The following pages will seek to develop an understanding of how the complex origins and current status of the corrosion products can help inform conservators as to the current and future stability of the iron itself.

The lifecycle of iron is best understood as a cyclical process. Throughout the nineteenth century, iron was manufactured on both large and small scales. Each manufacturer or maker extracted iron from ore through the addition of heat from a charcoal or coke flame and included an additive or flux, such as limestone, to help separate impurities from molten iron.[6] Each region's limestone, charcoal, and ore could have a different composition which affects the end product. Additionally, it was left to the ironmongers to determine the exact ratio of flux to charcoal to iron ore.[7] The result was that while architectural iron is classified as either cast iron, wrought iron, or steel, the combinations and exact compositions of iron products are endlessly varying.

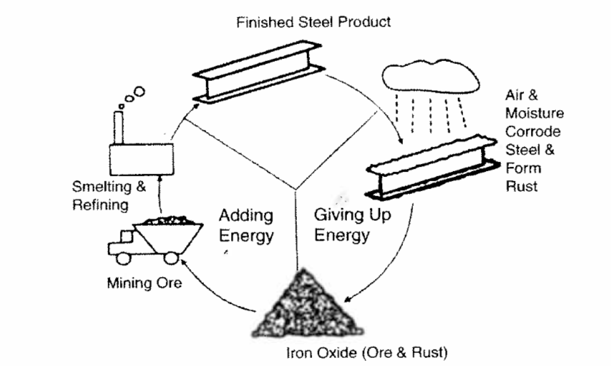

Figure 7.3 Lifecycle of ferrous products. (from Corrosion: Understanding the Basics)

Over the course of its service life, iron will be exposed to different environments, weather patterns, and uses all which ultimately shape how the object will corrode. As iron reacts with surrounding oxygen, water and other agents, the corrosion product (the constituents that make up the overall corrosion layer) increases in volume while the mass of the metallic iron decreases. The corrosion products from ferrous products are accepted to be seven to twelve times larger than the original volume.[8] It is these corrosion products that create the expansive forces that potentially damage surrounding

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[6] Sophie Martin Godfraind and Robyn Pender, eds., *Practical Building Conservation, Metals*, English Heritage (Farnham: Ashgate, 2012), 6.

[7] Geoff Wallis and Michael Bussell, "Cast Iron, Wrought Iron and Steel," in *Materials and Skills for Historic Conservation*, ed. Michael Forsyth (London: Blackwell Publishing, Ltd., 2008), 123.

[8] Peter Gibbs, *Corrosion in Masonry Clad Early 20th Century Steel Framed Buildings*, Historic Scotland Technical Advice Note 20 (Edinburgh: Historic Scotland, 2000), 4.

masonry. What is commonly referred to under the blanket term *corrosion product* is in reality a wildly complex range of components that are a result from the electrochemical reaction. Often these products are considered to more closely resemble the original iron ore than pure iron. The classification of these products is able help the conservator understand and predict the stability of historic iron objects. However, it helps to understand the entire lifecycle of iron before understanding the corrosion products themselves.

Composition of iron

The evolution of iron ore to iron to corroded iron can be seen as a simple evolution of iron, carbon, oxygen, and hydrogen atoms. The refinement of iron can be explained by the iron ore (Fe_2O_3) combing with carbon monoxide to form pure iron and carbon dioxide gas:

$$Fe_2O_2 \quad + \quad 3CO \quad \rightarrow \quad 2Fe \quad + \quad 3CO_2$$

Iron oxide + Carbon Monoxide = Iron Metal + Carbon Dioxide

During the manufacturing process, iron is extracted from its natural state and separates from other impurities found in the ore through heat.[9] The heat allows for the impurities to separate themselves from iron and form what is commonly known as slag. However, not all impurities separate themselves. It is the subsequent inclusion of carbon, phosphorous, and nickel that constitute an almost endless number of rations that comprise the alloys of cast iron and steel.[10]

Over the course of history there have been countless methods that produce workable and usable iron. Despite the fact that each manufacturers and blacksmith used different ores, limestone, heat intensities, and various types of coal and charcoal to refine iron, methods have generally remained fairly similar. As pure iron has a high melting temperature (1135°C), early refiners had difficulties in achieving the needed heat to remove impurities from the iron. However, a higher carbon content allowed the iron to melt at

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[9] David A Scott and Gerhard Eggert, *Iron and Steel in Art : Corrosion, Colorants, Conservation* (London: Archetype, 2009), 2.

[10] Typically, cast iron is considered to have a carbon content above 2% while steel has up to 2% carbon. Bussell, *Materials and Skills*, 111.

significantly lower temperatures (1150^{O}C) which was often achieved through the direct addition of carbon-heavy charcoal or coal. The then remaining slag could be siphoned off and the molten iron then poured into molds or 'pigs'. The resulting pig iron, while it had a high carbon content, making it brittle, could then be reheated and worked by hammering to remove much of the carbon to form wrought iron.[11]

The act of working the pig iron into cast iron causes the internal structure of the iron to reorganize and force the remaining slag into long strands within the object, giving it its distinctive form. The end product is a relatively pure iron that has a high workability and tensile strength.[12] On the other hand, cast iron, which is not worked like wrought iron, retains the high level carbon content. While the remaining carbon helps to minimize the corrosivity of the iron, it also forms graphite crystals which "act more or less like microscopic cracks, causing stress concentration and low tensile strength."[13] As discussed

Cast Iron	Wrought Iron	Mild Steel
1.8% -5% Carbon	Almost pure iron (<.1% Carbon, silicate slag content up to 4%)	.1-.4%
Crystalline structure	Fibrous wood-like structure	Crysalline Structure
Brittle, poor resistance to mechanical or thermal shock	Ductile, malleable	Ductile, Malleable
Good in compression, weak in tension	Good tension and compression	Good in tension and compression
Difficult to weld	Readily forge-welded	Readily welded
Good corrosion resistance	Better resistance than steel	Corrodible
Can chill hard in the mould	Ductile	Ductile, tough
formed by casting in mold	Rolled or hammered to shape	Rolld to shape

Table 7.1 Properities detailing the structure, composition, and workability of cast iron, wrought iron, and mild steel. (from Wallis, Materials & Skills, *129.)*

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[11] Bussell, *Materials and Skills*, 124.

[12] Giorgio Torraca, "Lectures on Materials Science for Architectural Conservation: Metals," in *Metals* (presented at the US/ICOMOS, Los Angeles, CA: The Getty Conservation Institute, 2009), 117.

[13] Torraca, "Lectures," 119.

in Chapter four, cast iron, despite its shortcomings, became increasingly popular in architecture as manufacturers were able to create an endless number of forms.

Until the Industrial Revolution, there were was no easy way to produce workable quantities of wrought iron on a large scale. Thus the realm of wrought iron was left largely to the local blacksmith. The development of the puddling process helped reduce the carbon content of molten iron to around 1% by separating the molten iron from the coal, re-melting cast iron into a 'puddle' and working it to remove the excess carbon.[14] Modern usage today defines steel as being refined with highly controlled manufacturing processes that remove many of the impurities that were found in earlier forms of iron and steel. Historically, steel was worked much like wrought iron (in a solid state) to remove carbon and increases its tensile strength. However, it was not until the Bessemer convertor, which allowed for higher levels of heat, that a reliable and consistent process was developed to burn off carbon from molten iron.

Over time, the manufactured iron will react with oxygen, water, and other agents and begin to corrode. A multitude of factors influence the rate and pattern of corrosion. As discussed earlier, oxygen, water, and contaminants such as salts play a large role in the general corrosion pattern. Additionally, the manufacturing process, possible flaws, and composition of the iron all contribute to the long-term stability of an architectural feature. As iron ages, the corrosion process creates a layer, or matrix, of corrosion products form along

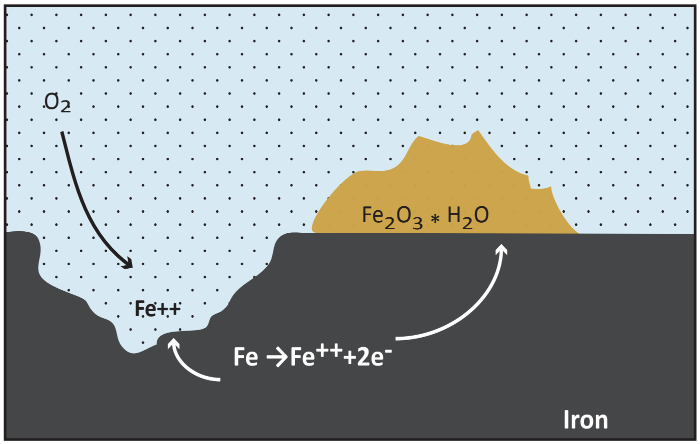

Figure 7.4 Basic Corrosion Cell (drawn by author)

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[14] Torraca, "Lectures," 122.

the surface. The pattern varies depending on numerous factors, including the environment and surrounding materials.

Crystalline in structure, cast iron is fairly corrosion resistant and is known to corrode relatively evenly resulting in a carbon-based network known as the *graphitized layer*. Considered an alloy of iron, it typically has a high percentage of carbon (2-5%) along with various other additives that can have a significant effect on the longevity of the object.[15] Generally, cast iron is known to fail at the imperfections in the casting or at the corrosion interface when exposed to high temperatures due to differential expansion properties. These failures will often result in highly localized losses that can result in failure of the pieces and surrounding masonry if the cast iron object is structural.

Just as cast iron is known to fail along its imperfections, wrought iron can fail along the slag planes. If cracks form along the slag lines, channels can form which allow corrosive agents (such as chloides) to travel deep within the metal and intiate further corrosion processes. If that occurs, the outcome often results in large portions of the corrosion product breaking apart the core metal, often in layers. Additionally, for rolled wrought iron

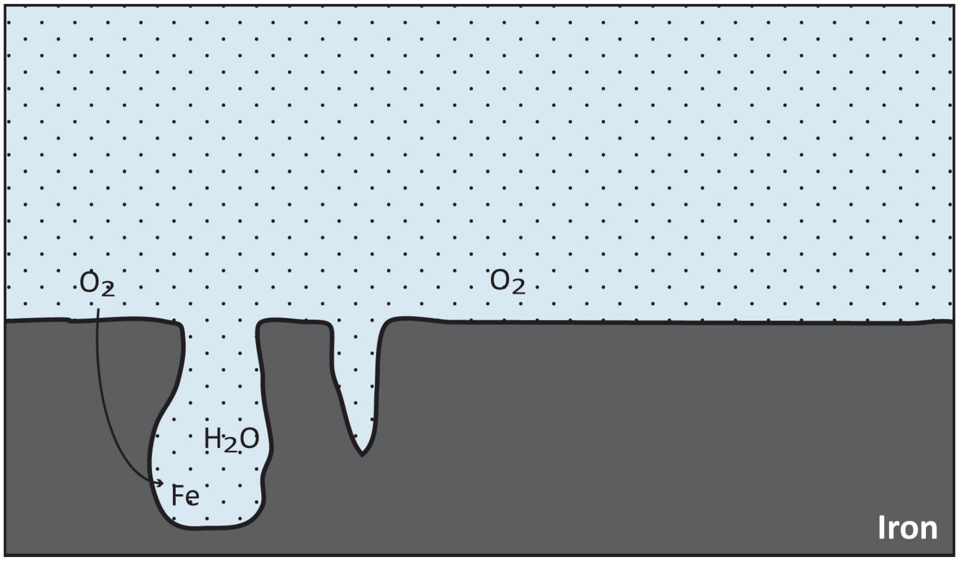

Figure 7.5 Schematic drawing showing pitting corrosion (drawn by author)

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[15] David A. Scott, *Metallography and Microstructure of Ancient and Historic Metals* ([Marina del Rey, CA]: Getty Conservation Institute in association with Archetype Books, 1991), 37.

pieces, corrosion will typically form along the slag lines, though it takes a thinner, more layered, appearance than a worked wrought iron piece.

As described in figure 7.5, corrosion products can and will transform the iron until a more mineralized form is reached, leaving little or no original iron. Different conditions are believed to influence the formation of different corrosion products and can combine to create a variety of compounds. Several of the most commonly found corrosion products in architectural iron, such as goethite (α-FeOOH), lepidocrocite (ϒ-FeOOH), and akaganéite (β-FeOOH), all stem from the same compound. However, each compound differs slightly from the others, and it is this difference that is believed to lead to the aggressivity of the corrosion reaction. Different environments and conditions can promote the formation of different compounds. For example, hematite (Fe_2O_3) is typically found when iron encountered a higher heat source, like a fire.

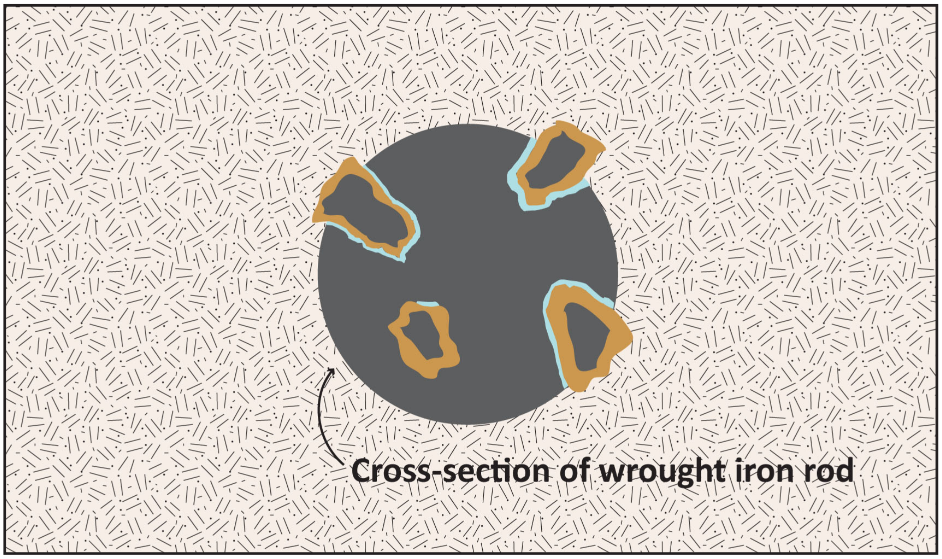

Figure 7.6 Cross-section of wrought iron rod and crossion forming along slag lines (drawn by author)

In the case of atmospheric corrosion, the corrosion products are believed to form and develop during the wet/dry cycles, continuously occurring on a historic object. In most

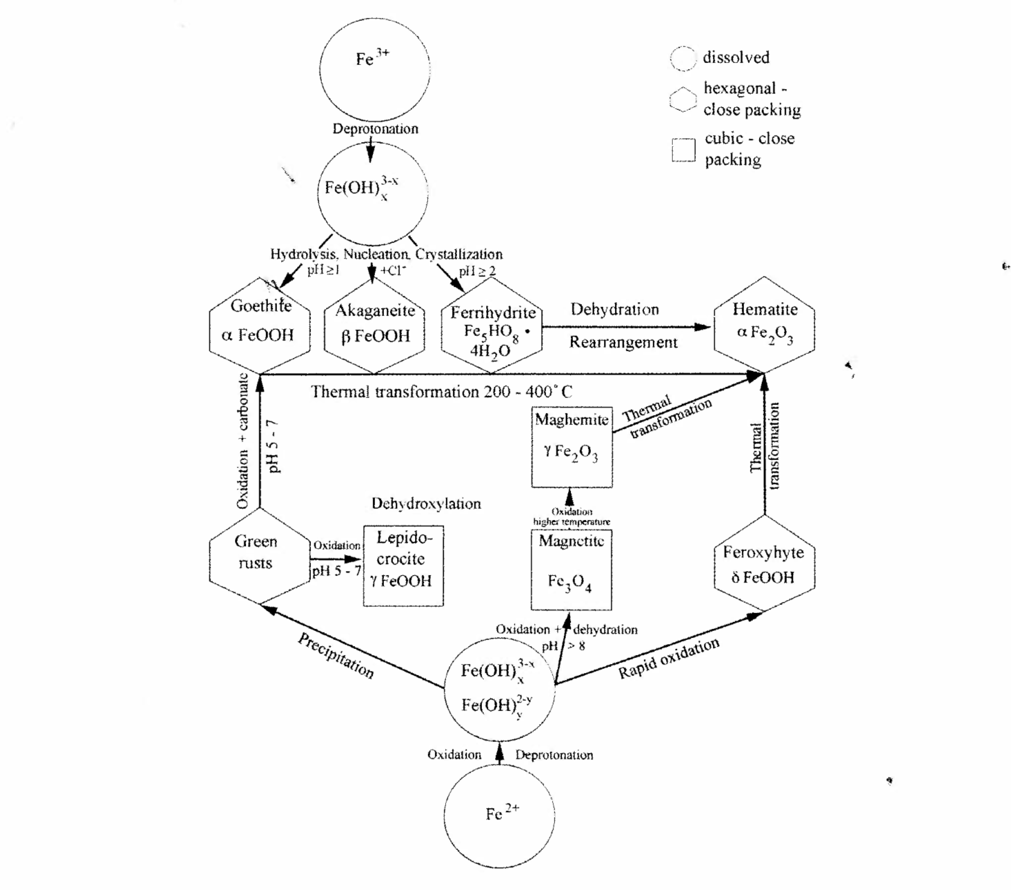

Figure 7.7 Transformation of corrosion products (from Scott, Iron and Steel in Art*)*

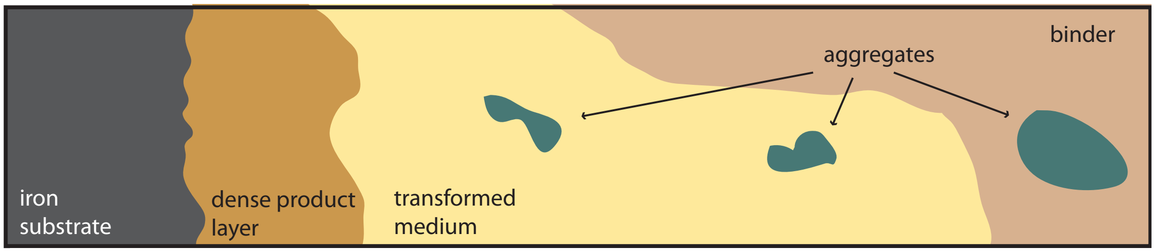

Figure 7.8 Schematic of corrosion product layer (after Chitty 2005)

environments, the wet/dry cycle contributes to the formation of a complex matrix with various corrosion products intermingled with others as opposed to one continuous and uniform type of corrosion product. A recent study found that the corrosion layer is dynamic and changes throughout a wet/dry cycle.[16] The study focused on analyzing the corrosion product layers that contained maghemite/magnetite and the transformations that occurred during exposure to higher humidity levels. During the wet/dry cycle magnetite was found to form from maghemite during the wetting stage but the newly formed magnetite, while traditionally considered to be one of the most stable corrosion products, proved to be unstable. When drying, the magnetite was shown to regenerate back to maghemite while drying thus advancing the corrosion rate of the iron.[17] Interestingly, the authors discussed the possibility that instability of the magnetite/maghemite layer could promote its own corrosion mechanism which affects the overall corrosion rate.[18]

Exposed iron has the ability to shed the expansive corrosion products by flaking or scaling, making it difficult to visually assess the extent of the corrosion prior to significant degradation. Embedded iron, on the other hand, has a surrounding binder in the form of mortar or stone that prevents the loss of the corrosion product. In long-term corrosion studies, corrosion patterns have been found to produce a matrix that can be classified in four levels: the metal substrate, a dense product layer (DPL), the transformed medium, and the binder. The DPL due to its location on the surface of the metal contains the primary corrosion products, while the transformed medium can be considered to be a less dense phase that contains elements of both the binder and the corrosion products. As with atmospheric corrosion layers, the structure of the DPL in embedded iron can include various levels of stable and unstable corrosion products.[19] In older layers, marbling was found to

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[16] E. Burger et al., "In Situ Structural Characterization of Nonstable Phases Involved in Atmospheric Corrosion of Ferrous Heritage Artefacts," *Corrosion Engineering, Science & Technology* 45, no. 5 (October 2010), 398.

[17] Burger, "Structural Characterization," 398.

[18] Burger, "Structural Characterization" 399.

[19] Walter-John Chitty et al., "Long-term Corrosion of Rebars Embedded in Aerial and Hydraulic Binders – Mechanisms and Crucial Physico-Chemical Parameters," *Corrosion Science* 50, no. 8 (August 2008), 2120.

consist mainly of magnetite/maghemite layers, signaling the likelihood that the corrosion layers were entering a more stable phase. In more recently formed corrosion layers, the corrosion products classified typically contained higher levels of goethite, lepidocrocite, and akaganéite as well as magnetite.[20] In other studies focusing on exposed interior corrosion pattern, lepidocrocite was found in the outer layers of the corrosion matrix and goethite was found in the inner layers.[21]

The classification of the corrosion products on artifacts of culture significance has the advantage of allowing a conservator to estimate the intensity or potential for future corrosion if left untreated. This is still a relatively new field of study for the architectural conservation community, and further study could potentially help to illuminate the corrosion mechanism for embedded architectural iron.[22]

Corrosion product classification

At Fort Sumter, this study utilized micro-Raman Spectroscopy to classify the corrosion products found on objects throughout the site. In an attempt to be minimally invasive, cross sections, which would allow for a more complete classification of the corrosion matrix were not taken. Instead, scrapings were done at different locations across the pieces studied in an attempt to identify the full range of corrosion products. Previous tests utilizing XRF technology showed that chlorine were present on each object which

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[20] Amélie Demoulin et al., "The Evolution of the Corrosion of Iron in Hydraulic Binders Analyzed From 46- and 260-Year-Old Buildings," *Corrosion Science* 52, no. 10 (October 2010), 3169.

[21] P Dillmann, F. Mazaudier, and S Hoerle, "Advances in Understanding Atmospheric Corrosion of Iron. I. Rust Characterization of Ancient Ferrous Artifact Exposed to Indoor Atmospheric Corrosion," *Corrosion Science* 46 (2004), 1427-1428.

[22] For more information on some of these studies, M.C. Bernard and S. Joiret, "Understanding Corrosion of Ancient Metals for the Conservation of Cultural Heritage," *Electrochimica Acta* 54, no. 22 (September 2009): 5199–5205,; E. Burger et al., "In Situ Structural Characterization of Non-stable Phases Involved in Atmospheric Corrosion of Ferrous Heritage Artifacts," *Corrosion Engineering, Science & Technology* 45, no. 5 (October 2010): 395–399; H. Matthiesen and K. Wonsyld, "In Situ Measurement of Oxygen Consumption to Estimate Corrosion Rates," *Corrosion Engineering, Science & Technology* 45, no. 5 (October 2010): 350–356.

suggested that active corrosion was probable. Thus, micro-Raman spectroscopy could potentially result in a more complete understanding of the corrosion layer.[23]

Similar to many of the other studies attempting to classify the corrosion patterns in historic iron, all of the objects tested here demonstrated the presence of multiple corrosion products. Likely, this points to the fact that each of the objects at Fort Sumter hosts a complex matrix of corrosion products. When coming from the soil, other studies have largely classified corrosion patterns as having a mix of goethite, magnetite, and maghemite.[24] However, if soils were found to have higher chlorine content, then it was not atypical to find matrices that included akaganéite.[25] Interestingly, at Fort Sumter, goethite was only found along the pieces that have been sheltered in the Right Face from the climatic elements for the longest period of time. The rest, as will be explained, appear to represent a complex and actively corroding layer.

A common corrosion product, goethite (α-FeOOH) was found on the objects that were the least exposed to weather and atmospheric changes: the pintle and traverse rails. Goethite is generally believed to be the primary corrosion product formed in many conditions as well as being found on objects that have been entirely converted to corrosion product.[26] Goethite was found on the objects at Fort Sumter that were partially sheltered from exposure to the effects of rain and wind. These pieces had a more noticeable thick layer of corrosion product that almost completely covered the objects. While these pieces are outdoors and subjected to the highs and lows of temperature changes as well as the extremes of atmospheric relative humidity, the casemates provide a protective covering over the objects preventing them from being exposed to other climate phenomena such as wind and rain. Likely, the shelter causes the corrosion patterns to more closely emulate indoor corrosion patterns. In these studies, it was more common to find goethite closest to the

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[23] The protocol and reasons for the objects selected for further testing is explain in more detail in Chapter 3.

[24] D. Neff et al., "Corrosion of Iron Archaeological Artifacts in Soil: Characterization of the Corrosion System," *Corrosion Science* 47, no. 2 (February 2005), 530.

[25] Neff, "Corrosion of Iron Archaeological Artifacts", 530.

[26] Scott, 35.

Object	Corrosion Product
Tie-rod	Lepidocrocite
	Lepidocrocite
	Lepidocrocite
	Lepidocrocite
	Lepidocrocite
	inconclusive
	Lepidocrocite
	Lepidocrocite
	akaganeite
	Lepidocrocite
Left Flank Lintel	inconclusive
	akaganeite
	Lepidocrocite
	Lepidocrocite
	akaganeite/lepidocrocite
	akaganeite/lepidocrocite
	akaganeite/lepidocrocite
	Lepidocrocite
	akaganeite/lepidocrocite
	akaganeite
A-14 Traverse Rails	inconclusive
	goethite
	goethite
	goethite
	inconclusive
Gorge Wall Lintel	Lepidocrocite
	inconclusive
	akaganeite
	Lepidocrocite
	Lepidocrocite

Object	Corrosion Product
B1-3 Pintle	inconclusive
	Lepidocrocite
	Lepidocrocite
	goethite
	goethite
	Lepidocrocite
	lepidocrocite
	Lepidocrocite
	goethite
	goethite
	lepidocrocite
	inconclusive
	inconclusive
	lepidocrocite
A-14 Pintle	akaganeite
	goethite
	inconclusive
	lepidocrocite
	akaganeite/lepidocrocite
	goethite
	akaganeite
	lepidocrocite
	goethite
	akagneite

Table 7.2 Types of corrosion products found on Civil War Era iron at Fort Sumter National Monument

metallic core with marbling of lepidocrocite. Goethite was considered to be an isolating and inert corrosion layer while lepidocrocite was assumed to be the active phase.[27]

Lepidocrocite (ϒ -FeOOH) was the most commonly found corrosion product on the iron pieces at Fort Sumter. Lepidocrocite is considered to promote a lesser corrosive reaction than akaganéite. However, its presence still indicates that active corrosion is occurring.[28] At Fort Sumter, the lepidocrocite was found on all objects. Most of the testing was done on exposed parts of the iron objects. However, two of the pieces, the lintel and tie-rod from the Left Flank fireplace, had been removed prior to testing and samples were able to be taken from areas that previously were embedded in the masonry. The finding of lepidocrocite on these pieces suggests that there was significant water absorption and retention on the embedded iron by the masonry to allow for lepidocrocite's formation.

Akaganéite (β-FeOOH) is typically considered to signal that extremely active corrosion is occurring. Associated with chlorine-rich environments, akaganéite's chemical formula does not reflect its connection to chloride. Akaganéite forms through the oxidation of the acidic ferric chloride ($FeCl_2$) solution. Ferric chloride solutions are often commonly referred to as *weeping* on archaeological iron.[29] However, akaganéite is assumed to form only when sufficient chloride ions are present on the surface; otherwise, goethite or lepidocrocite will form. Less dense in structure than goethite, washing techniques have been found to lessen the influence of the chlorides that can be trapped in the tunnel like structure of akaganéite, although it is unlikely to completely remove all chlorides from the iron.[30]

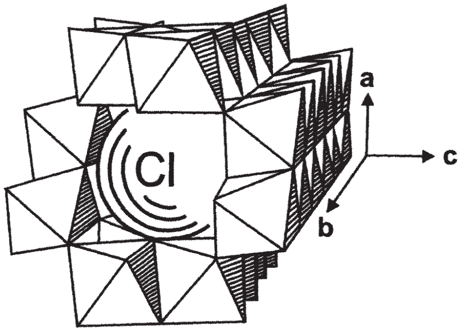

Figure 7.9 Idealized model of akaganéite with opening in center allowing for embedded chlorine. (from Selwyn, 1999)

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[27] Dillmann, "Advances in Understanding Atmospheric Corrosion," 1426.
[28] Demoulin, "Evolution of Corrosion of Iron," 3171; Scott, 37.
[29] Selwyn, "Corrosion of Excavated Archaeological Iron," 225.
[30] Scott, 37; Néstor G. González et al., "Hunting Free and Bound Chloride in the Wrought Iron Rivets from the American Civil War Submarine H. L. Hunley," *Journal of the American Institute for Conservation* 43, no. 2 (July 1, 2004), 161–174.

It was anticipated that akaganéite would likely be found on the outdoor objects at Fort Sumter as XRF testing showed the presence of chlorides on all objects. Largely protected from wind, rain, and the bulk of visitor impact, the pintle tongue in casemate B1-3 and the front traverse rails in casemate A-14 did not demonstrate the presence of akaganéite though all other objects did. This is not to say that akaganéite is not present on those objects. Further testing using Energy Dispersive Spectroscopy (EDS) showed the presence of chlorine on the B1-3 pintle tongue and A-14 traverse rail suggesting that the presence of akaganéite is likely. Further analysis could prove that it is present, but at the time of this study no considerable amounts were found.

Spectrum	**C**	**O**	**Na**	**Mg**	**Al**	**Si**	**S**	**Cl**	**K**	**Ca**	**Fe**
Spectrum 1	6.05	37.88	3.7	1.03	0.2	1.31	0.09	2.52	0.08	3.32	43.82
Spectrum 2	6.61	36.59	6.59	1.1	0.48	2.59	0.07	4.75	0.16	3.44	37.62
Spectrum 3	5.71	35.25	6.87	1.14	0.48	1.29	0.05	4.7	0.08	3.45	40.98
Spectrum 4	8.18	36.5	4.48	1.11	0.59	3.9	0.15	3.64	0.25	5.44	35.77
Spectrum 5	8.86	38.17	6.08	0.19	1.09	5.29	-0.02	4.3	0.12	0.88	35.04
Spectrum 6	6.8	43.67	1.6	0.87	0.09	0.7	0.04	1.07	0.05	11.97	33.14
Spectrum 7	5.31	33.92	2.37	1.37	0.41	2.03	0.05	1.5	0.12	1.18	51.74
Spectrum 8	5.59	41.41	1.48	0.38	0.27	0.94	0.1	0.92	0.08	0.77	48.07
Spectrum 9	9.53	34.55	1.89	0.24	0.21	1.56	0.05	0.95	0.08	0.93	50.02
Spectrum 10	12.56	40.57	1.98	0.18	1.18	3.42	0.04	0.6	0.09	0.84	38.54
Mean	7.52	37.85	3.7	0.76	0.5	2.3	0.06	2.49	0.11	3.22	41.47
Std. deviation	2.29	3.17	2.16	0.46	0.37	1.49	0.04	1.7	0.06	3.47	6.62
Max.	12.56	43.67	6.87	1.37	1.18	5.29	0.15	4.75	0.25	11.97	51.74
Min.	5.31	33.92	1.48	0.18	0.09	0.7	-0.02	0.6	0.05	0.77	33.14

Table 7.3 Energy Dispersive Spectroscopy (EDS) results of sample from A-14 Pintle

Spectrum	C	O	Na	Si	S	Cl	Fe
Spectrum 1	12.58	23.52	0.2	0.09	0.04	0.63	62.93
Spectrum 2	8.74	29.28	0.16	0.2	0.14	0.8	60.68
Spectrum 3	6.04	31.66	0.13	0.18	0.15	0.77	61.08
Spectrum 4	7.51	30.22	0.23	0.19	0.14	0.88	60.83
Spectrum 5	7.84	31.94	0.17	0.41	0.14	1.26	58.25
Spectrum 6	8.04	35.16	0.19	0.15	0.09	0.67	55.7
Spectrum 7	8.07	31.78	0.15	0.16	0.15	0.94	58.73
Spectrum 8	6.44	41.91	0.12	0.16	0.14	1.85	49.38
Spectrum 9	8.75	38.15	0.31	0.21	0.33	1.93	50.32
Spectrum 10	5.24	31.09	0.07	0.13	0.15	0.74	62.58
Mean	7.92	32.47	0.17	0.19	0.15	1.05	58.05
Std. deviation	2.01	5.02	0.06	0.08	0.07	0.48	4.82
Max.	12.58	41.91	0.31	0.41	0.33	1.93	62.93
Min.	5.24	23.52	0.07	0.09	0.04	0.63	49.38

Table 7.4 Energe Dispersive Spectroscopy (EDS) Results of sample from B1-3 Pintle

CHAPTER EIGHT
THE COMBINED INFLUENCES OF FORT SUMTER'S IRON CORROSION

Fort Sumter National Monument has identified many of its Civil War era iron features as character-defining objects. For the park, the loss of these objects would diminish the historic importance of the fort and the visitor experience. It is accepted that the iron features of the fort have shorter lifespans than the surrounding brick masonry. Their longevity should be better understood before appropriate and sensitive conservation treatments can be implemented. The past four chapters have each been devoted to the origin or one influence on the corrosion of the historic iron. While each of these chapters could easily be expanded into its own study, it is more important to understand how each aspect may be detrimental or beneficial to a specific feature.

This research will lead to a better understanding of what was the most influential aspect of corrosion on the fort's iron. The atmosphere, surrounding material, and the compositional characteristics of iron all influence an object's unique corrosion pattern. A comprehensive understanding of the mechanisms that lead to an architectural iron object's failure will potentially develop better and less invasive methods to help ensure the material integrity of historic iron. The pattern of corrosion is rarely a result of one factor being more influential than all others. As buildings age, the structure can generally be assumed to go through periods of maintenance, neglect, and renovations or rehabilitation. An earthquake can introduce a crack in a wall that will allow for the ingress of moisture to structural supports. Even if the crack is later fixed, the previous interaction with water from the crack's exposure will affect an object's corrosion pattern long into the future.

All structures are dynamic. Conditions change; they are not static. Atmospheric changes (airborne impurities, relative humidity, temperature) influence an object's corrosion both in the past and present. An object that was originally intended to be embedded completely in masonry might over time become exposed to a variety of conditions. For example, if a flood occurs, the surrounding masonry will likely become saturated and soluble salts can travel to the interior or the masonry. During the flood, the embedded iron will likely begin to corrode. As flood waters recede and the structure dries, the embedded iron may stabilize but the soluble salts will remain along the interface between the corrosion products and the iron (i.e. corrosion interface). As the building ages, settlement may cause cracking to occur and re-expose embedded iron that has not been in direct contact with the atmosphere in decades. The sudden change in exposure can re-introduce the needed moisture levels and reactivate the electro-chemical corrosion process while the chlorides remaining from the flood may exacerbate rapid and destructive corrosion mechanisms.[1]

The surrounding materials themselves can influence the corrosion rate of embedded metal. Granite, with its low porosity and high strength can help encapsulate iron and prevent oxygen, moisture, and salts from saturating the iron. On the other hand, lime-based mortar is highly porous and its inclusion in an otherwise impermeable masonry structure can allow for the introduction of higher levels of moisture that promote a more aggressive corrosion rate. In the same way, cracking caused by expansive corrosion can accelerate corrosion rates by allowing the moisture and salts to better access the embedded iron.

Lastly, the history and composition of the metal itself can often dictate how an architectural feature will corrode. Cast iron, for instance tends to pit and corrode at points of imperfection in the casting. Wrought iron can corrode along the slag lines allowing for greater material loss as the expansive corrosion products force the original metallic core to separate from itself. Additionally, the instability and porosity of the corrosion products can potentially influence the corrosion rate.

The reality is that the corrosion rate of an individual object is influenced by a countless number of variables. At Fort Sumter it is possible that some objects are more heavily influenced by one aspect of the corrosion mechanism than others. For example, the

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[1] Studies examining the corrosion of recently excavated archaeological iron can help describe this phenomena in further detail. L. S. Selwyn, P. J. Sirois, and V. Argyropoulos, "The Corrosion of Excavated Archaeological Iron with Details on Weeping and Akaganéite," *Studies in Conservation* 44, no. 4 (January 1, 1999): 217–232, doi:10.2307/1506652; S. Turgoose, "Post-Excavation Changes in Iron Antiquities," *Studies in Conservation* 27, no. 3 (August 1, 1982): 97–101, doi:10.2307/1506144; David Watkinson, "Degree of Mineralization: Its Significance for the Stability and Treatment of Excavated Ironwork," *Studies in Conservation* 28, no. 2 (May 1, 1983): 85–90.

pintle tongues, due to their suspended placement with the casemates appear to be most heavily influenced by atmospheric factors. In others, such as the Left Flank tie-rod, the masonry appears to have the largest impact in the failure of the piece. However, masonry is not always detrimental to the iron. The granite surrounding the pintles seems to be protecting them from destructive chlorides that would otherwise accelerate the corrosion of the pintles. The following pages will attempt to explain the influences that are causing the surveyed Civil War era ironwork to corrode.

Influences of corrosion on Fort Sumter's historic iron

To classify the primary influence of the corrosion process for each item would be to overlook the complex processes that occur in outdoor and exposed ferrous objects. In the end, the unique conditions of each object on site should be taken into account in order to develop a comprehensive understanding of the corrosion pattern of each object.

Traverse Rails

The remaining traverse rails at Fort Sumter are in radically different conditions. Historically, the traverse rails were anchored in a granite plinth by wrought iron bolts encased in a lead footing. An asphalt mastic applied to the underside of the rails prevented the accumulation of water beneath the rail. Additionally, archival research suggests that all the traverse rails came from the same manufacturer in Watervilet, NY and were installed at roughly the same time.[2] Today, the traverse rails along the Left Face are broken and many are missing all or part of the rail. The bolts that anchored the rails into the granite base often remain in

Figure 8.1: Traverse rails in Right Face with no visible paint layers. (photo by author)

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[2] For a full discussion on the history of the traverse rails, see Chapter four.

place where the original iron rail is gone, or has been removed due to fragility of the artifact or safety concerns. On the other hand, of the traverse rails in the sheltered Right Face many remain present but are encapsulated in a corrosion layer. Settlement of the granite bases in both casemates appears to have created depressions in the casemate floors that allowed dirt, debris, and water to accumulate against the traverse rails. The traverse rails in the Right Face show no signs of previous paint campaigns though the Left Face traverse rails have previously been painted multiple times.

The composition of the iron appears to have little influence in the rate of corrosion of the traverse rails as the manufacturers are the same for each piece. However, there are several factors that could contribute to the different conditions of the rails. First, the level of exposure between the Left and Right Face is believed to play a large role in the material loss of the rails. In the Right Face, the rails are covered and largely protected from wind and rain by Battery Huger and the casemate vaults. However, during the winter months, there is almost a continual layer of condensation on the iron rails, pintle tongues, and cannons. This suggests that the iron ordnance in the Right Face would be in the highest danger of material loss due to the extended surface relative humidity.

Visual analysis shows that more aggressive corrosion of the Right Face ordnance may not be occurring. The Left Face traverse rails, while not covered in a thick corrosion product layer, are nonetheless missing large portions of the original material. This suggests that while the humidity level may be higher in the Right Face, rain and wind are washing away the corrosion layer on the Left Face rails at Fort Sumter. Additionally, the rails that are sheltered from the effects of weather conditions show little evidence of akaganéite formation. Chloride levels, while present on the surface, may not be on the interface of the iron rail in a large enough concentration to allow for the formation of akaganéite.

While the surface chlorides are likely washed away in the rain, the removal of the existing corrosion layer causes the remaining iron to become fully exposed to airborne chlorides and moisture. This near constant exposure prevents the rails from forming a protective rust layer that would slow the corrosion process. Staining of the granite anchors is also noticeable suggesting that water is pooling in these areas and increasing the corrosion rate. As the bolts along the Left Face are in significantly better condition, it is assumed that the lead footing and granite base minimize the bolt's exposure to water and oxygen, slowing their corrosion rate.

Figure 8.2: Traverse Rails along Left Face showing staining from pooling water. (photo by author)

Pooling water, abrasion from surface containments and rain all appear to have a significant effect on the traverse rails. As a result, the traverse rails at Fort Sumter appear to be more affected by the settlement of the granite bases and high level of exposure of the rails than by the surrounding granite or asphalt mastic that adheres to the bottom. It is expected that the exposed rails will continue to corrode until there is little metal left unless interventive steps are taken.

Pintle Tongues

In some cases, certain aspects of the corrosion process can be discounted. The pintle tongues, which are part of the fort's ordnance, are suspended from the cast iron pintles, not embedded in the surrounding masonry; thus, it is unlikely that the surrounding masonry has a significant influence on the objects' corrosion. The majority of the pintle tongue is sheltered by two granite lintels, and it is probable that the additional shelter protects the majority of the piece from aggressive climatic conditions. Much like the traverse rails, the pintle tongues were installed around 1850. They are believed to come from the same or a similar manufacturer in Watervilet, NY.[3]

Corrosion was noted to occur along the slag lines of the pintle tongues as they consist of rolled wrought iron. At some point (whether it is from visitor impact or from

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[3] Again, for further information regarding the history of Fort Sumter's ordnance see Chapter four.

Figure 8.3: A-19 Pintle showing corrosion along slag lines. (photo by author)

a defect in the manufacturing) the pintle tongues break fairly consistently at the point where the plate recesses into the casemate wall. The pintle tongues that remain intact are in varying stages of corrosion. Though the surviving pintle tongues are more sheltered from rain and wind than their broken counterparts. The exception to this pattern of failure is the pintle tongue located along the Left Flank in the casemate labeled A-13. While the A-13 pintle tongue is intact, it is partially embedded in brick masonry. The rest of the pintle tongue is exposed to climatic changes and interference. It is possible that the surrounding masonry prevents the object from failing like the others because the failure point is supported and encapsulated by brick and mortar. It should be noted that as the pintle tongues remained buried for half a century, the sudden exposure during excavation has likely played a significant role in the condition and subsequent degradation of many of these objects.

Similar to the traverse rails, the different rate of corrosion for each object implies that it is unlikely that the composition of the metal is the most influential factor for the objects corrosion. Raman Spectroscopy showed that the two pintle tongues had similar but different corrosion products on the interface of the metal. The A-14 pintle tongue showed evidence of akaganéite at the interface of the pintle tongue and the corrosion product layer suggesting that active corrosion was occurring. The B1-3 pintle tongue showed no evidence of akaganéite. Of the two pintles tested, both are located in the sheltered Right Face. However, the A-14 casemate is exposed to climatic changes due to an open air space between its casemate vault and Battery Huger. The pintle tongue in this casemate was found broken, damaged, and corroded along the slag lines. On the other hand, the B1-3 pintle tongue was largely intact and retained its original dimensions, though there was a thick corrosion layer covering the surface. Likely, the B1-3 pintle tongue is protected from rain and wind due to its location deep within the casemate vaults.

It is possible that the difference in exposure to climatic fluctuations has induced varying stages of degradation. Some of the casemate vaults are standing, while others have collapsed which creates a variance in how weather conditions interact with the metal. The more sheltered pintle tongues are well-protected. Despite the fact that many are broken and split, they still retain their original shape instead of being obscured by expansive corrosion products, such as the tie-rod. Furthermore, many still have signs of early paint treatments, although it is believed that these paint layers date from the National Park Service's stewardship of Fort Sumter since 1948.

The more exposed pintle tongues are found to be in worse condition. Some are mineralized to the point of complete loss of the metal core. For these objects, the more sheltered the object, the more intact the pintle tongue is. This pattern implies that the climatic conditions of varying wind speed, rain, and the deposit rate of airborne salts have the largest influence on the longevity of Fort Sumter's pintle tongues. The B1-3 pintle tongue, while not washed by the rain, had an extended time of wetness, and showed significant chlorine levels during XRF analysis. Additionally, it showed less signs of material loss, possibly due to the fact that water was not taking away the corrosion product layer and exposing the remaining iron to the environment.

Pintles

Unlike the traverse rails and the pintle tongues, the cast iron pintles that are embedded in the granite lintels of the casemate walls are in particularly good condition.[4] Those that receive the most exposure to atmospheric changes show signs of pitting and stress cracking at the juncture of the rubble concrete and the iron pintle. However, the granite, with its low porosity, seems to largely protect the pintles from exposure to the

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[4] A more complete description of the pintle and pintle tongue can be found in Chapter four.

atmospheric agents. The pintles are hollow which appears to allow the moisture that forms in the interior of the pintle to drain thereby minimizing the time of wetness. These pintles appear to be in the best condition out of all Civil War era iron objects at Fort Sumter. All retain their original shape. There is little evidence of expansive corrosion products, which would potentially crack the surrounding masonry and allow for the ingress of water and airborne contaminants. Some of the pintles have never been fully excavated and remain filled with dirt and debris on the interior, although the overall condition appears to have few, if any, changes. These pieces with the filled dirt and debris show signs of staining in the dirt layer which indicates the possibility that the dirt is causing the iron to have a longer time of wetness and corrode more quickly than those pintles with no fill. In this case, it appears as if the low porosity of the granite has a beneficial influence on the embedded iron, but further investigation into this hypothesis is needed.

Figure 8.4: Filled cavity in pintle in casemate C-4. (photo by author)

Tie-Rod and Lintels

Archival research shows that both lintels are from different manufactures than the other iron ordnance at Fort Sumter. Thus, it is unlikely that the lintels are from the same time period. The Gorge Wall fireplace was believed to be constructed during the Civil War. The Left Flank fireplace dates from the 1870s-1880s reconstruction. The photographs taken in the 1950s during the excavation capture the fireplace in acceptable condition with no visible signs of cracking in the surrounding masonry due to expansive corrosion products.

Figure 8.5 Metal loss in Gorge Wall fireplace lintel. Photo by author.

Sixty years later, both lintels have corroded to the point of structural failure. Both lintels have uniform corrosion over the entire surface, but the highest visible material loss appears at the point where the iron lintel embeds itself in the mortar and brick. Raman Spectroscopy identified both akaganéite and lepidocrocite at this interface of the metal and masonry, indicating that both moisture and chlorine levels, acting in conjunction with differential aeration and exposure to oxygen, are promoting active corrosion processes.

There is crevice corrosion occurring in the joint of the lintel and fireplace and the adhesive nature of the mortar is causing the corrosion product to layer and force the fireplace to crack. Over the course of history, Fort Sumter has flooded and been buried in soils from the harbor which contain salts. While the fireplaces remained buried, corrosion is believed to have progressed slowly due to the limited levels of oxygen in the soil. After exposure to the atmosphere upon excavation, the lintels and tie-rod, with possible embedded chlorides were once again subjected to atmospheric oxygen and moisture and the active corrosion process restarted and gained momentum. Each time it rains or there is a prolonged condensation period, the fireplaces become near-saturated and the pores of the brick and mortar transport both water and chloride ions into the center of the masonry and to the embedded iron.

The tie-rod experienced a similar corrosion pattern as the lintels. Moisture from the rain penetrated the masonry surrounding the tie-rod allowing for soluble salts to be transported to the embedded iron. As the wrought iron tie-rod corroded, iron began to separate from the original surface and fall away. Those portions that were embedded were not able to separate which contributed to significant the cracking of the fireplace.

Figure 8.6 Mortar around emebbed tie-rod in Left Flank. (photo by author)

Interestingly, the influences that most affect the tie-rod and lintels appear to be a combination of both atmospheric conditions as well as the surrounding materials. The presence of iron oxyhydroxides on both the embedded and exposed portions of the lintels and tie-rods suggests that aqueous corrosion was occurring on both the exposed and embedded potions of the metal. As akaganéite was found on each piece, chlorides are assumed to have been transported from the air as well as through the pores in the brick and mortar to the interface of the metal creating a highly corrosive environment that caused relatively stable pieces to corrode and fail within sixty years after Fort Sumter's excavation.

Piping

After Colonel Anderson vacated Fort Sumter, confederate soldiers rebuilt and improved the fort. One of these improvements was the installation of a gasworks and gas lighting in the stairwells to illuminate the stairs and casemates. While the gasworks and much of the gas piping no longer exists at Fort Sumter, some fragments remain in the area that formerly held the stairs between the Gorge Wall and Left Flank. The fragments of the gas piping have undergone several attempts to protect them. One such attempt filled the cavity with a mortar, likely in an attempt to prevent moisture from collecting in the interior of the pipe.

The exact composition of the mortar that is in the center of the pipe is unknown, but it shows signs of being detrimental to the pipe. Along the length of the gouged brickwork, the mortar remains, though much of the original pipe no longer exists. The lower portion that is closest to the ground has the greatest physical integrity, but the mortar has expanded causing the weaker pipe to crack. In this situation, earlier conservation treatments believed that the atmospheric conditions were causing the iron to corrode and mitigation treatments were attempted. These treatments changed the primary influence on the corrosion pattern of the iron piping and caused significant damage that resulted in a higher rate of loss.


Figure 8.7 Gas pipiing fragments found along the Gorge Wall. (photo by author)

Door Hardware

The remnants of the cast iron door hardware found along the Gorge Wall are from the original magazine's iron door and casings that George Cullum designed to provide extra security in case of fire. Today, they bear very little resemblance to their original form as the magazine was damaged during the Union bombardment and buried. It is unknown if the door hardware suffered most of its material loss during the bombardment or after the exposure during the 1950s excavations. The excavations reports described all the ferrous objects found in this area as being melted and corroded into unrecognizable masses.[5] If an object was identified, the park documented the object and made note of it in the subsequent reports.

As the hardware was not discussed in the excavation reports, it is likely that the condition of these objects was found to be similar to their current status. The bombardment caused much of the Gorge Wall to catch fire and consequently destroyed much of the

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[5] One theory for the state of the objects found along the Gorge Wall was that the bombardment and subsequent fires caused all of the iron to fail. As the Confederate soldiers were more concerned with fortifying that wall, the iron was left untouched until the 1950s excavations.

structural iron. The remaining pieces were possibly able to stabilize as the fire was sufficiently hot enough to form hematite on the door hardware thus allowing the corrosion layer to transform into a more stable phase. Additionally, the majority of the hardware is embedded in masonry. The relatively sheltered nature of the hardware is believed to protect the pieces from the harshest exposures. The surrounding brick masonry shows no signs of cracking due to expansive corrosion.

Classifying iron conservation at Fort Sumter National Monument

All too often, it would be simpler to blame the corrosion of the significant ironwork on time and the instability of the iron in general. Iron corrosion is a much more complex and complicated process. For much of the history of this country, construction materials have been made locally with local materials. The result is that a wide range of materials have their own unique characteristics. These characteristics make it difficult to create standard solutions for the conservation of a building containing historic iron. Furthermore, historic iron can prove to be temperamental. Its inclination to revert to a mineralized state makes its degradation both unpredictable and erratic in the sense that the confluence of aspects that affect the corrosion process cannot be accurately and consistently predicted.

A one-size fits all prescription for iron conservation, with collective treatment recipes will fail. One set of solutions cannot respond to multiple causes or anticipate every reaction. Instead, it would be far more efficient and cost-effective in the long-term to approach a structure's historic iron object by object and develop a better understanding of the influences acting on the significant iron objects. A firm comprehension of the site specific characteristics, such as cycles of moisture and atmospheric contaminant levels can help the architectural conservator choose the most appropriate coating system and treatment plan for a historic iron feature. Additionally, a proper survey detailing factors such as the porosity levels and failures in masonry surrounding embedded iron can identify future problem areas.

For Fort Sumter National Monument, many of the pieces can be treated to ensure the longest period of material integrity. A routine inspection is vital to ensuring that potential problems and failures are identified early. Early identification will allow the park to take mitigating actions before the corrosion reaches a point where the stability of both the iron and the surrounding masonry are jeopardized to the degree where replacement is the only viable option.

CHAPTER NINE
DEVELOPING AN INFORMED TREATMENT PLAN

Iron's complex nature makes it difficult to develop a treatment plan for a historic structure or site that addresses both the metal's historical integrity and material longevity. Architectural iron, despite its role in maintaining structural and historic integrity, is an expensive and time-consuming aspect of a building's rehabilitation or restoration. Maintaining an original iron feature can prove to be over-whelming, time-consuming and costly. Often, the end result is that the most cost-effective treatment for a historic iron feature involves one of two options: paint or replace.

The goal of this study was to develop an understanding of the fort's unique conditions that were causing the Civil War Era ironwork at Fort Sumter to corrode and fail. Such a study will help the staff at Fort Sumter National Monument develop and implement minimally invasive, comprehensive and cost-effective treatments that will preserve the remaining iron fragments. Painting is an effective and efficient way to treat architectural iron objects, but it must be acknowledged that eventually iron will corrode to a point where it becomes a safety hazard and must be replaced. Fortunately, these are not the only options available to a site wishing to conserve the iron in their historic structures. As in so many other situations, the most effective treatment plan is to ensure proper and continual maintenance that will allow for an early, minimally-invasive, and less costly treatment of historic iron.

Generally, masonry is considered to be stable with minimal cleaning needed to maintain the overall condition of the brick or stone. While interventions will need to take place, a comprehensive conditions assessment and cyclical maintenance will be able to mitigate destructive forces and ensure masonry's longevity. Metal, by its very nature, requires more frequent assessment. A small crack in the masonry, if identified early, can be addressed and fixed before embedded metal begins to corrode and create larger problems. However, deferring maintenance while the failure is small will likely only result in more expense, loss of original material, and more invasive techniques in the future in order to remedy the problem. Over the course of this study, Fort Sumter National Monument, in conjunction with the Warren Lasch Conservation Center, began treating the fort's antebellum era ironwork. Many of these treatments will be discussed along with other treatment options as possible remedies that would be both cost-effective and minimally invasive.

The ironwork at Fort Sumter is in various states of degradation. Some, like the pintle tongue in casemate B1-3 are in remarkable condition and resemble their original state despite their age and exposure. Others, like the tie-rod and lintel in the Left Flank fireplace have corroded to the point of failure. There are few accepted methods believed to radically slow or stop corrosion. First, corrosion will not happen when the metal is not in contact with an electrolyte. Inhibiting corrosion can be done by either keeping the metal dry or implementing a barrier coating that hinders the electrochemical reaction. Secondly, corrosion can be stopped by excluding oxygen from coming in contact with the metal, either by coating or submerging it in an inert liquid. Thirdly, corrosion can be minimized if the cathode/anode contact is broken. Often this can be achieved by insulating two metals from each other, or by reversing the electrical potential of the cathode/anode. The reverse current is often used to provide sacrificial protection by applying a baser metal to a more noble metal, thereby allowing the sacrificial base metal to corrode and not the historic iron.[1] Unfortunately, for most architectural iron, other factors can hinder these methods. Any intervention should combine several facets that work in conjunction with each other to ensure the most successful treatment.

The Civil War era architectural and ordnance iron pieces at Fort Sumter are considered historically significant and important and require a comprehensive analysis of possible conservation treatments.[2] Any treatment should align with modern conservation ethics and be more sensitive to the historical importance of the pieces than other, less

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[1] Materials and Skills, 136.

[2] For a more in-depth discussion of classifying architectural character, please see the follow source. Lee H. Nelson, *Architectural Character: Identifying the Visual Aspects of Historic Buildings as an Aid to Preserving Their Character*, Preservation Brief 17 (Washington D.C.: United States Department of the Interior, National Park Service, Technical Preservation Services, 1988).

historically significant architectural pieces. A plan should focus on finding an acceptable balance between cost-effective maintenance treatments and more sensitive, but costly treatments. There are many published works that extensively detail methods to approach the conservation of architectural iron. These can and should be referenced for an overview of options.[3]

A maintenance plan should be developed that implements regular assessment, documentation, and cleaning policies. Ideally, the same person should assess the ironwork at the fort in order to ensure the most familiarity with the conditions of the objects. Particular attention should be made during the assessment to areas where moisture can become trapped and promote more aggressive corrosion. Photo documentation will allow the park to maintain a timeline of the historic iron's condition and help evaluate changes. High-risk objects, or those pieces that are considered most in danger of failure, should be inspected more frequently.

It is often easier to forgo regular monitoring of historic materials as a cost-cutting measure. However, regular housekeeping and maintenance can extend the life of the fort's historic iron in a cost-effective and efficient manner. The harsh climate of the fort means that surface chlorides and dust and dirt particles allow for extended times of wetness on the ironwork and promote a more rapid corrosion rate. Devoting the time and manpower to train staff in appropriate cleaning methods will lessen these destructive influences and potentially slow the rate of corrosion. Locations that will require particular attention are the tops of pintles and the traverse rails. These locations have shown to be prone to collect large amounts of grass and dirt. A simple brushing down would be sufficient to remove the dust and dirt particles without requiring further cleaning.

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[3] Sophie Martin Godfraind and Robyn Pender, eds., *Practical Building Conservation, Metals*, English Heritage (Farnham: Ashgate, 2012); Aylin Orbasli, *Architectural conservation : principles and practice* (Malden, MA: Blackwell Science, 2008); Repairs and Maintenance of Heritage Architecture International Conference on Structural Studies and C. A Brebbia, "Structural studies, repairs and maintenance of heritage architecture XI" (Southampton: WIT, 2009); John G Waite, *The Maintenance and Repair of Architectural Cast Iron*, Preservation Brief 27 (Washington D.C.: United States Department of the Interior, National Park Service, Technical Preservation Services, 1991).

If the routine inspection reveals that further intervention is needed, the main cause, or causes, for the iron's corrosion should be addressed before any conservation treatment is implemented. Therefore, if rain water is pooling or excessively washing the objects, the cause should be identified and corrected to ensure the best possible survival of the treatment. If masonry is cracking, rinsing the embedded metal with deionized water and a rust inhibitor and grouting or repointing would help prevent the further ingress of airborne contaminants. In the same way, if water is pooling at the base of an iron object causing staining and loss of material, the best way to extend the life of the metal is to divert the water source away from the historic metal.[4] Unfortunately, some of the mitigation attempts will undoubtedly prove to be costly, invasive, and will hinder the visitor experience. The creation of a hierarchy of significance would help determine both the need for interventive work as well as the cost-effectiveness of such a treatment. Once the need for further treatment is determined, the following options can be considered.

Coatings

Coatings are not always the most historically sensitive treatment for objects that would not originally have been painted; nevertheless, they are cost-effective methods for maintaining historic iron. A coating should be applied in a setting that can ensure proper coating and adhesion. Fort Sumter's location on an island makes this a difficult option because of the cost of transportation, size of the iron objects, and the effect removal would have on the surrounding materials. Thus, *in situ* treatments are considered to be the best option despite the fact that coating treatments will occur in adverse conditions.

Proper cleaning and prepping of the historic surface should be implemented before re-coating an object.[5] Prepping includes removing failed paint layers and rinsing the iron to remove surface contaminants. All forms of paint removal (chemical stripping, water-cleaning, grit/sponge blasting, and dry ice) should be explored to find the most effective

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[4] *Practical Building Conservation: Metals*, 179

[5] show treatment possibilities….

Modern Paints for Metalwork	
Advantages	**Disadvantages**
Alkyd	
easy to apply good decorative appearance resistance to salt spray, low cost can be formulated to give reasonable surface tolerance	usually requires multiple coats poor water immersion resistance moderate to poor chemical resistance poor solvent resistance not recommended for use on zinc
Acrylated Rubber, Vinyl, Chlorinated Rubber	
Good water resistance good resistance to salt spray fairly good weathering properities good chemical resistance flexible, with good adhesion between coats	brushing may leave visible lines too fragile for off-site application very poor solvent resistance require multiple coats fairly expensive
Water-Based Acrylic	
Low VOC	Relatively poor corrosion protection relatively expensive
Epoxy	
Properities can be fine-tuned very good resistance to salt spray very good alkali resistance moderate acid resistance very good solvent resistance tough when cured	loses gloss and color when exposed prone to chalking best appearance when sprayed two-pack systems, so can be difficult to hangle curing is temperature-dependent fairly expensive
Polyurethane	
very good weather resistance very good resistance to salt spray very good chemical resistance very good solvent resistance can be formulated to give reasonable surface tolerance tough good low-temperature curing good working properities, attractive	moderate water resistance (to immersion) retreatability may be poor depending on type two pack versions can be difficult to handle single pack versions are moisture-sensitive usually expensive
Zinc Silicate	
hard and abrasion-resistant generally good solvent resistance withstands imersion very good resistance to salt spray	very poor acid-alkali resistance two-pack can be difficult to handle difficult to overcoat spray application only high standard of surface prepartion required salts form on exterior exposure prone to cracking and pin-holing if over-applied
Other zinc-rich coatings	
strengths depend on binder	poor acid-alkali resistance salts form on exterior exposure high standard of surface prepartion required

Table 9.1 Modern paints for metalwork (after Practical Building Conservation: Metals, 187)

method before treatment. Additionally, there are many coating options available, and each should be explored for the most appropriate finish.

Unfortunately at this point in time, there is a discrepancy between applying coating systems that are effective and those that are historically sensitive. Historically, iron has been painted or treated. As time progressed, people have searched for better, less hazardous and longer lasting coatings, and many historic iron structures have lost their original historic coating. Unlike paint in historic houses, treatment of iron has traditionally involved blasting and cleaning, and there are few, if any, architectural pieces that have evidence of their original coatings. Original coatings may have been equally, or perhaps more effective, than modern treatments, but the products often included hazardous chemicals (lead paint) or invasive coating applications (electroplating). For this reason, these coatings are considered impractical and unusable today. [6] The result is that a conservator often is forced to make the decision between implementing a historically sensitive treatment or using a coating with a reversible and long application life. A shiny black iron cannon or fence is ubiquitous today. Historically, there were far more coatings options outside of glossy black paint.[7]

At Fort Sumter, the traverse rails along the Left Face were treated in August 2012 by cleaning and applying an epoxy/polyurethane coating. Due to the fragile nature of the remaining rails, the impracticality of controlling visitor traffic around the pieces, and their connection to historic masonry, it was decided that removing the rails and blasting to remove old paint and corrosion was not practical. Instead, the rails were cleaned and stripped of their paint by applying a chemical paint-stripper and hand-cleaning the rails. After washing the rails to slow flash-corrosion, they were primed and painted with an epoxy coating and polyurethane top-coat. Traverse rails would likely not have received a paint coating originally due to the abrasion from the cannon carriage. Instead, they had a layer of grease applied to the rails in order to ease movement of the cannon carriages. However,

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[6] Martin E. Weaver, *Conserving Buildings: Guide to Techniques and Materials*, Rev. ed (New York: Preservation Press, 1997), 197.

[7] David A Scott et al., "Ancient & historic metals : conservation and scientific research : proceedings of a symposium organized by the J. Paul Getty Museum and the Getty Conservation Institute, November 1991" (Marina del Rey, CA: Getty Conservation Institute, 1994), 201-202.

the epoxy coating was considered to be the most effective at withstanding both the harsh climate of the fort and visitor impact. As the rails are still attached to their granite blocks, it was impossible to completely coat the rails. As a result, corrosion is already appearing in locations where water pools at the fort and where the coating was imperfect.

Consolidation

In a different treatment, the cast-iron shells that are currently embedded in the masonry walls were treated in December 2012. These objects are unique for the fact that artillery shells were never intended to be embedded in masonry for the long-term. Due to their historical importance, it is essential that their placement be unchanged, and an *in situ* treatment was chosen as the best and least invasive conservation treatment. Unlike the wrought iron tie-rod, these shells do not serve a structural role. There is little evidence of cracking around the surrounding masonry due to the corrosion of the shells. Likely, this is due to the solid cast iron shell corroding differently than wrought iron. Therefore, there was little need to remove the shells. Each shell was rinsed with deionized water and a light corrosion inhibitor to remove surface chlorides and then consolidated.[8]

Using an epoxy resin, a consolidant is able to completely saturate and coat the metal thereby increasing its stability by breaking contact with outside contaminants. However, this treatment is considered irreversible due to the nature of the coating. While the object is stabilized, the object can never be further treated or tested. A consolidant acts as a last resort effort to conserve and protect an object.

Cathodic protection

The high surface relative humidity of many of the iron objects in the Right Face makes it unlikely that coatings will adhere properly and have a long-lasting effect. Currently, it appears as if the corrosion product layer is helping protect the iron in the Right Face

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[8] It was important to use deionized water as this water contains no contaminants to serve as an electrolyte and promote corrosion.

from surface containments. It would likely be both time-consuming and detrimental to the existing metal to entirely remove this layer. As the pintles and traverse rails cannot be removed without significant time and labor, a possible option for treatment of these pieces would be to implement a cathodic protection system.

Cathodic protection is not new and has been in use since 1824 in the form of protective copper sheathing on vessels. More recently, it is beginning to be implemented in Europe in order to protect embedded architectural iron elements.[9] Cathodic protection works by introducing a sacrificial anode that will create a predictable galvanic current. A less noble metal is introduced and forces the iron to become the cathode. Thus, when water comes in contact with the historic iron, the sacrificial anode will corrode before the iron.[10] For the cathodic protection system to function the anode must be connected to the historic metal to allow for a constant stream of electrons to flow, and it must sit in the same electrolyte as the historic metal.[11]

Cathodic protection is particularly useful when iron is in continuous contact with water, or it is completely embedded in masonry. This system has the potential to be particularly useful for the objects in the Right Face. When surface relative humidity levels reach a high point, the anode will allow the electro-chemical reaction to occur in a predictable manner; thereby, protecting the pintles and traverse rails with minimal intervention. Furthermore, the exposed portions of the pintles and traverse rails will allow a current to be set up with minimal interference to the historic masonry.

Subcritical Fluid Technology

Currently, most treatments focus on ways to slow and inhibit the corrosion process. The goal is not to stop the corrosion, as this usually is considered impossible, but rather to slow it. A newly developing technology using subcritical fluids is showing signs that in some cases corrosion can be stabilized and stopped. Sub-critical fluid technology works on

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[9] *Practical Building Conservation: Metals* ,191

[10] *Practical Building Conservation: Metals,* 192

[11] *Practical Building Conservation: Metals* 193.

the premise that high heat and pressure reduce the viscosity and density of liquids while increasing the diffusion rate, thereby allowing deeply embedded destructive chlorides to be removed from a metal object.[12] At the point of this study, the technology was size limited to objects that could fit within a forty liter chamber. While proving to be effective in stabilizing objects, subcritical fluid technology is still largely untested for architectural items. The necessity to remove the object from its original location makes this a treatment more practical for significant but removable architectural pieces, such as locks, hinges, and doorknobs.

Removal and Replacement

The last and often least desirable outcome for treatment of historic metal is removal and replacement of the object. It must be acknowledged and accepted that at some point in time, historic iron will have to be removed from its current location when it becomes unstable, unsafe and destructive to the surrounding material. This replacement is inevitable with all building material, but the lifespan of an iron feature is much shorter than brick, glass, or timber. When removal and replacement is necessary, there are several paths available for the architectural conservator.

Portions of the piece can be removed, replaced with a similar material and attached to the original material. The Secretary of Interior Standards Guidelines for Rehabilitation of Historic Properties requires that all replacements be visually distinct from the original. The simple act of attaching and fixing a part will allow a trained eye to differentiate between replacement and original parts. At other times, the level of degradation or need for structural support may require the entire iron piece to be removed and replaced.

When the decision is made to remove a historically significant iron architectural feature from a building, it must then be decided what to do with the removed material. Some cases may prove that the iron is in such a state of corrosion that there is little benefit

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[12] L. Nasansen, N. González, and S. Cretté, “The Subcritical Mass-Treatment of a Range of Iron Artifacts from Varying Contexts,” in *Asia-Pacific Regional Conference on Underwater Culture Heritage Proceedings* (Philippines, 2011).

to storing or conserving the feature. Other cases may prove that the features are too large to be effectively stored for any length of time and thus discarded. On the other hand, if available, smaller pieces should be conserved and stored in appropriate conditions in order to maintain the original fabric if it cannot be maintained *in situ*. A conservation treatment should still be implemented after removing and storing iron objects. Consolidation that involves impregnating the iron with epoxy resins is one option for treatment. Though this process is irreversible, it is able to encapsulate the iron and slow the corrosion process.

In the Fall of 2012, the park decided to implement this treatment for the tie-rod and lintel found in the fireplace along the Left Face at Fort Sumter. The tie-rod and lintel were corroding to the point that the structural stability of the entire fireplace was jeopardized. The tie-rod was causing cracking to travel the length of the fireplace. Additionally, the oxide jacking loosened two of the bricks that protected the tie-rod from direct exposure to condensation and rain. As the wrought iron bar corroded along the slag lines, corrosion was causing the bar to break apart and accumulation of lost metal was visible along the bottom of the fireplace.

In November 2012, before a conservation treatment could be implemented, the lintel broke at the point of connection between the masonry and the plate. The park and Warren Lasch Conservation Center worked together to remove the pieces because of their instability and replace them with stainless steel replicas. Before removal occurred, the remaining pieces were treated with an emergency consolidant to help prevent further material loss. The pieces were then removed by masons under the supervision of a conservator from the Warren Lasch Conservation Center and will be stored at the park's collection center. This treatment was chosen because of the advanced state of corrosion of the pieces as well as the damage they were causing to the surrounding masonry.

Future treatments

Much of Fort Sumter's Civil War era ironwork is in need of mitigation treatments. The fort's location means that the outdoor ironwork will always require a higher level of maintenance in order to preserve it for the long-term. This is not a unique problem to Fort Sumter; many other outdoor museums are grappling with the best way to treat and maintain historic material. For example, the Mystic Seaport Museum implemented a routine washing of the vessels' decks. Previously, the museum fought with teak decks that leaked each time it rained introducing excessive moisture in the depths of the vessel where mold and fungal growth encouraged rot. Instead of introducing new materials to stop the leaks that would possibly have destructive side effects, each day several shipwrights spend a few hours washing the decks with salt water. The end result allowed the original teak decking to swell naturally, and the leaks stopped without introducing new material. Additionally, the deck and vessels are inspected daily and any changes are noticed before a serious problem can occur. In this case, the museum considered it worthwhile to dedicate manpower to this easy task in order to best maintain the historic material.

Similar treatments could easily be implemented at Fort Sumter National Monument. Not only would such a treatment have the effect of both continual monitoring but also it would allow for maintenance to be performed that would mitigate corrosion influences before they have the chance to become serious problems. It is ultimately the decision of the park to decide which pieces are essential to the historical importance of the fort and should require more frequent monitoring and treatment.

The table to the left suggests several conservation approaches for the remaining Civil War era ironwork. Additionally, a risk level is assigned as a result of the previous research and each collection is described as high, medium, or low risk. The highest risk items are classified as such because of both their potential to destructively corrode as well as because of their historical importance. Low Risk items are classified as such because of their material loss, or earlier treatment. Suggested inspection intervals for cleaning and monitoring are given based on the risk level. Lastly, the treatments are suggestions based on their likely success as well as cost-effectiveness.

Looking at the table more closely, the piping for the gasworks, while historically important, is in such a state of degradation that any treatment would likely result in further destruction of the material. Evidence of the gas works still exists along the fort, and the original piping is unlikely to further enhance interpretation of the site. On the other hand, the pintle tongues in the Right Face are historically significant pieces. Their current placement means that cathodic protection is presently the most viable options for treatment. At this moment, the smaller size of the tank for subcritical fluid treatment restricts the ability to have any of the pieces treated with this method. However, the chloride levels and the presence of akaganéite on many of the pieces mean that subcritical fluid technology would be a viable option once reactor chamber size increases.

At the time of writing, these treatments were considered to be the most effective and least-invasive treatment possible. It should be noted however, that before any conservation treatment is implemented, a full conditions assessment should be completed for each object in order to determine the most appropriate treatment. As time progresses and the pieces continue to corrode, the most successful treatment will likely change and any future treatment should reflect those changes in order to ensure the best possible treatment.

Iron Object	Suggested Treatment	Urgency
Piping	Terminal Approach: Pipe appears to be irrevocably damaged by prior treatments.	Medium
Right Face Pintles	Clean and Monitor	Low
Pintle Tongues	Cathodic Protection	High
Left Face Pintles	Clean and Monitor	High
Left Flank Pintles	Clean and Monitor, coat exposed portions	High
Door Tred	Monitor, appears to be stable	Medium
Door Hardware	Monitor, appears to be stable	Low
Left Face Traverse Rails	coat	Medium
Right Face Traverse Rails		Medium
Tie-Rod	monitor, replaced in 2012	Low
Left Flank Lintel	monitor, replaced in 2012	Low
Gorge Wall Lintel	consolidate, repair surrounding mortar	High

Table 9.2 Possible treatment options for Fort Sumter National Monument ironwork

CONCLUSION
THE NEXT STEP

Fort Sumter's historic iron is merely a starting point in the discussion of creating better methods to understand architectural iron conservation. As more buildings from the late-nineteenth to early-twentieth century become classified as historic structures, it is essential that new, more comprehensive methods are developed to understand and approach what can be considered a relatively new material for the historic preservation field. For these modern buildings, iron and steel features are essential to understanding the structure and the longevity of the material should be as important as maintaining other features around it.

The intended outcome of this study was to determine if there was one, more influential, cause of corrosion in architectural iron. Superficially, masonry appears to have the strongest influence in the corrosion pattern of architectural iron. This influence can both be beneficial and detrimental. Granite appears to protect embedded iron (provided there are no cracks in the stone to allow for the ingress of moisture and salts). Lime mortars, on the other hand, with their high porosity and can introduce moisture and salts even though there are no failures in the masonry. It is the embedded iron pieces that appear to be in the highest level of degradation at Fort Sumter, lending proof to the influential status of masonry in the corrosion process. However, the result is ultimately more complicated than one material being more influential than all others. It is the combined effect of all influences (weather, material, manufacture) that ultimately determine the risk level of a historic iron feature.

Unfortunately, iron will continue to be a temperamental, time-consuming, and resource demanding material. The best way to ensure the longest survival time is to understand the degradation cycle of architectural iron. This understanding can help the conservator approach and implement a mitigation treatment before it becomes necessary to replace the historic material. The classification of the environment, surrounding material,

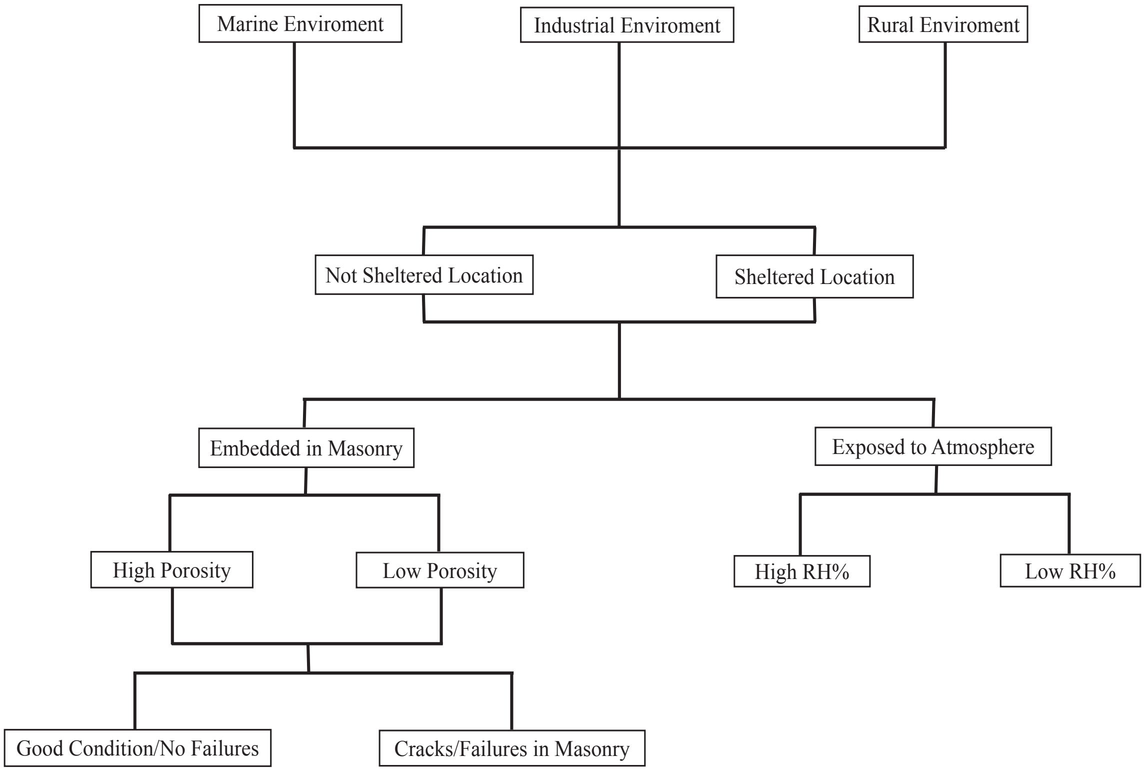


Figure 10.1 Aspects of iron corrosion (drawn by author)

and type of metal are all necessary to crafting a more informed approach to preservation that will respect original iron as a historic material worthy of its own treatment.

The following diagram (Figure 10.1) details and shows only a few influential aspects of atmospheric corrosion and the effect of the surrounding material. By progressing through the options, an enhanced awareness of the varying conditions that affect the corrosivity, or risk level, of historic iron can be formed. These influences are not isolated, and all are dependent on the others. Ideally, this will help shape maintenance plans by ensuring that some of the most influential aspects of iron corrosion are addressed in a timely manner.

For example, the pintle tongue in casemate B1-3 can be classified as being located in a marine environment, a sheltered location, and exposed to an atmosphere with a high relative humidity. The marine environment will typically signify that the overall corrosivity of the pintle tongue will be higher than if the pintle tongue was in a land-locked rural environment. However, the pintles, which are in the same atmospheric environment, are embedded in granite which has a low porosity and there are no cracks or failures in the masonry. These factors suggest that the pintles, while in a marine environment will corrode at a slower rate than the pintle tongues. Each of these factors is merely one part of an intertwined web of corrosion influences, and one aspect cannot be mitigated without first understanding that there are many influences to one object's corrosion pattern.

In the same way, this can be applied to structures outside of Fort Sumter. A cast iron fence in a rural environment that is exposed in a high relative humidity environment will corrode for different reasons than an embedded iron I-beam in an industrial environment. Approaching different objects in different environments in the same manner could result in a treatment that is more invasive and less reversible than necessary. Corrosion and the damage it causes to historic structures is an unavoidable part of its inclusion. Proper maintenance and early action, however, can do much to address the current causes that plague the field.

Developing a stronger comprehensive understanding of the history of the piece and its current state, as well as the corrosion influences on historic iron will help architectural conservators and the historic preservation field to take more sensitive approaches to ensure both the material and structural integrity of historic iron. Iron will degrade at a faster rate than brick, mortar or timber, thus early action to address the corrosion found on historic iron is essential to maintain the material integrity of a historic structure.

APPENDICES

APPENDIX A:

CIVIL WAR ERA IRON SURVERY

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Tie-rod

Location

Left Flank

Casemate

n/a

Date of Installation

1870-1880

Materials/Exposure:

Type of Metal	Surrounding Materials
wrought	brick/mortar

Solar Exposure	Object Exposure
direct sunlight	<50% exposure

Current Conditons:

Type of Corrosion	Priority Level	Risk Level
crevice, general	low, replaced in 2012	high

Conditions Comments

metal seperating and flaking off daily. mortar appears to be mixture of portland/rosendale, plates are spalling, paint failure rust jacking around entire surface, mortar preventing material to flake away causing jacking

Previous Treatment

emergency consolidation November 2012, removed and replaced with stainless steel replica in December 2012

Survey Images

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Traverse Rail (2)

Location

Left Flank

Casemate

A-4

Date of Installation

1850

Materials/Exposure:

Type of Metal	**Surrounding Materials**
rolled wrought	bluestone
Solar Exposure	**Object Exposure**
sunlight/shade	>50% exposure

Current Conditons:

Type of Corrosion	**Priority Level**	**Risk Level**
general, stress cracking	low, not original	medium

Conditions Comments

paint failure

Previous Treatment

not original

Survey Images

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Pintle

Location

Left Flank

Casemate

A-4

Date of Installation

1850

Materials/Exposure:

Type of Metal	Surrounding Materials
cast	concrete (brick rubble), granite
Solar Exposure	**Object Exposure**
shade	<50% exposure

Current Conditons:

Type of Corrosion	Priority Level	Risk Level
pitting, stress cracking	high	low

Conditions Comments

staining and spalling of surronding concrete, paint failure

Previous Treatment

painted, date unknown, likely not original

Survey Images

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Pintle

Location

Left Flank

Casemate

A-5

Date of Installation

1850

Materials/Exposure:

Type of Metal	Surrounding Materials
cast	concrete (brick rubble), granite
Solar Exposure	**Object Exposure**
shade	<50% exposure

Current Conditons:

Type of Corrosion	Priority Level	Risk Level
general, pitting, stress cracking	high	low

Conditions Comments

paint failure, jacking of surrounding masonry, open on bottom, cement made with brick and shell aggregate

Previous Treatment

paint, date unknown

Survey Images

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Lintel

Location

Left Flank

Casemate

Date of Installation

1870-1880

Materials/Exposure:

Type of Metal	**Surrounding Materials**
rolled wrought	brick/mortar
Solar Exposure	**Object Exposure**
direct sunlight	50% exposure

Current Conditons:

Type of Corrosion	Priority Level	Risk Level
crevice, general	low, replaced in 2012	medium

Conditions Comments

very little iron left, jacking face of firebox; mortar, charleston grey brick and yellow firebrick present around object, inability to wash causing build up then failure

Previous Treatment

emergency consolidation November 2012

Survey Images

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Damper/Cap

Location

Left Flank

Casemate

Date of Installation

1870-1880

Materials/Exposure:

Type of Metal	**Surrounding Materials**
cast	concrete (modern)
Solar Exposure	**Object Exposure**
shade	<50% exposure

Current Conditons:

Type of Corrosion	**Priority Level**	**Risk Level**
crevice, general	low	low

Conditions Comments

embedded around top of chimney, no direct exposure to sunlight/rain

Previous Treatment

none, not original

Survey Images

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Clip

Location

Left Face

Casemate

B-1

Date of Installation

unknown

Materials/Exposure:

Type of Metal	Surrounding Materials
wrought	brick/mortar

Solar Exposure	Object Exposure
direct sunlight	>50% exposure

Current Conditons:

Type of Corrosion	Priority Level	Risk Level
general, pitting	low	low

Conditions Comments

original purpose and date of installation is unknown

Previous Treatment

none visible

Survey Images

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Traverse Rail (1)

Location

Left Face

Casemate

B-2

Date of Installation

1850

Materials/Exposure:

Type of Metal	Surrounding Materials
rolled wrought	granite

Solar Exposure	Object Exposure
sunlight/shade	>50% exposure

Current Conditons:

Type of Corrosion	Priority Level	Risk Level
galvanic, general	medium	high

Conditions Comments

material loss, staining visible on granite

Previous Treatment

painted in August 2012 with a two-part epoxy/polyurethane combination

Survey Images

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Shutter Pins

Location

Left Face

Casemate

A-7

Date of Installation

unknown

Materials/Exposure:

Type of Metal	Surrounding Materials
wrought	sandstone
Solar Exposure	**Object Exposure**
sunlight/shade	50% exposure

Current Conditons:

Type of Corrosion	Priority Level	Risk Level
crevice, erosion, general	medium	high

Conditions Comments

staining around brownstone, material loss evident with corrosion occuring along slag lines

Previous Treatment

none visible

Survey Images

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Traverse Rails (2)

Location

Left Face

Casemate

A-8

Date of Installation

1850

Materials/Exposure:

Type of Metal

rolled wrought

Surrounding Materials

granite

Solar Exposure

sunlight/shade

Object Exposure

>50% exposure

Current Conditons:

Type of Corrosion

galvanic, general

Priority Level

medium

Risk Level

high

Conditions Comments

smaller rail corroded to only remaining pins, larger rails has light corrosion, some material loss, staining around granite caused by pooling of water

Previous Treatment

painted in August with epoxy/polyurethane combo

Survey Images

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Shell

Location

Left Face

Casemate

A-8

Date of Installation

1860

Materials/Exposure:

Type of Metal	**Surrounding Materials**
cast	brick/mortar
Solar Exposure	**Object Exposure**
shade	<50% exposure

Current Conditons:

Type of Corrosion	**Priority Level**	**Risk Level**
general, pitting	high	medium

Conditions Comments

deeply embedded shell/ little visible jacking

Previous Treatment

consolidated in December 2012

Survey Images

Object

Traverse Rails (2)

Location
Left Face

Casemate
A-9

Date of Installation
1850

Materials/Exposure:

Type of Metal	**Surrounding Materials**
rolled wrought	granite
Solar Exposure	**Object Exposure**
sunlight/shade	>50% exposure

Current Conditons:

Type of Corrosion	**Priority Level**	**Risk Level**
general, pitting	medium	high

Conditions Comments

staining around granite, material loss around edges

Previous Treatment

painted in August with epoxy/polyurethane combo

Survey Images

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Traverse Rails (partial)

Location

Left Face

Casemate

A-10

Date of Installation

1850

Materials/Exposure:

Type of Metal	Surrounding Materials
rolled wrought	granite

Solar Exposure	Object Exposure
sunlight/shade	>50% exposure

Current Conditons:

Type of Corrosion	Priority Level	Risk Level
galvanic, general, pitting	medium	high

Conditions Comments

missing large portion of rail

Previous Treatment

painted in August with epoxy/polyurethane combination

Survey Images

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Pintle Tongue

Location

Left Face

Casemate

A-10

Date of Installation

1850

Materials/Exposure:

Type of Metal	**Surrounding Materials**
cast	granite
Solar Exposure	**Object Exposure**
shade	>50% exposure

Current Conditons:

Type of Corrosion	Priority Level	Risk Level
general, stress cracking	low	low

Conditions Comments

fragment remaining, little original metal remaining

Previous Treatment

none visible

Survey Images

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Shell

Location

Left Face

Casemate

A-11

Date of Installation

1860

Materials/Exposure:

Type of Metal	Surrounding Materials
cast	brick/mortar
Solar Exposure	**Object Exposure**
sunlight/shade	50% exposure

Current Conditons:

Type of Corrosion	Priority Level	Risk Level
general	high	medium

Conditions Comments

material loss evident

Previous Treatment

consolidated in December 2012

Survey Images

Object

Pintle & Pintle Tongue

Location

Left Face

Casemate

A-11

Date of Installation

1850

Materials/Exposure:

Type of Metal	**Surrounding Materials**
cast	concrete (brick rubble), granite
Solar Exposure	**Object Exposure**
shade	50% exposure

Current Conditons:

Type of Corrosion	**Priority Level**	**Risk Level**
general, stress cracking	high	low

Conditions Comments

connection between pintle and tongue still visible, no visible jacking of masonry staining visible around granite, little metal remaining

Previous Treatment

none visible

Survey Images

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Traverse Rails (2)

Location

Left Face

Casemate

A-11

Date of Installation

1850

Materials/Exposure:

Type of Metal	Surrounding Materials
rolled wrought	granite

Solar Exposure	Object Exposure
sunlight/shade	50% exposure

Current Conditons:

Type of Corrosion	Priority Level	Risk Level
galvanic, general, pitting	medium	high

Conditions Comments

staining visible, middle portion of rails missing

Previous Treatment

painted in August with epoxy/polyurethane combo

Survey Images

Object

Traverse Rails (2)

Location

Left Face

Casemate

A-12

Date of Installation

1850

Materials/Exposure:

Type of Metal	Surrounding Materials
rolled wrought	granite

Solar Exposure	Object Exposure
shade	>50% exposure

Current Conditons:

Type of Corrosion	Priority Level	Risk Level
galvanic, general, pitting	medium	high

Conditions Comments

center of rails missing, staining visible around granite base

Previous Treatment

painted in August with epoxy/polyurethane combo

Survey Images

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Pipe

Location

Left Face

Casemate

A-12

Date of Installation

unknown

Materials/Exposure:

Type of Metal	**Surrounding Materials**
cast	brick/mortar
Solar Exposure	**Object Exposure**
sunlight/shade	50% exposure

Current Conditons:

Type of Corrosion	**Priority Level**	**Risk Level**
general	low	high

Conditions Comments

missing iron rails, staining of remaining asphalt mastic visible, unknown purpose and date of installation

Previous Treatment

none visible

Survey Images

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Shell

Location

Left Face

Casemate

A-12

Date of Installation

1860

Materials/Exposure:

Type of Metal	**Surrounding Materials**
cast	brick/mortar
Solar Exposure	**Object Exposure**
sunlight/shade	50% exposure

Current Conditons:

Type of Corrosion	**Priority Level**	**Risk Level**
general, pitting	high	high

Conditions Comments

material loss evident

Previous Treatment

consolidated in December 2012

Survey Images

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Traverse Rails (2)

Location

Left Face

Casemate

A-13

Date of Installation

1850

Materials/Exposure:

Type of Metal	Surrounding Materials
rolled wrought	granite

Solar Exposure	Object Exposure
sunlight/shade	>50% exposure

Current Conditons:

Type of Corrosion	Priority Level	Risk Level
general, pitting	medium	high

Conditions Comments

high material loss, staining around granite

Previous Treatment

painted in August with two-part epoxy/polyurethane combination

Survey Images

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Pintle Tongue

Location

Left Flank

Casemate

A-13

Date of Installation

1850

Materials/Exposure:

Type of Metal	Surrounding Materials
cast	brick/mortar, concrete (brick rubble)

Solar Exposure	Object Exposure
shade	>50% exposure

Current Conditons:

Type of Corrosion	Priority Level	Risk Level
general, pitting	high	medium

Conditions Comments

weakening and material loss at connection between iron and brick masonry

Previous Treatment

painted in August 2012 with two-part epoxy/polyurethane combination

Survey Images

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Door Hardware

Location

Salient Angle

Casemate

A-13/B-2

Date of Installation

1850

Materials/Exposure:

Type of Metal	**Surrounding Materials**
cast	brick/mortar, concrete (modern)
Solar Exposure	**Object Exposure**
shade	>50% exposure

Current Conditons:

Type of Corrosion	**Priority Level**	**Risk Level**
general	medium	high

Conditions Comments

high material loss

Previous Treatment

none visible

Survey Images

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Door Tred

Location

Gorge Wall

Casemate

Date of Installation

1850

Materials/Exposure:

Type of Metal	**Surrounding Materials**
cast	brick/mortar
Solar Exposure	**Object Exposure**
shade	<50% exposure

Current Conditons:

Type of Corrosion	**Priority Level**	**Risk Level**
general	high	medium

Conditions Comments

high material loss

Previous Treatment

none visible

Survey Images

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Door Hardware

Location

Gorge Wall

Casemate

n/a

Date of Installation

1850

Materials/Exposure:

Type of Metal	Surrounding Materials
cast	bluestone
Solar Exposure	**Object Exposure**
shade	<50% exposure

Current Conditons:

Type of Corrosion	Priority Level	Risk Level
general	high	low

Conditions Comments

high material loss likely result of damage from Civil War

Previous Treatment

none visible

Survey Images

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Pintle & Pintle Tongue

Location

Salient Angle

Casemate

B1-2

Date of Installation

1850

Materials/Exposure:

Type of Metal	**Surrounding Materials**
cast	concrete (brick rubble), granite
Solar Exposure	**Object Exposure**
shade	<50% exposure

Current Conditons:

Type of Corrosion	**Priority Level**	**Risk Level**
general, pitting	high	high

Conditions Comments

pintle filled in with unknown soil, no visible jacking

Previous Treatment

previous paint campaigns visible

Survey Images

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Traverse Rails (2)

Location

Salient Angle

Casemate

B1-2

Date of Installation

1850

Materials/Exposure:

Type of Metal	**Surrounding Materials**
rolled wrought	granite
Solar Exposure	**Object Exposure**
shade	>50% exposure

Current Conditons:

Type of Corrosion	Priority Level	Risk Level
general	medium	high

Conditions Comments

little wear, lots of corrosion

Previous Treatment

previous paint campaigns visible

Survey Images

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Pintle & Pintle Tongue

Location

Salient Angle

Casemate

C-4

Date of Installation

1850

Materials/Exposure:

Type of Metal

cast

Surrounding Materials

concrete (brick rubble), granite

Solar Exposure

shade

Object Exposure

50% exposure

Current Conditons:

Type of Corrosion	Priority Level	Risk Level
general	high	high

Conditions Comments

broken in half, no visible jacking, staining of surrounding rubble concrete

Previous Treatment

previous paint campaigns visible

Survey Images

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Pintle & Pintle Tongue

Location

Right Face

Casemate

B1-3

Date of Installation

1850

Materials/Exposure:

Type of Metal	**Surrounding Materials**
cast	concrete (brick rubble), granite
Solar Exposure	**Object Exposure**
shade	50% exposure

Current Conditons:

Type of Corrosion	**Priority Level**	**Risk Level**
general	high	high

Conditions Comments

still intact, no visible jacking

Previous Treatment

previous paint campaigns visible

Survey Images

Object

Traverse Rails (2)

Location

Casemate

B-3

Date of Installation

1850

Materials/Exposure:

Type of Metal	**Surrounding Materials**
rolled wrought	granite
Solar Exposure	**Object Exposure**
shade	50% exposure

Current Conditons:

Type of Corrosion	**Priority Level**	**Risk Level**
general	medium	high

Conditions Comments

still intact, pooling causing select material loss

Previous Treatment

previous paint campaigns visible

Survey Images

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Pintle & Pintle Tongue

Location

Right Face

Casemate

A-14

Date of Installation

1850

Materials/Exposure:

Type of Metal	Surrounding Materials
cast	concrete (brick rubble), granite

Solar Exposure	Object Exposure
sunlight/shade	50% exposure

Current Conditons:

Type of Corrosion	Priority Level	Risk Level
general, stress cracking	high	high

Conditions Comments

staining of rubble concrete

Previous Treatment

previous paint campaigns visible

Survey Images

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Travese Rails (2)

Location

Right Face

Casemate

A-14

Date of Installation

1850

Materials/Exposure:

Type of Metal	Surrounding Materials
rolled wrought	granite
Solar Exposure	**Object Exposure**
sunlight/shade	50% exposure

Current Conditons:

Type of Corrosion	Priority Level	Risk Level
general, pitting	medium	high

Conditions Comments

intact, thick corrosion product layer

Previous Treatment

previous paint campaigns visible

Survey Images

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Pintle & Pintle Tongue

Location

Right Face

Casemate

A-15

Date of Installation

1850

Materials/Exposure:

Type of Metal	Surrounding Materials
cast	concrete (brick rubble), granite

Solar Exposure	Object Exposure
sunlight/shade	50% exposure

Current Conditons:

Type of Corrosion	Priority Level	Risk Level
general, pitting	high	high

Conditions Comments

intact, visible pitting

Previous Treatment

previous paint campaigns visible

Survey Images

Object

Traverse Rails (2)

Location

Right Face

Casemate

A-15

Date of Installation

1850

Materials/Exposure:

Type of Metal	Surrounding Materials
rolled wrought	granite

Solar Exposure	Object Exposure
sunlight/shade	50% exposure

Current Conditons:

Type of Corrosion	Priority Level	Risk Level
general	medium	high

Conditions Comments

largely intact

Previous Treatment

none visible

Survey Images

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Pintle & Pintle Tongue

Location

Right Face

Casemate

A-16

Date of Installation

1850

Materials/Exposure:

Type of Metal	Surrounding Materials
cast	concrete (brick rubble), granite

Solar Exposure	Object Exposure
shade	50% exposure

Current Conditons:

Type of Corrosion	Priority Level	Risk Level
general, pitting	high	high

Conditions Comments

jacking/spalling of concrete occuring around metal interface, staining on top of granite lintel

Previous Treatment

previous paint campaigns visible

Survey Images

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Pintle & Pintle Tongue

Location

Right Face

Casemate

Date of Installation

1850

Materials/Exposure:

Type of Metal	Surrounding Materials
cast	concrete (brick rubble), granite
Solar Exposure	**Object Exposure**
shade	50% exposure

Current Conditons:

Type of Corrosion	Priority Level	Risk Level
general, pitting	high	high

Conditions Comments

spalling of stucco

Previous Treatment

previous paint campaigns visible

Survey Images

Object

Pintle & Pintle Tongue

Location

Right Face

Casemate

A-18

Date of Installation

1850

Materials/Exposure:

Type of Metal	Surrounding Materials
cast	concrete (brick rubble), granite

Solar Exposure	Object Exposure
shade	>50% exposure

Current Conditons:

Type of Corrosion	Priority Level	Risk Level
general, pitting, stress cracking	high	high

Conditions Comments

none

Previous Treatment

previous paint campaigns visible

Survey Images

Object

Traverse Rails

Location

Right Face

Casemate

A-18

Date of Installation

1850

Materials/Exposure:

Type of Metal	**Surrounding Materials**
rolled wrought	granite
Solar Exposure	**Object Exposure**
shade	50% exposure

Current Conditons:

Type of Corrosion	Priority Level	Risk Level
general, pitting	medium	high

Conditions Comments

portions missing

Previous Treatment

none visible

Survey Images

Object

Pintle & Pintle Tongue

Location
Right Face

Casemate
A-19

Date of Installation
1850

Materials/Exposure:

Type of Metal	**Surrounding Materials**
cast	concrete (brick rubble), granite
Solar Exposure	**Object Exposure**
shade	50% exposure

Current Conditons:

Type of Corrosion	Priority Level	Risk Level
general	high	high

Conditions Comments

broken, corrosion around slag lines visible

Previous Treatment

previous paint campaigns visible

Survey Images

Object

Traverse Rails (2)

Location

Right Face

Casemate

A-20

Date of Installation

1850

Materials/Exposure:

Type of Metal	**Surrounding Materials**
rolled wrought	granite
Solar Exposure	**Object Exposure**
shade	50% exposure

Current Conditons:

Type of Corrosion	**Priority Level**	**Risk Level**
general	medium	high

Conditions Comments

portions missing

Previous Treatment

none visible

Survey Images

Object

Pintle & Pintle Tongue

Location

Right Face

Casemate

A-20

Date of Installation

1850

Materials/Exposure:

Type of Metal	Surrounding Materials
cast	concrete (brick rubble), granite
Solar Exposure	**Object Exposure**
shade	50% exposure

Current Conditons:

Type of Corrosion	Priority Level	Risk Level
general, pitting	high	high

Conditions Comments

staining of rubble concrete, pintle tongue largely intact

Previous Treatment

none visible

Survey Images

Object

Pintle & Pintle Tongue

Location

Right Face

Casemate

B1-3

Date of Installation

1850

Materials/Exposure:

Type of Metal	**Surrounding Materials**
cast	concrete (brick rubble), granite
Solar Exposure	**Object Exposure**
shade	50% exposure

Current Conditons:

Type of Corrosion	**Priority Level**	**Risk Level**
general, pitting	high	high

Conditions Comments

intact, high humidity level, corrosion occuring along slag lines

Previous Treatment

previous paint campaigns visible

Survey Images

Fort Sumter National Monument
Civil War Era Metal Survey

Object

Lintel

Location

Gorge Wall

Casemate

n/a

Date of Installation

1860

Materials/Exposure:

Type of Metal	**Surrounding Materials**
rolled wrought	brick/mortar
Solar Exposure	**Object Exposure**
sunlight/shade	50% exposure

Current Conditons:

Type of Corrosion	**Priority Level**	**Risk Level**
crevice, general	high	high

Conditions Comments

jacking and material loss evident at brick/metal interface

Previous Treatment

none visible

Survey Images

Object

Piping

Location

Gorge Wall

Casemate

n/a

Date of Installation

1860

Materials/Exposure:

Type of Metal	**Surrounding Materials**
cast	other
Solar Exposure	**Object Exposure**
shade	50% exposure

Current Conditons:

Type of Corrosion	**Priority Level**	**Risk Level**
general	medium	high

Conditions Comments

essential non-existant, surrounded by mortar

Previous Treatment

previous fill in several parts, date unknown

Survey Images

APPENDIX B:

ANALYTICAL RESULTS

September 2012:
Fort Sumter National Monument
Daily High/Low Temperature & RH%

Date	Max: Temp, °F	Min: Temp, °F	**Temp. Swing**	Max: RH, %	Min: RH, %	**RH Swing**
9/11/2012	88.72	71.45	**17.27**	71.7	34.2	**37.5**
9/12/2012	88.72	68.36	**20.36**	81.8	43.8	**38**
9/13/2012	89.36	69.51	**19.85**	95.7	47.8	**47.9**
9/14/2012	90.29	69.56	**20.73**	92.1	54.9	**37.2**
9/15/2012	95.28	70.33	**24.95**	95.4	43.6	**51.8**
9/16/2012	94.66	73.77	**20.88**	94.3	46	**48.3**
9/17/2012	99.51	72.74	**26.78**	95.1	46.3	**48.8**
9/18/2012	94.42	77.12	**17.30**	93.2	58.2	**35**
9/19/2012	97.16	69.77	**27.39**	95	47.8	**47.2**
9/20/2012	89.04	67.29	**21.76**	88.8	53.2	**35.6**
9/21/2012	89.87	67.97	**21.90**	88	42.3	**45.7**
9/22/2012	95.09	71.88	**23.21**	91.6	47	**44.6**
9/23/2012	90.98	70.85	**20.14**	94.6	46.1	**48.5**
9/24/2012	86.62	65.79	**20.83**	86.6	34.8	**51.8**
9/25/2012	91.26	64.63	**26.63**	87.4	40.5	**46.9**
9/26/2012	90.10	67.20	**22.90**	89.8	49.8	**40**
9/27/2012	94.66	71.36	**23.30**	92.6	41.6	**51**
9/28/2012	101.31	70.80	**30.50**	93.7	38.7	**55**
9/29/2012	94.75	72.14	**22.62**	96.7	47	**49.7**
9/30/2012	82.13	72.14	**9.99**	93.2	71.4	**21.8**
Average:			**21.96**			**44.12**

October 2012:
Fort Sumter National Monument
Daily High/Low Temperature & RH%

Date	Max: Temp, °F	Min: Temp, °F	Temp. Swing	Max: RH, %	Min: RH, %	RH Swing
10/1/2012	97.50	74.77	22.73	99.2	57.4	41.8
10/2/2012	94.42	77.64	16.78	96.9	62.9	34
10/3/2012	94.80	73.82	20.98	96.5	49.9	46.6
10/4/2012	93.52	72.96	20.56	94.5	57.4	37.1
10/5/2012	92.10	72.14	19.97	93.3	42.7	50.6
10/6/2012	97.94	71.27	26.67	93.5	40	53.5
10/7/2012	96.97	71.79	25.18	98.8	51.3	47.5
10/8/2012	77.77	55.95	21.82	99.9	77.3	22.6
10/9/2012	73.73	55.78	17.96	100	59.3	40.7
10/10/2012	85.62	55.69	29.93	95.7	45	50.7
10/11/2012	82.75	60.13	22.62	92.8	36.9	55.9
10/12/2012	90.42	61.38	29.05	87	35.9	51.1
10/13/2012	79.88	61.12	18.76	88.9	52.9	36
10/14/2012	89.13	61.93	27.20	94.5	44	50.5
10/15/2012	90.15	69.26	20.89	95.6	58.5	37.1
10/16/2012	86.03	57.89	28.14	79.7	30.8	48.9
10/17/2012	79.04	61.63	17.41	84.8	53	31.8
10/18/2012	91.12	66.94	24.18	97.3	53.8	43.5
10/19/2012	90.52	63.86	26.66	97.2	24.4	72.8
10/20/2012	87.48	59.36	28.13	85.1	27	58.1
10/21/2012	85.58	56.60	28.98	78.7	32	46.7
10/22/2012	83.96	56.64	27.32	79.9	29.1	50.8
10/23/2012	85.89	59.83	26.06	94.4	43	51.4
10/24/2012	89.22	65.36	23.87	97	46.8	50.2
10/25/2012	85.80	69.13	16.67	96.2	56.6	39.6
10/26/2012	80.01	67.93	12.08	97.2	61	36.2
10/27/2012	69.73	64.76	4.97	99.2	79.7	19.5
10/28/2012	75.59	62.96	12.63	82.9	52.6	30.3
10/29/2012	68.40	50.97	17.43	77.8	38.8	39
10/30/2012	64.50	47.24	17.26	70.4	36.8	33.6
10/31/2012	71.32	45.81	25.51	61.3	25.6	35.7
Average:			**21.88**			**43.35**

November 2012:
Fort Sumter National Monument
Daily High/Low Temperature & RH%

Date Time	Max: Temp, °F	Min: Temp, °F	Temp. Swing	Max: RH, %	Min: RH, %	RH Swing
11/1/2012	70.42	48.72	21.70	69.1	26.4	42.7
11/2/2012	81.29	49.74	31.55	88	26.8	61.2
11/3/2012	76.85	52.42	24.43	92.2	25	67.2
11/4/2012	89.09	59.06	30.03	99	48.1	50.9
11/5/2012	73.26	52.20	21.05	100	37	63
11/6/2012	61.85	45.49	16.36	96.5	60.5	36
11/7/2012	60.05	42.11	17.94	92.6	51.4	41.2
11/8/2012	70.93	42.71	28.22	97	30.8	66.2
11/9/2012	76.81	46.66	30.15	89.8	25.3	64.5
11/10/2012	83.60	50.80	32.80	98.1	21.6	76.5
11/11/2012	81.55	55.17	26.39	97.8	53	44.8
11/12/2012	87.07	60.69	26.38	98.2	50.6	47.6
11/13/2012	90.06	54.43	35.63	97.6	49.4	48.2
11/14/2012	54.69	48.72	5.97	97.4	81.7	15.7
11/15/2012	52.77	44.63	8.14	100	85.9	14.1
11/16/2012	55.99	46.80	9.20	99.8	83.5	16.3
11/17/2012	58.80	44.49	14.31	89.7	67.5	22.2
11/18/2012	54.30	49.12	5.18	100	81.7	18.3
11/19/2012	60.69	52.51	8.18	100	82.9	17.1
11/20/2012	64.59	48.54	16.05	98.6	71.8	26.8
11/21/2012	67.76	47.47	20.29	98.6	49.4	49.2
11/22/2012	51.76	44.81	6.96	85.9	71.6	14.3
11/26/2012	73.65	47.78	25.86	93.7	28.4	65.3
11/27/2012	66.69	46.71	19.98	98.5	61	37.5
11/28/2012	67.29	45.53	21.75	100	50.7	49.3
11/29/2012	66.30	42.20	24.10	88.7	46.9	41.8
11/30/2012	74.12	47.56	26.56	97.4	53.2	44.2
			20.56			**42.30**

December 2012:
Fort Sumter National Monument
Daily High/Low Temperature & RH%

Date Time	Max: Temp, °F	Min: Temp, °F	Temp. Swing	Max: RH, %	Min: RH, %	RH Swing
12/1/2012	65.66	53.08	12.58	96.9	69	27.9
12/2/2012	76.81	55.99	20.82	100	64.3	35.7
12/3/2012	83.11	53.91	29.20	100	56.4	43.6
12/4/2012	79.04	58.24	20.80	98.9	60.8	38.1
12/5/2012	78.65	53.99	24.65	100	55.8	44.2
12/6/2012	64.72	53.34	11.38	97.3	71.4	25.9
12/7/2012	67.16	53.21	13.95	98	72.4	25.6
12/8/2012	76.55	52.51	24.04	100	58.5	41.5
12/9/2012	77.29	55.82	21.47	100	68.2	31.8
12/10/2012	74.55	60.86	13.69	100	73.7	26.3
12/11/2012	73.95	61.21	12.74	100	79.3	20.7
12/12/2012	61.38	46.97	14.40	100	92.6	7.4
12/13/2012	49.56	43.76	5.80	100	89.2	10.8
12/14/2012	68.83	42.16	26.67	98.3	48.3	50
12/15/2012	61.12	50.75	10.37	100	73.2	26.8
12/16/2012	74.47	53.69	20.78	100	73.8	26.2
12/17/2012	70.63	59.53	11.10	100	82.2	17.8
12/18/2012	70.93	51.50	19.43	100	39.4	60.6
12/19/2012	75.25	47.20	28.05	98.7	37	61.7
12/20/2012	75.25	49.16	26.09	100	65.3	34.7
12/21/2012	61.68	42.94	18.74	99.2	43.4	55.8
12/22/2012	62.32	38.04	24.28	76.8	25.5	51.3
12/23/2012	62.88	38.18	24.70	89.1	33.7	55.4
12/24/2012	68.48	46.53	21.96	98.9	48.9	50
12/25/2012	63.48	52.03	11.45	100	79.8	20.2
12/26/2012	70.63	44.31	26.32	100	64.5	35.5
12/27/2012	63.73	38.08	25.65	89.6	45.9	43.7
12/28/2012	62.96	38.89	24.07	94.8	66.3	28.5
12/29/2012	63.39	44.86	18.53	100	65.8	34.2
12/30/2012	57.42	36.51	20.92	85.6	37.7	47.9
12/31/2012	67.84	37.99	29.85	94.9	42.2	52.7
			19.82			**36.53**

January 2013:
Fort Sumter National Monument
Daily High/Low Temperature & RH%

Date Time	Max: Temp, °F	Min: Temp, °F	Temp. Swing	Max: RH, %	Min: RH, %	RH Swing
1/1/2013	70.12	46.84	23.27	100	72.3	27.7
1/2/2013	60.52	52.55	7.96	99.8	90.4	9.4
1/3/2013	52.73	47.29	5.44	100	93.2	6.8
1/4/2013	65.62	38.80	26.82	100	34.7	65.3
1/5/2013	63.09	37.94	25.15	93.9	40.7	53.2
1/6/2013	54.91	47.15	7.75	100	75.1	24.9
1/7/2013	59.36	43.49	15.87	93	47.8	45.2
1/8/2013	69.47	45.08	24.39	93.7	65.6	28.1
1/9/2013	73.13	55.04	18.09	100	70.7	29.3
1/10/2013	69.51	53.43	16.09	100	72.9	27.1
1/11/2013	79.66	54.21	25.44	100	69.4	30.6
1/12/2013	80.10	55.82	24.28	100	63.1	36.9
1/13/2013	80.49	55.08	25.41	100	67.8	32.2
1/14/2013	79.00	57.59	21.40	100	71.7	28.3
			19.10			**31.79**

September 2012-November 2012:
Custom House, Charleston, SC
Daily High/Low Temperature

Date Time	*Max: Temp, °F*	*Min: Temp, °F*
9/11/2012	*80*	*71*
9/12/2012	*78*	*70*
9/13/2012	*80*	*70*
9/14/2012	*82*	*71*
9/15/2012	*83*	*71*
9/16/2012	*81*	*75*
9/17/2012	*81*	*75*
9/18/2012	*83*	*77*
9/19/2012	*83*	*69*
9/20/2012	*78*	*67*
9/21/2012	*79*	*69*
9/22/2012	*81*	*72*
9/23/2012	*80*	*72*
9/24/2012	*76*	*66*
9/25/2012	*77*	*68*
9/26/2012	*79*	*69*
9/27/2012	*83*	*73*
9/28/2012	*84*	*71*
9/29/2012	*85*	*72*
9/30/2012	*79*	*72*
10/1/2012	*83*	*75*
10/2/2012	*83*	*78*
10/3/2012	*83*	*75*
10/4/2012	*83*	*73*
10/5/2012	*82*	*72*
10/6/2012	*83*	*73*
10/7/2012	*82*	*70*
10/8/2012	*70*	*55*
10/9/2012	*65*	*55*
10/10/2012	*76*	*55*
10/11/2012	*74*	*61*
10/12/2012	*76*	*62*
10/13/2012	*73*	*62*
10/14/2012	*79*	*61*
10/15/2012	*80*	*69*
10/16/2012	*73*	*60*
10/17/2012	*74*	*63*
10/18/2012	*76*	*68*
10/19/2012	*78*	*66*
10/20/2012	*76*	*59*
10/21/2012	*73*	*58*
10/22/2012	*73*	*58*
10/23/2012	*76*	*60*
10/24/2012	*81*	*65*
10/25/2012	*78*	*70*
10/26/2012	*78*	*68*
10/27/2012	*71*	*66*
10/28/2012	*74*	*62*
10/29/2012	*65*	*50*
10/30/2012	*60*	*48*
10/31/2012	*67*	*48*
11/1/2012	*66*	*50*
11/2/2012	*71*	*47*
11/3/2012	*65*	*55*
11/4/2012	*79*	*60*
11/5/2012	*66*	*52*
11/6/2012	*57*	*46*
11/7/2012	*55*	*43*
11/8/2012	*65*	*41*
11/9/2012	*62*	*46*

**November 2012-December 2013:
Custom House, Charleston, SC
Daily High/Low Temperature**

Date Time	Max: Temp, °F	Min: Temp, °F
11/10/2012	71	50
11/11/2012	72	56
11/12/2012	75	62
11/13/2012	75	54
11/14/2012	55	49
11/15/2012	53	46
11/16/2012	56	46
11/17/2012	56	45
11/18/2012	56	50
11/19/2012	61	53
11/20/2012	62	49
11/21/2012	62	48
11/22/2012	63	46
11/23/2012	68	44
11/24/2012	62	48
11/25/2012	57	40
11/26/2012	64	46
11/27/2012	63	51
11/28/2012	61	47
11/29/2012	61	44
11/30/2012	64	49
12/1/2012	71	46
12/2/2012	74	50
12/3/2012	78	49
12/4/2012	76	55
12/5/2012	76	48
12/6/2012	67	52
12/7/2012	62	51
12/8/2012	70	48
12/9/2012	78	51
12/10/2012	75	59
12/11/2012	73	59
12/12/2012	60	45
12/13/2012	49	42
12/14/2012	61	38
12/15/2012	61	47
12/16/2012	75	51
12/17/2012	70	59
12/18/2012	68	46
12/19/2012	72	39
12/20/2012	75	40
12/21/2012	57	42
12/22/2012	59	35
12/23/2012	59	31
12/24/2012	64	44
12/25/2012	61	49
12/26/2012	68	43
12/27/2012	56	35
12/28/2012	58	33
12/29/2012	62	41
12/30/2012	52	29
12/31/2012	62	26

September 12, 2012: Temperature, Relative Humidity, Moisture Residue, Fort Sumter National Monument

Date, Time	Wetness, %	Temp, ˚F	RH, %
9/12/2012 0:00	4.39	71.186	72.4
9/12/2012 0:30	5.39	70.741	73.7
9/12/2012 1:00	5.59	70.572	74.4
9/12/2012 1:30	5.96	69.915	75.1
9/12/2012 2:00	6.22	69.487	76.1
9/12/2012 2:30	6.36	69.074	75.6
9/12/2012 3:00	6.45	69.179	75.5
9/12/2012 3:30	7.12	68.878	76.7
9/12/2012 4:00	7.47	68.603	77.4
9/12/2012 4:30	6.91	68.589	76.6
9/12/2012 5:00	6.48	68.518	75
9/12/2012 5:30	6.04	68.567	74.7
9/12/2012 6:00	4.94	68.492	73.3
9/12/2012 6:30	4.54	68.542	71
9/12/2012 7:00	4.14	68.836	70.2
9/12/2012 7:30	3.96	69.462	70.6
9/12/2012 8:00	2.46	71.352	69.9
9/12/2012 8:30	1.76	74.951	63.2
9/12/2012 9:00	1.76	76.734	55.8
9/12/2012 9:30	1.76	78.017	55.3
9/12/2012 10:00	1.76	79.024	53.8
9/12/2012 10:30	2.1	80.492	52.2
9/12/2012 11:00	2.35	81.833	50.3
9/12/2012 11:30	2.35	83.22	51.3
9/12/2012 12:00	2.39	84.432	49.5
9/12/2012 12:30	2.35	85.308	48
9/12/2012 13:00	2.41	85.945	49
9/12/2012 13:30	2.44	86.356	50.9
9/12/2012 14:00	2.29	84.578	52.7
9/12/2012 14:30	2.33	86.145	51.4
9/12/2012 15:00	2.27	84.663	53.4
9/12/2012 15:30	2.15	84.967	53.5
9/12/2012 16:00	1.76	84.08	53.5
9/12/2012 16:30	1.7	82.766	58.8
9/12/2012 17:00	1.28	79.421	62.3
9/12/2012 17:30	1.18	77.724	62.6
9/12/2012 18:00	1.32	76.904	63.6
9/12/2012 18:30	1.74	76.255	64.7
9/12/2012 19:00	2.49	75.564	67.9
9/12/2012 19:30	4.41	74.941	72.9
9/12/2012 20:00	6.17	74.545	74.8
9/12/2012 20:30	7.25	74.276	76.8
9/12/2012 21:00	7.25	73.542	76
9/12/2012 21:30	7.34	73.321	76.5
9/12/2012 22:00	8.42	72.812	77.9
9/12/2012 22:30	10.59	72.329	79.9
9/12/2012 23:00	12.45	72.099	81
9/12/2012 23:30	11.74	72.278	81.8
9/13/2012 0:00	25.47	71.57	90.7

October 12, 2012: Temperature, Relative Humidity, Moisture Residue, Fort Sumter National Monument

Date Time	Wetness, %	Temp, ˚F	RH, %
10/12/2012 0:00	4.62	63.633	78.59
10/12/2012 0:30	4.45	63.4	78.287
10/12/2012 1:00	4.41	63.045	78.362
10/12/2012 1:30	4.29	62.928	78.287
10/12/2012 2:00	4.37	62.667	78.803
10/12/2012 2:30	4.24	62.827	78.51
10/12/2012 3:00	4.48	62.56	79.147
10/12/2012 3:30	4.43	62.677	78.927
10/12/2012 4:00	4.25	62.555	78.563
10/12/2012 4:30	4.48	62.405	78.955
10/12/2012 5:00	4.3	62.098	78.265
10/12/2012 5:30	4.69	61.884	79.35
10/12/2012 6:00	5.71	61.574	81.045
10/12/2012 6:30	34.98	61.625	85.448
10/12/2012 7:00	27.09	61.731	84.27
10/12/2012 7:30	10.36	61.998	83.303
10/12/2012 8:00	6.67	62.184	83.65
10/12/2012 8:30	2.19	64.42	78.095
10/12/2012 9:00	2.18	68.619	70.875
10/12/2012 9:30	2.35	73.472	59.23
10/12/2012 10:00	2.35	76.531	52.693
10/12/2012 10:30	2.83	79.377	47.97
10/12/2012 11:00	3.02	81.673	45.438
10/12/2012 11:30	3.41	84.056	43.63
10/12/2012 12:00	3.52	86.568	41.192
10/12/2012 12:30	3.53	88.487	38.922
10/12/2012 13:00	3.41	87.957	39.013
10/12/2012 13:30	3.26	87.693	39.487
10/12/2012 14:00	2.72	86.146	41.278
10/12/2012 14:30	2.98	87.901	40.062
10/12/2012 15:00	2.94	87.549	40.038
10/12/2012 15:30	2.79	87.13	39.977
10/12/2012 16:00	2.24	85.079	43.295
10/12/2012 16:30	1.43	81.783	48.948
10/12/2012 17:00	1.18	77.498	54.898
10/12/2012 17:30	1.17	75.072	57.992
10/12/2012 18:00	1.12	73.867	60.282
10/12/2012 18:30	0.99	72.758	61.83
10/12/2012 19:00	1.05	72.216	62.387
10/12/2012 19:30	1.18	71.984	62.638
10/12/2012 20:00	1.18	71.702	64.133
10/12/2012 20:30	1.18	71.268	67.245
10/12/2012 21:00	1.22	70.782	70.613
10/12/2012 21:30	1.76	70.161	76.285
10/12/2012 22:00	1.99	69.934	76.513
10/12/2012 22:30	3.16	69.31	80.295
10/12/2012 23:00	3.66	68.686	80.222
10/12/2012 23:30	2.48	68.424	76.478

November 12, 2012: Temperature, Relative Humidity, Moisture Residue, Fort Sumter National Monument

Date Time	Wetness, %	Temp, °F	RH, %
11/12/2012 0:00	100	61.598	97.423
11/12/2012 0:30	100	61.568	97.348
11/12/2012 1:00	100	61.269	97.758
11/12/2012 1:30	100	61.003	97.998
11/12/2012 2:00	100	60.882	97.702
11/12/2012 2:30	100	61.725	96.527
11/12/2012 3:00	100	63.109	95.298
11/12/2012 3:30	100	62.653	96.013
11/12/2012 4:00	100	63.331	94.832
11/12/2012 4:30	100	62.168	96.645
11/12/2012 5:00	100	63.184	96.545
11/12/2012 5:30	100	63.376	96.092
11/12/2012 6:00	100	62.41	97.093
11/12/2012 6:30	100	63.312	96.127
11/12/2012 7:00	100	63.296	95.943
11/12/2012 7:30	100	62.935	96.235
11/12/2012 8:00	100	62.651	95.955
11/12/2012 8:30	100	62.009	97.643
11/12/2012 9:00	100	64.352	95.167
11/12/2012 9:30	49.3	67.685	87.9
11/12/2012 10:00	3.22	73.793	77.932
11/12/2012 10:30	2.98	77.746	69.527
11/12/2012 11:00	2.99	79.052	64.203
11/12/2012 11:30	2.84	78.65	62.878
11/12/2012 12:00	2.94	80.353	60.287
11/12/2012 12:30	3	81.388	59.922
11/12/2012 13:00	3.58	83.994	56.06
11/12/2012 13:30	2.61	82.415	56.635
11/12/2012 14:00	2.35	79.867	61.275
11/12/2012 14:30	2.33	78.052	65.16
11/12/2012 15:00	2.28	77.116	66.518
11/12/2012 15:30	2.17	72.865	74.517
11/12/2012 16:00	3.64	70.947	78.112
11/12/2012 16:30	5.96	70.37	79.875
11/12/2012 17:00	13.08	69.353	82.435
11/12/2012 17:30	18.4	68.97	83.475
11/12/2012 18:00	19.82	68.759	82.24
11/12/2012 18:30	22.47	68.473	82.218
11/12/2012 19:00	27.22	68.111	83.408
11/12/2012 19:30	47.59	67.276	85.34
11/12/2012 20:00	98.44	66.273	87.58
11/12/2012 20:30	99.34	66.329	88.328
11/12/2012 21:00	100	65.392	90.723
11/12/2012 21:30	100	65.829	91.047
11/12/2012 22:00	100	65.936	91.632
11/12/2012 22:30	100	66.587	90.778
11/12/2012 23:00	100	66.751	90.42
11/12/2012 23:30	100	66.381	91.16

December 12, 2012: Temperature, Relative Humidity, Moisture Residue, Fort Sumter National Monument

Date Time	Wetness, %	Temp, °F	RH, %
12/12/2012 0:00	100	61.135	93.487
12/12/2012 0:30	100	61.083	93.577
12/12/2012 1:00	100	60.737	94.585
12/12/2012 1:30	100	61.103	94.682
12/12/2012 2:00	100	60.923	93.867
12/12/2012 2:30	100	61.013	93.375
12/12/2012 3:00	100	60.805	93.387
12/12/2012 3:30	100	60.553	94.495
12/12/2012 4:00	100	60.526	94.388
12/12/2012 4:30	100	60.493	93.817
12/12/2012 5:00	100	60.415	93.27
12/12/2012 5:30	100	60.346	93.32
12/12/2012 6:00	100	60.348	94.092
12/12/2012 6:30	100	59.825	95.3
12/12/2012 7:00	100	59.332	96.02
12/12/2012 7:30	100	59.372	95.833
12/12/2012 8:00	100	58.328	97.338
12/12/2012 8:30	100	56.947	97.962
12/12/2012 9:00	100	56.286	99.317
12/12/2012 9:30	100	56.338	99.755
12/12/2012 10:00	100	56.628	99.67
12/12/2012 10:30	100	56.496	99.98
12/12/2012 11:00	100	56.668	100
12/12/2012 11:30	100	56.644	100

Date Time	Wetness, %	Temp, °F	RH, %
12/12/2012 12:00	100	56.275	100
12/12/2012 12:30	100	55.947	100
12/12/2012 13:00	100	55.624	100
12/12/2012 13:30	100	54.794	100
12/12/2012 14:00	100	54.154	100
12/12/2012 14:30	100	53.12	100
12/12/2012 15:00	100	51.914	100
12/12/2012 15:30	100	51.036	100
12/12/2012 16:00	100	50.947	100
12/12/2012 16:30	100	50.437	100
12/12/2012 17:00	100	50.059	100
12/12/2012 17:30	100	49.727	100
12/12/2012 18:00	100	49.52	100
12/12/2012 18:30	100	49.341	100
12/12/2012 19:00	100	49.149	99.995
12/12/2012 19:30	100	49.051	99.965
12/12/2012 20:00	100	48.788	99.887
12/12/2012 20:30	100	48.33	99.982
12/12/2012 21:00	100	48.151	100
12/12/2012 21:30	100	47.715	100
12/12/2012 22:00	100	47.238	100
12/12/2012 22:30	100	47.393	100
12/12/2012 23:00	100	48.049	100
12/12/2012 23:30	100	48.342	100

January 12, 2012: Temperature, Relative Humidity, Moisture Residue, Fort Sumter National Monument

Date Time	Wetness, %	Temp, ˚F	RH, %
1/12/2013 0:00	100	56.3	100
1/12/2013 0:30	100	56.344	100
1/12/2013 1:00	100	56.238	100
1/12/2013 1:30	100	57.266	100
1/12/2013 2:00	100	56.939	100
1/12/2013 2:30	100	56.557	100
1/12/2013 3:00	100	56.257	100
1/12/2013 3:30	100	56.514	100
1/12/2013 4:00	100	56.676	100
1/12/2013 4:30	100	57.304	100
1/12/2013 5:00	100	57.659	100
1/12/2013 5:30	100	57.897	100
1/12/2013 6:00	100	57.355	100
1/12/2013 6:30	100	57.259	100
1/12/2013 7:00	100	56.734	100
1/12/2013 7:30	100	56.451	100
1/12/2013 8:00	100	57.045	100
1/12/2013 8:30	100	57.953	100
1/12/2013 9:00	94.48	59.479	100
1/12/2013 9:30	74.74	62.7	100
1/12/2013 10:00	56.81	67.148	97.5
1/12/2013 10:30	40.06	69.786	88.8
1/12/2013 11:00	20.18	72.601	80.3
1/12/2013 11:30	4.93	74.046	75
1/12/2013 12:00	4.12	74.09	74.5
1/12/2013 12:30	4.12	74.027	75.4
1/12/2013 13:00	4.12	74.357	76.6
1/12/2013 13:30	4.1	74.322	76.1
1/12/2013 14:00	3.8	76.642	70.9
1/12/2013 14:30	3.53	76.298	70.5
1/12/2013 15:00	3.89	78.786	68.2
1/12/2013 15:30	6.7	73.255	80.8
1/12/2013 16:00	10.62	71.028	82.2
1/12/2013 16:30	20.56	69.541	85.7
1/12/2013 17:00	43.98	67.022	89.7
1/12/2013 17:30	83.52	64.255	93.7
1/12/2013 18:00	100	62.525	95.8
1/12/2013 18:30	100	61.537	97.2
1/12/2013 19:00	100	60.879	97.3
1/12/2013 19:30	100	60.099	97.6
1/12/2013 20:00	100	59.511	98.4
1/12/2013 20:30	100	58.996	99
1/12/2013 21:00	100	58.596	99.3
1/12/2013 21:30	100	58.76	99.6
1/12/2013 22:00	100	59.334	100
1/12/2013 22:30	100	59.118	100
1/12/2013 23:00	100	58.529	100
1/12/2013 23:30	100	59.375	100

September 12, 2012: Wind Speed and Direction, Fort Sumter National Monument

Date Time	Wind Speed, mph	Wind Direction, ø
9/12/2012 0:00	0	96.3
9/12/2012 0:30	0.01	129.3
9/12/2012 1:00	0.03	120.9
9/12/2012 1:30	0.09	93.8
9/12/2012 2:00	0.09	133
9/12/2012 2:30	0.01	126.1
9/12/2012 3:00	0.07	129
9/12/2012 3:30	0.05	124.7
9/12/2012 4:00	0.07	114.4
9/12/2012 4:30	0.11	124.3
9/12/2012 5:00	0.01	133.5
9/12/2012 5:30	0.21	133.9
9/12/2012 6:00	0.44	134
9/12/2012 6:30	0.23	130
9/12/2012 7:00	0.21	122.7
9/12/2012 7:30	0.13	128.2
9/12/2012 8:00	0.26	127.3
9/12/2012 8:30	0.38	137.2
9/12/2012 9:00	0.82	133.5
9/12/2012 9:30	0.83	123.8
9/12/2012 10:00	1.31	121.6
9/12/2012 10:30	0.92	132
9/12/2012 11:00	0.73	135.5
9/12/2012 11:30	0.98	115.6
9/12/2012 12:00	1.45	126.7
9/12/2012 12:30	1.22	105.5
9/12/2012 13:00	1.51	91.9
9/12/2012 13:30	2.4	108.4
9/12/2012 14:00	2.42	183.1
9/12/2012 14:30	2.69	263.8
9/12/2012 15:00	2.29	214
9/12/2012 15:30	2	245.3
9/12/2012 16:00	2.12	199.4
9/12/2012 16:30	1.96	171.5
9/12/2012 17:00	1.86	233
9/12/2012 17:30	1.59	252.2
9/12/2012 18:00	1.56	236
9/12/2012 18:30	1.28	221.1
9/12/2012 19:00	1.69	225.5
9/12/2012 19:30	1.29	201.1
9/12/2012 20:00	0.92	93.7
9/12/2012 20:30	0.21	119.2
9/12/2012 21:00	0.22	124.2
9/12/2012 21:30	0.22	135.1
9/12/2012 22:00	0.16	129.2
9/12/2012 22:30	0.04	146
9/12/2012 23:00	0.2	172
9/12/2012 23:30	0.09	153.4

October 12, 2012: Wind Speed and Direction, Fort Sumter National Monument

Date Time	Wind Speed, mph	Wind Direction, ø
10/12/2012 0:00	0.01	107
10/12/2012 0:30	0.01	94.4
10/12/2012 1:00	0	73
10/12/2012 1:30	0.17	68.2
10/12/2012 2:00	0	77.6
10/12/2012 2:30	0	141.6
10/12/2012 3:00	0	97.4
10/12/2012 3:30	0	109.1
10/12/2012 4:00	0	152.3
10/12/2012 4:30	0	88.2
10/12/2012 5:00	0	52.2
10/12/2012 5:30	0	256.9
10/12/2012 6:00	0	147.2
10/12/2012 6:30	0	130.6
10/12/2012 7:00	0	296.9
10/12/2012 7:30	0	354.5
10/12/2012 8:00	0	355.1
10/12/2012 8:30	0	351.3
10/12/2012 9:00	0	343.8
10/12/2012 9:30	0	344
10/12/2012 10:00	0	278.2
10/12/2012 10:30	0	234
10/12/2012 11:00	0	251.7
10/12/2012 11:30	0.01	264
10/12/2012 12:00	0	270.5
10/12/2012 12:30	0.01	292.5
10/12/2012 13:00	0.18	121.7
10/12/2012 13:30	0.42	105.7
10/12/2012 14:00	0.47	128.7
10/12/2012 14:30	0.39	274
10/12/2012 15:00	0.26	311.1
10/12/2012 15:30	0.19	310.3
10/12/2012 16:00	0.5	312.2
10/12/2012 16:30	0.43	301.5
10/12/2012 17:00	0.36	304.6
10/12/2012 17:30	0.08	282.4
10/12/2012 18:00	0	316.7
10/12/2012 18:30	0	242.7
10/12/2012 19:00	0	104.1
10/12/2012 19:30	0	13.3
10/12/2012 20:00	0	29.9
10/12/2012 20:30	0	125.9
10/12/2012 21:00	0	124.3
10/12/2012 21:30	0	96.9
10/12/2012 22:00	0	63.7
10/12/2012 22:30	0	71.5
10/12/2012 23:00	0	40.3
10/12/2012 23:30	0	108.2

November 12, 2012: Wind Speed and Direction, Fort Sumter National Monument

Date Time	Wind Speed, mph	Wind Direction, ø	Date Time	Wind Speed, mph	Wind Direction, ø
11/12/2012 0:00	0.32	58.8	11/12/2012 12:00	0.91	305.6
11/12/2012 0:30	0.37	49	11/12/2012 12:30	0.33	303.7
11/12/2012 1:00	0.03	56.3	11/12/2012 13:00	0.07	303.5
11/12/2012 1:30	0.2	83	11/12/2012 13:30	0.02	40.6
11/12/2012 2:00	0	32.5	11/12/2012 14:00	0	32.4
11/12/2012 2:30	0.01	272.9	11/12/2012 14:30	0.04	34.1
11/12/2012 3:00	0.02	321.3	11/12/2012 15:00	0.14	36.4
11/12/2012 3:30	0	351.3	11/12/2012 15:30	0.19	46.6
11/12/2012 4:00	0	346.8	11/12/2012 16:00	0.21	43.9
11/12/2012 4:30	0	346.8	11/12/2012 16:30	0.18	37
11/12/2012 5:00	0	162.3	11/12/2012 17:00	0.29	182.3
11/12/2012 5:30	0	5.6	11/12/2012 17:30	0.44	267.9
11/12/2012 6:00	0.01	6.4	11/12/2012 18:00	0.08	202.6
11/12/2012 6:30	0	3.6	11/12/2012 18:30	0.02	243.2
11/12/2012 7:00	0	124.7	11/12/2012 19:00	0	122.4
11/12/2012 7:30	0	355.2	11/12/2012 19:30	0	110.7
11/12/2012 8:00	0	337.8	11/12/2012 20:00	0	56.2
11/12/2012 8:30	0.01	130.8	11/12/2012 20:30	0	102.2
11/12/2012 9:00	0.07	244.3	11/12/2012 21:00	0	272.5
11/12/2012 9:30	0.01	63.9	11/12/2012 21:30	0.06	297
11/12/2012 10:00	0	52.1	11/12/2012 22:00	0	303.7
11/12/2012 10:30	0	31.8	11/12/2012 22:30	0	315.4
11/12/2012 11:00	0.41	39.6	11/12/2012 23:00	0	315.9
11/12/2012 11:30	0.88	264.5	11/12/2012 23:30	0	315.9

December 12, 2012: Wind Speed and Direction, Fort Sumter National Monument

Date Time	Wind Speed, mph	Wind Direction, ø
12/12/2012 0:00	0	105.4
12/12/2012 0:30	0	95.5
12/12/2012 1:00	0	58.3
12/12/2012 1:30	0.18	136.5
12/12/2012 2:00	0	92.8
12/12/2012 2:30	0	146
12/12/2012 3:00	0.03	122.5
12/12/2012 3:30	0.02	114.7
12/12/2012 4:00	0.03	130.8
12/12/2012 4:30	0.05	84.8
12/12/2012 5:00	0	125.7
12/12/2012 5:30	0	121.8
12/12/2012 6:00	0.03	136.9
12/12/2012 6:30	0.29	121.4
12/12/2012 7:00	0.31	137.3
12/12/2012 7:30	0.02	194.1
12/12/2012 8:00	0.05	158.6
12/12/2012 8:30	0.2	114.2
12/12/2012 9:00	0.38	171.6
12/12/2012 9:30	0.33	156.1
12/12/2012 10:00	0.37	152
12/12/2012 10:30	0.23	116.6
12/12/2012 11:00	0.21	123.5
12/12/2012 11:30	0.18	172.7

Date Time	Wind Speed, mph	Wind Direction, ø
12/12/2012 12:00	0.67	162.5
12/12/2012 12:30	0.11	119.2
12/12/2012 13:00	0.36	144.9
12/12/2012 13:30	0.6	135.5
12/12/2012 14:00	0.95	109.6
12/12/2012 14:30	0.9	101.8
12/12/2012 15:00	0.8	151.5
12/12/2012 15:30	0.8	152.4
12/12/2012 16:00	0.55	157.1
12/12/2012 16:30	0.47	158.3
12/12/2012 17:00	0.7	185.8
12/12/2012 17:30	0.72	135.9
12/12/2012 18:00	1.24	122.8
12/12/2012 18:30	0.78	125.7
12/12/2012 19:00	0.64	127.8
12/12/2012 19:30	0.55	115.3
12/12/2012 20:00	0.52	124.1
12/12/2012 20:30	0.25	131.7
12/12/2012 21:00	1.12	118
12/12/2012 21:30	0.43	132.2
12/12/2012 22:00	0.53	115.2
12/12/2012 22:30	1.52	102.2
12/12/2012 23:00	2.48	75.5
12/12/2012 23:30	1.13	118.1

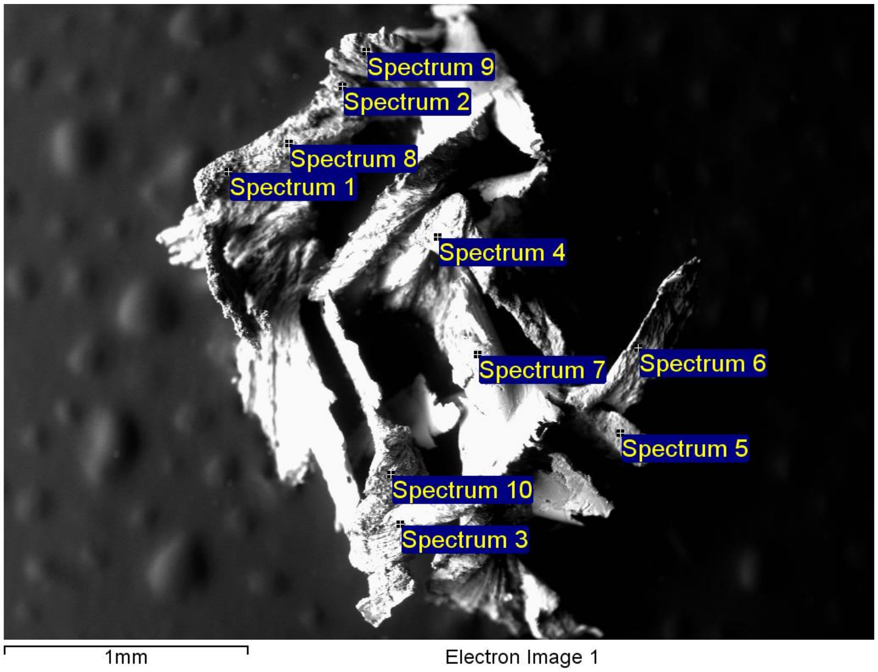
January 13, 2013: Wind Speed and Direction, Fort Sumter National Monument

Date Time	Wind Speed, mph	Wind Direction, ø
1/12/2013 0:00	0	63.2
1/12/2013 0:30	0	63.2
1/12/2013 1:00	0	63.2
1/12/2013 1:30	0	62.1
1/12/2013 2:00	0	60.4
1/12/2013 2:30	0	60.4
1/12/2013 3:00	0	60.4
1/12/2013 3:30	0	60.4
1/12/2013 4:00	0	62.1
1/12/2013 4:30	0	61.5
1/12/2013 5:00	0	54.3
1/12/2013 5:30	0	29
1/12/2013 6:00	0	16.8
1/12/2013 6:30	0	16.8
1/12/2013 7:00	0	16.8
1/12/2013 7:30	0	16.8
1/12/2013 8:00	0	16.8
1/12/2013 8:30	0	16.8
1/12/2013 9:00	0	18
1/12/2013 9:30	0	21.5
1/12/2013 10:00	0	28.1
1/12/2013 10:30	0	28.1
1/12/2013 11:00	0.02	36.3
1/12/2013 11:30	0.17	25.4

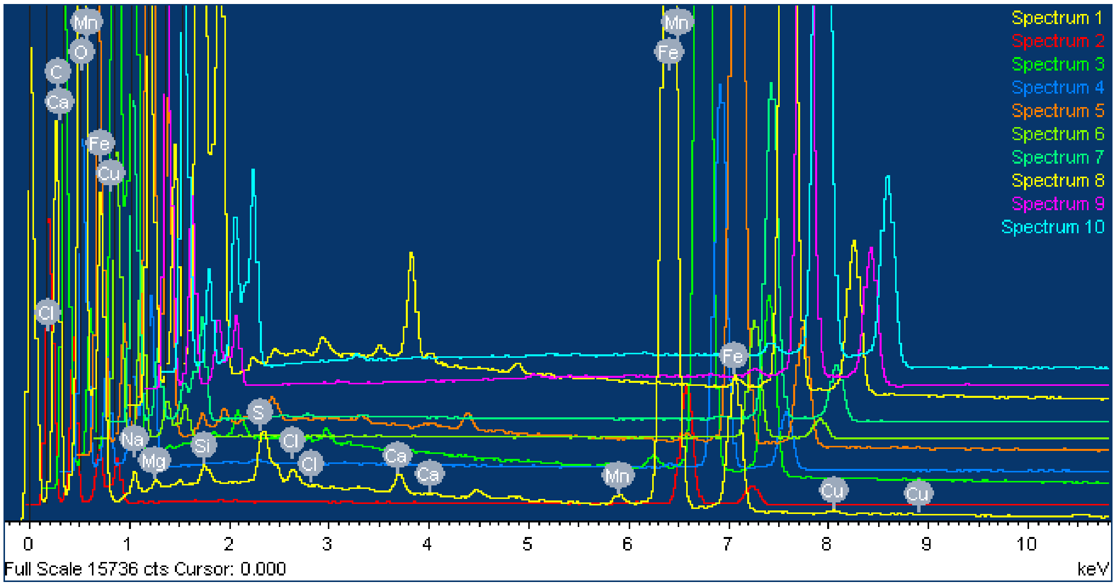
Date Time	**Wind Speed, mph**	**Wind Direction, ø**
1/12/2013 12:00	0	286.9
1/12/2013 12:30	0.01	278.6
1/12/2013 13:00	0.07	269.3
1/12/2013 13:30	0.05	262.4
1/12/2013 14:00	0.14	278.8
1/12/2013 14:30	0.19	232.7
1/12/2013 15:00	0.07	178.1
1/12/2013 15:30	0.08	207.4
1/12/2013 16:00	0.01	91.4
1/12/2013 16:30	0.01	83.5
1/12/2013 17:00	0	352.4
1/12/2013 17:30	0.02	328.9
1/12/2013 18:00	0	0.9
1/12/2013 18:30	0	0
1/12/2013 19:00	0	32.4
1/12/2013 19:30	0.01	210.1
1/12/2013 20:00	0.01	237.7
1/12/2013 20:30	0	143.1
1/12/2013 21:00	0	5.6
1/12/2013 21:30	0	5.6
1/12/2013 22:00	0	5.6
1/12/2013 22:30	0	5.6
1/12/2013 23:00	0	5.6
1/12/2013 23:30	0	6.5

20130312 Amy Elizabeth Fort Sumter Iron

3/12/2013 3:54:24 PM



Electron Image 1



Comment:

Project: 20130312 Amy Elizabeth Fort Sumter Iron

Owner: INCA

Sample: Lintel 1

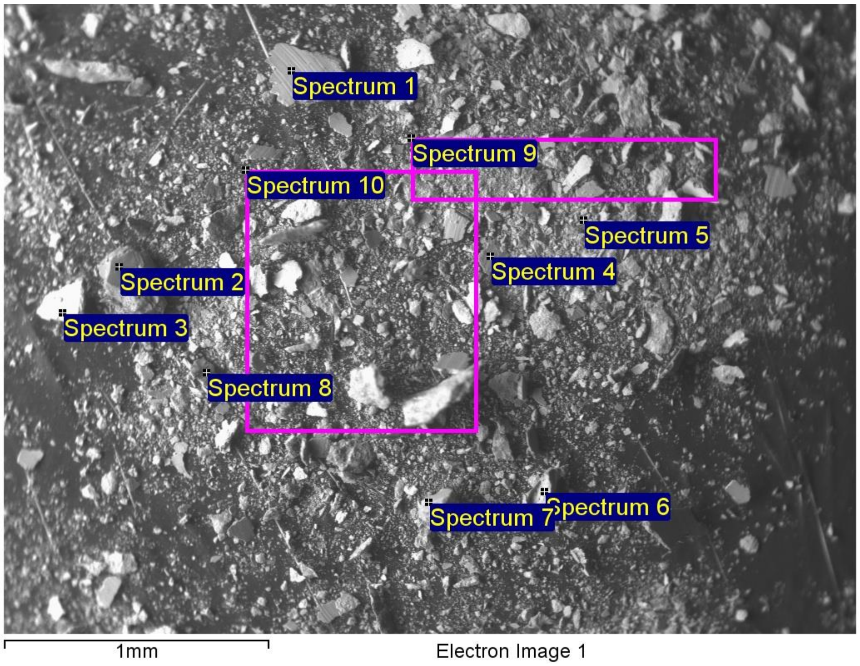
Type: Default

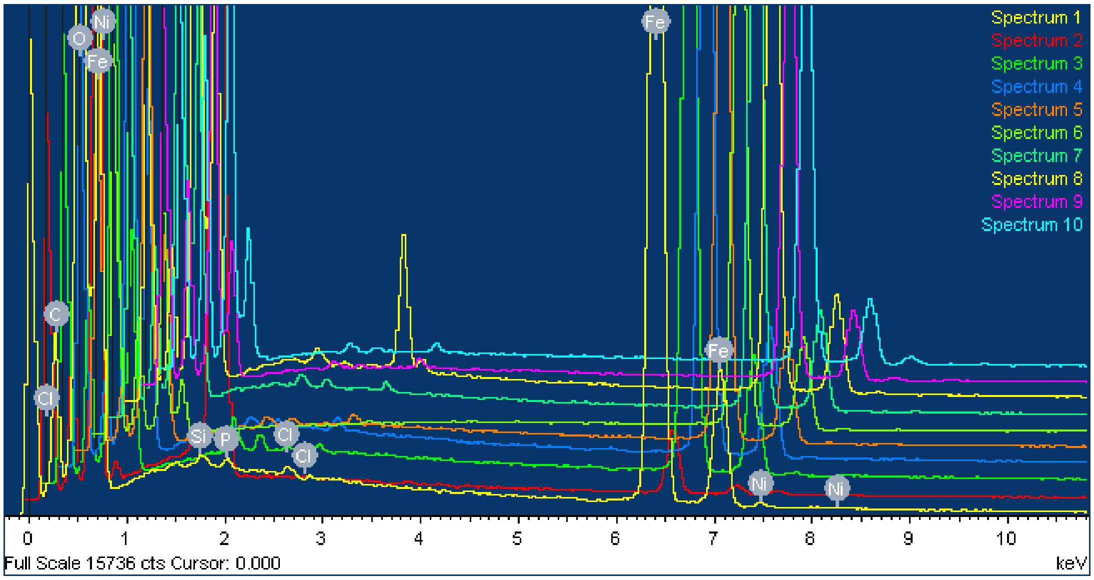
Processing option : All elements analysed (Normalised) - All results in weight%

Spectrum	In stats.	C	O	Na	Mg	Si	S	Cl	Ca	Mn	Fe	Cu	Total
Spectrum 1	Yes	23.83	32.49	0.62	0.13	0.17	0.37	0.18	0.25	0.33	41.38	0.26	100.00
Spectrum 2	Yes	49.30	18.63	0.07	0.03	0.10	0.02	0.08	0.05	0.29	31.26	0.16	100.00
Spectrum 3	Yes	10.65	35.35	0.16	-0.01	0.25	0.04	0.17	0.00	0.39	52.88	0.11	100.00
Spectrum 4	Yes	27.91	12.73	0.12	0.03	0.14	0.07	0.04	0.02	0.41	58.40	0.11	100.00
Spectrum 5	Yes	10.43	40.58	0.63	0.36	0.31	0.02	0.11	0.28	0.36	46.88	0.04	100.00
Spectrum 6	Yes	52.65	14.11	0.07	0.07	0.13	0.03	0.04	0.01	0.31	32.32	0.26	100.00
Spectrum 7	Yes	25.05	5.98	0.07	0.06	0.14	0.09	0.01	0.01	0.44	68.07	0.07	100.00
Spectrum 8	Yes	14.86	40.07	0.34	0.14	0.16	0.10	1.18	0.11	0.26	42.71	0.06	100.00
Spectrum 9	Yes	25.21	4.39	0.02	0.01	0.06	0.00	0.03	0.10	0.48	69.50	0.20	100.00
Spectrum 10	Yes	11.91	6.31	0.09	0.03	0.11	0.02	0.01	0.04	0.58	80.80	0.07	100.00
Mean		25.18	21.07	0.22	0.08	0.16	0.08	0.19	0.09	0.38	52.42	0.13	100.00
Std. deviation		15.12	14.62	0.23	0.11	0.07	0.11	0.35	0.10	0.10	16.59	0.08	
Max.		52.65	40.58	0.63	0.36	0.31	0.37	1.18	0.28	0.58	80.80	0.26	
Min.		10.43	4.39	0.02	-0.01	0.06	0.00	0.01	0.00	0.26	31.26	0.04	

20130312 Amy Elizabeth Fort Sumter Iron

3/12/2013 4:00:54 PM





Comment:

Project: 20130312 Amy Elizabeth Fort Sumter Iron

Owner: INCA

Sample: Tierod Drill

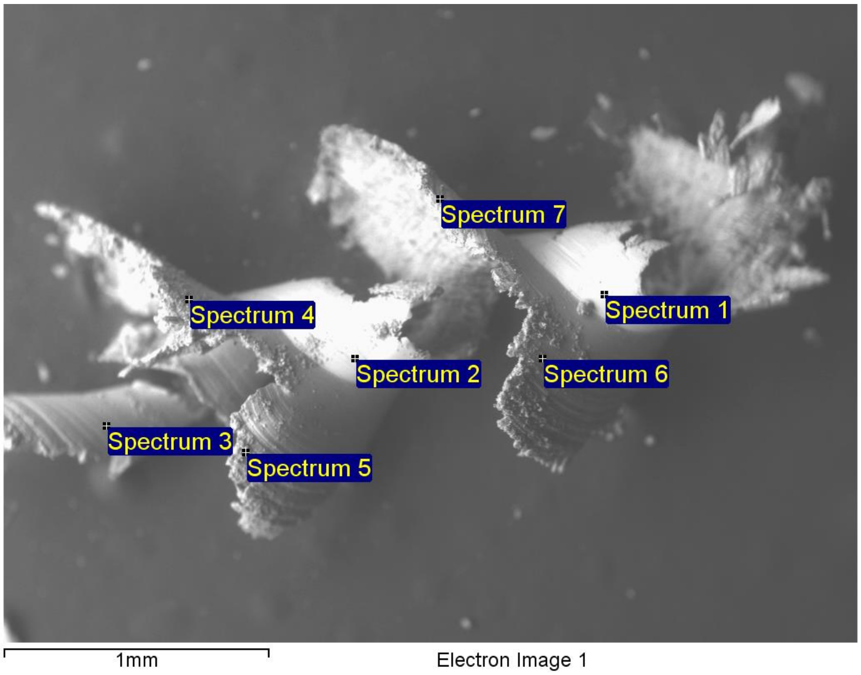
Type: Default

Processing option : All elements analysed (Normalised) - All results in weight%

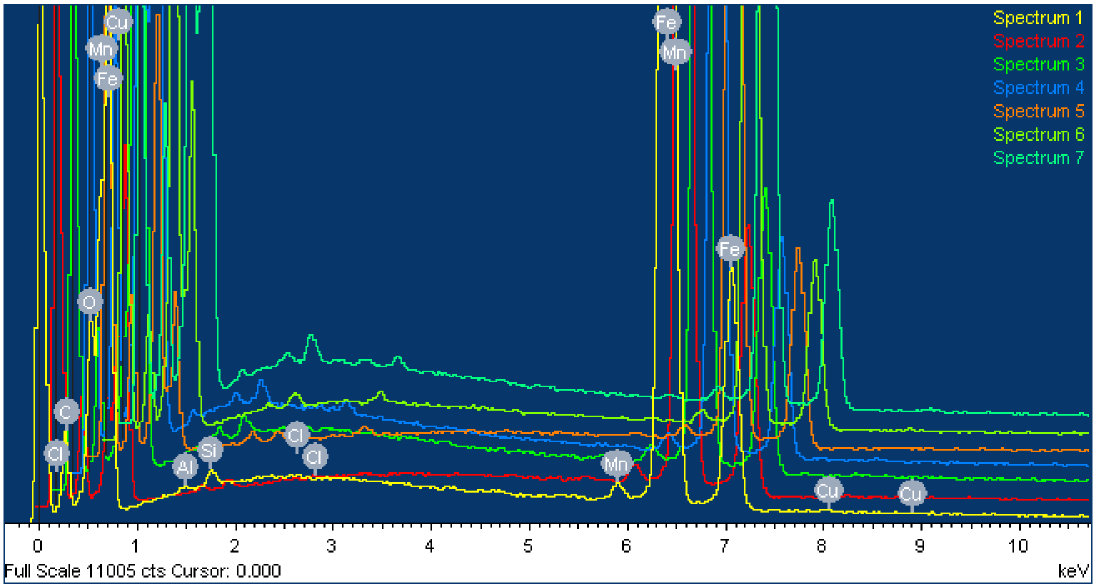
Spectrum	In stats.	C	O	Si	P	Cl	Fe	Ni	Total
Spectrum 1	Yes	11.37	43.15	0.09	0.14	0.11	44.88	0.25	100.00
Spectrum 2	Yes	16.16	52.62	28.61	0.03	0.02	2.36	0.20	100.00
Spectrum 3	Yes	16.56	34.56	0.46	0.29	0.11	47.74	0.28	100.00
Spectrum 4	Yes	7.10	38.02	0.14	0.14	0.24	54.22	0.14	100.00
Spectrum 5	Yes	7.46	32.62	0.18	0.15	0.25	59.20	0.15	100.00
Spectrum 6	Yes	19.14	16.59	0.04	0.05	0.10	63.83	0.25	100.00
Spectrum 7	Yes	14.20	41.94	0.16	0.15	0.15	43.30	0.11	100.00
Spectrum 8	Yes	12.05	47.02	0.18	0.06	2.07	38.45	0.18	100.00
Spectrum 9	Yes	24.13	32.69	0.14	0.08	0.23	42.38	0.35	100.00
Spectrum 10	Yes	31.74	32.38	0.15	0.09	0.19	34.64	0.81	100.00
Mean		15.99	37.16	3.02	0.12	0.35	43.10	0.27	100.00
Std. deviation		7.58	9.94	8.99	0.07	0.61	16.96	0.20	
Max.		31.74	52.62	28.61	0.29	2.07	63.83	0.81	
Min.		7.10	16.59	0.04	0.03	0.02	2.36	0.11	

20130312 Amy Elizabeth Fort Sumter Iron

3/12/2013 4:14:39 PM



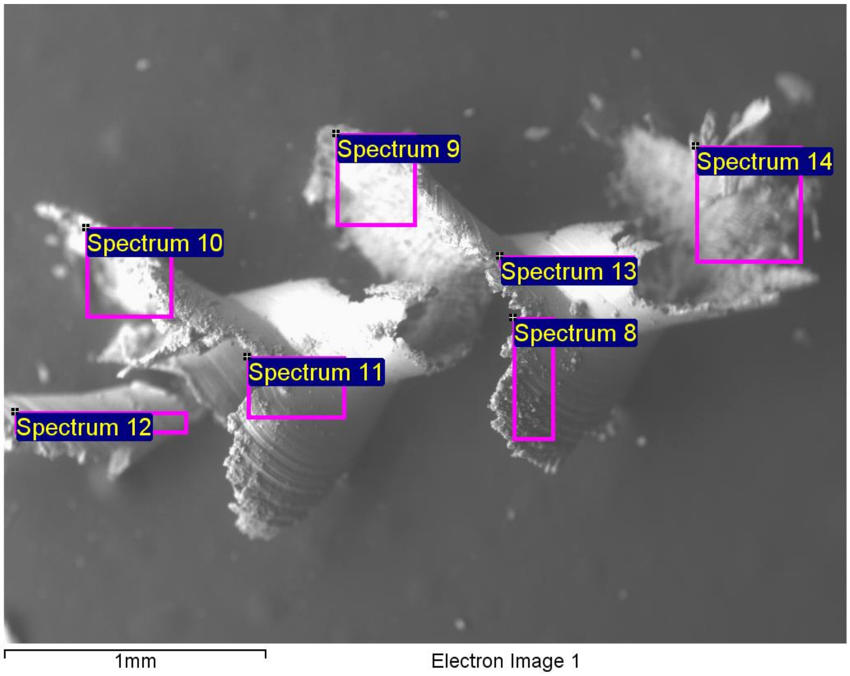
Electron Image 1



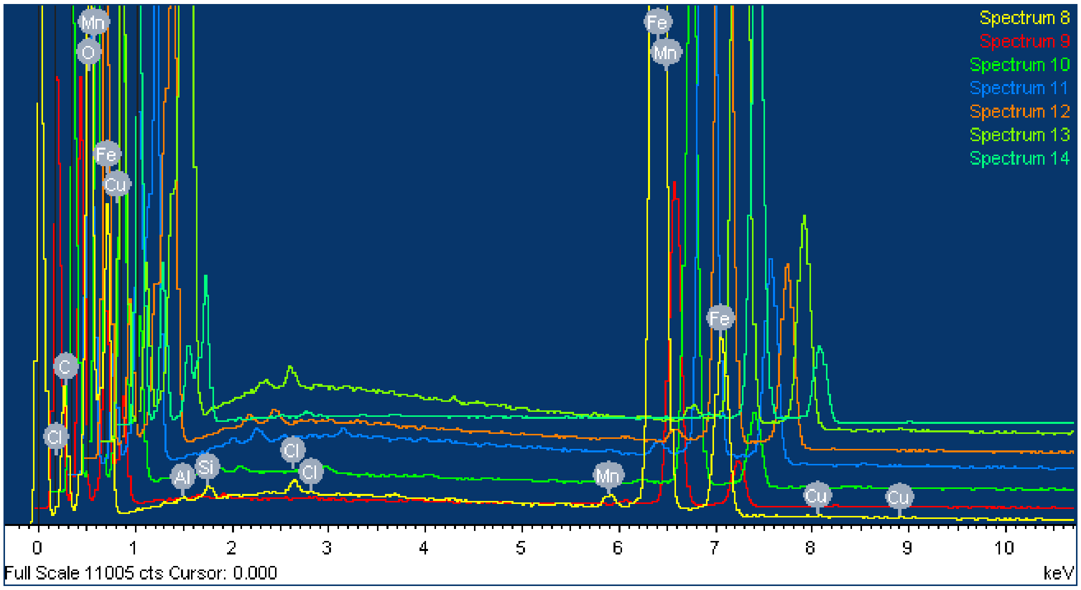
Comment:

20130312 Amy Elizabeth Fort Sumter Iron

3/12/2013 4:15:31 PM



Electron Image 1



Comment:

Project: 20130312 Amy Elizabeth Fort Sumter Iron

Owner: INCA

Sample: Lintel 2

Type: Default

Processing option : All elements analysed (Normalised)

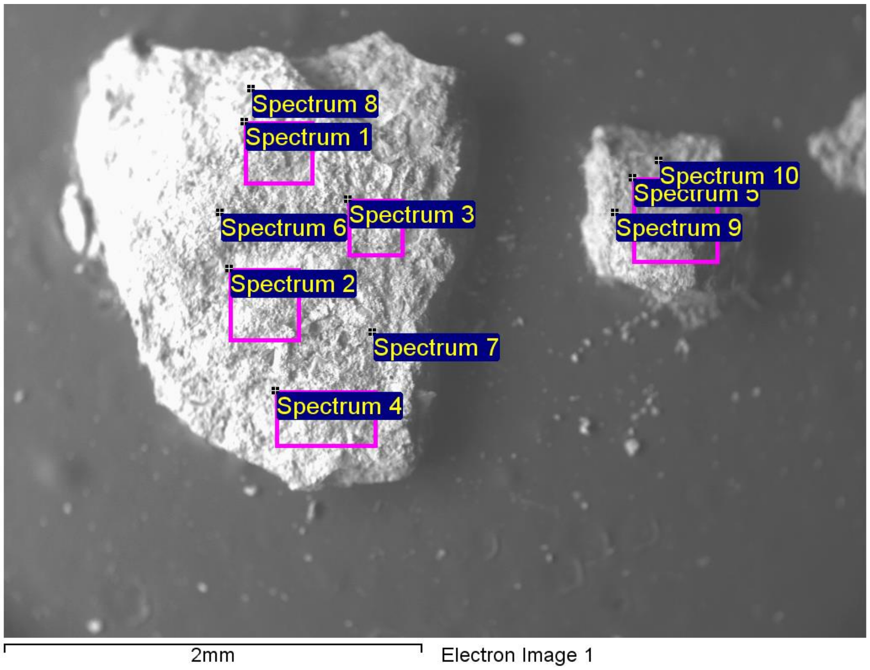
Spectrum	In stats.	C	O	Al	Si	Cl	Mn	Fe	Cu	Total
Spectrum 1	Yes	7.60	5.12	0.08	0.22	0.03	0.60	86.21	0.12	100.00
Spectrum 2	Yes	9.48	2.73	0.13	0.10	0.04	0.67	86.71	0.14	100.00
Spectrum 3	Yes	11.25	2.26	0.19	0.24	0.01	0.54	85.39	0.13	100.00
Spectrum 4	Yes	20.83	28.95	0.11	0.18	0.11	0.39	49.33	0.10	100.00
Spectrum 5	Yes	13.92	15.03	0.17	0.14	0.11	0.43	70.06	0.13	100.00
Spectrum 6	Yes	10.24	27.51	0.10	0.16	0.16	0.47	61.24	0.12	100.00
Spectrum 7	Yes	18.09	23.13	0.11	0.26	0.13	0.40	57.72	0.16	100.00
Spectrum 8	Yes	12.46	19.98	0.10	0.17	0.22	0.55	66.38	0.14	100.00
Spectrum 9	Yes	46.33	22.13	0.06	0.10	0.06	0.30	30.73	0.31	100.00
Spectrum 10	Yes	41.13	28.86	0.11	0.08	0.10	0.16	29.42	0.12	100.00
Spectrum 11	Yes	10.82	11.37	0.13	0.19	0.14	0.60	76.56	0.18	100.00
Spectrum 12	Yes	16.10	5.64	0.22	0.20	0.04	0.61	77.14	0.04	100.00
Spectrum 13	Yes	14.42	6.45	0.14	0.30	0.01	0.64	77.89	0.15	100.00
Spectrum 14	Yes	29.75	7.96	0.09	0.14	0.02	0.42	61.52	0.10	100.00

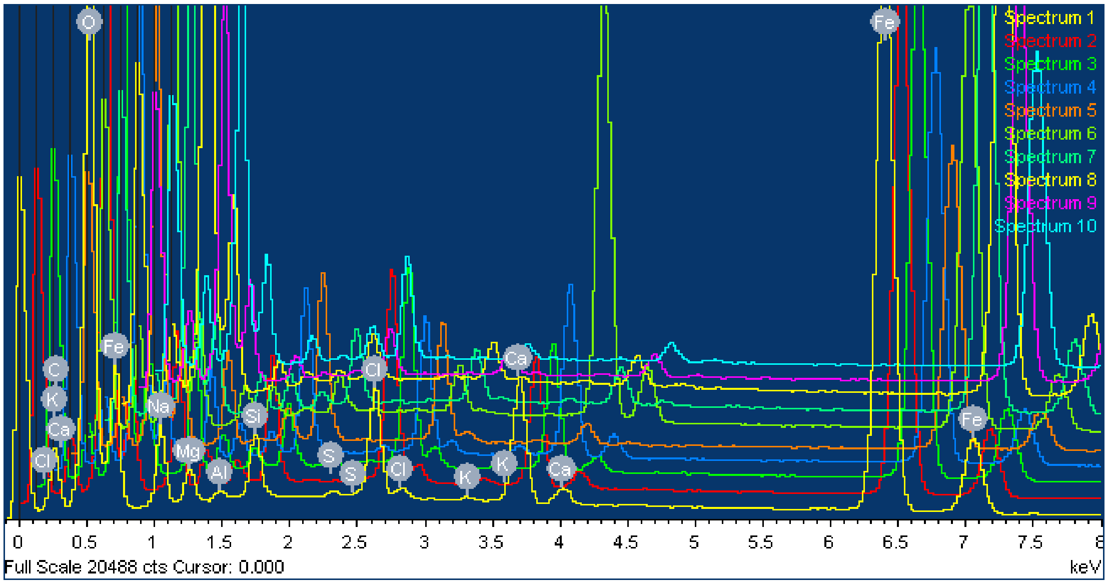
Mean	18.74	14.79	0.12	0.18	0.08	0.48	65.45	0.14	100.00
Std. deviation	12.02	10.07	0.04	0.06	0.06	0.14	18.76	0.06	
Max.	46.33	28.95	0.22	0.30	0.22	0.67	86.71	0.31	
Min.	7.60	2.26	0.06	0.08	0.01	0.16	29.42	0.04	

All results in weight%

20130312 Amy Elizabeth Fort Sumter Iron

3/12/2013 4:20:25 PM





Comment:

Project: 20130312 Amy Elizabeth Fort Sumter Iron

Owner: INCA

Sample: A 14 Pintel

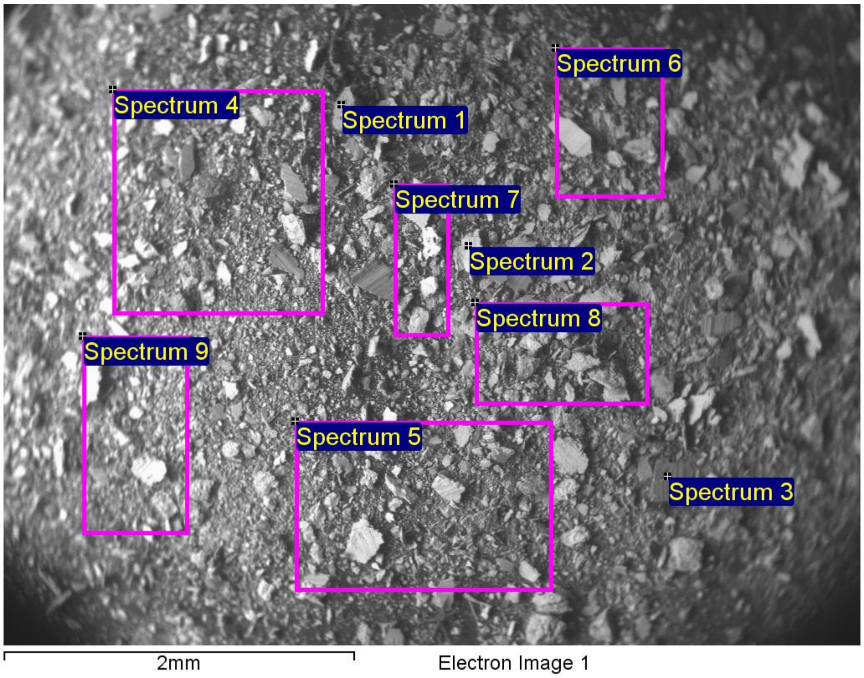
Type: Default

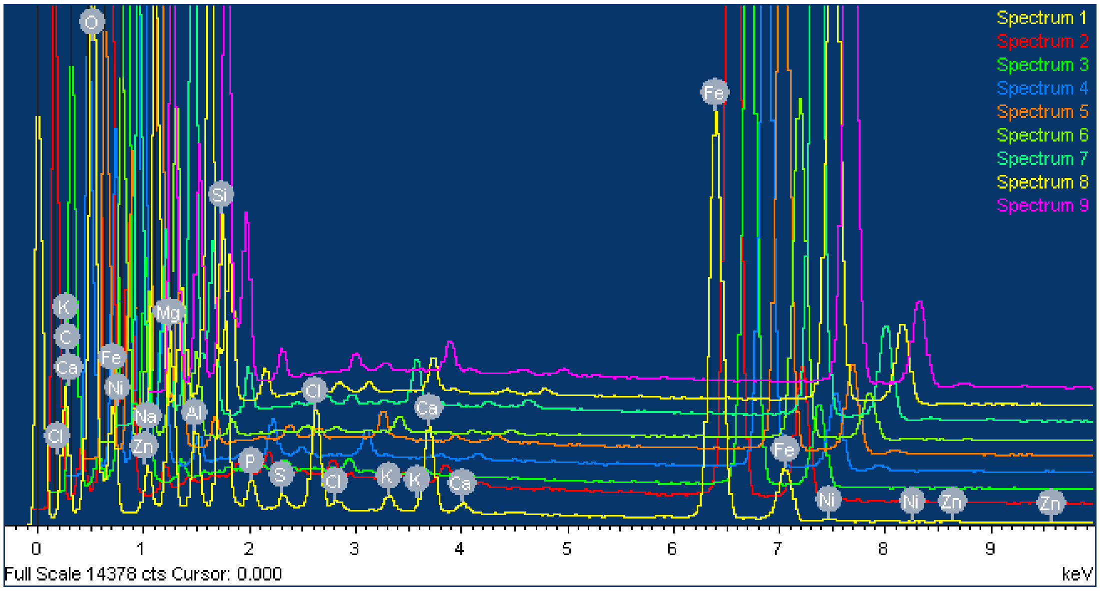
Processing option : All elements analysed (Normalised) - All results in weight%

Spectrum	In stats.	C	O	Na	Mg	Al	Si	S	Cl	K	Ca	Fe	Total
Spectrum 1	Yes	6.05	37.88	3.70	1.03	0.20	1.31	0.09	2.52	0.08	3.32	43.82	100.00
Spectrum 2	Yes	6.61	36.59	6.59	1.10	0.48	2.59	0.07	4.75	0.16	3.44	37.62	100.00
Spectrum 3	Yes	5.71	35.25	6.87	1.14	0.48	1.29	0.05	4.70	0.08	3.45	40.98	100.00
Spectrum 4	Yes	8.18	36.50	4.48	1.11	0.59	3.90	0.15	3.64	0.25	5.44	35.77	100.00
Spectrum 5	Yes	8.86	38.17	6.08	0.19	1.09	5.29	-0.02	4.30	0.12	0.88	35.04	100.00
Spectrum 6	Yes	6.80	43.67	1.60	0.87	0.09	0.70	0.04	1.07	0.05	11.97	33.14	100.00
Spectrum 7	Yes	5.31	33.92	2.37	1.37	0.41	2.03	0.05	1.50	0.12	1.18	51.74	100.00
Spectrum 8	Yes	5.59	41.41	1.48	0.38	0.27	0.94	0.10	0.92	0.08	0.77	48.07	100.00
Spectrum 9	Yes	9.53	34.55	1.89	0.24	0.21	1.56	0.05	0.95	0.08	0.93	50.02	100.00
Spectrum 10	Yes	12.56	40.57	1.98	0.18	1.18	3.42	0.04	0.60	0.09	0.84	38.54	100.00
Mean		7.52	37.85	3.70	0.76	0.50	2.30	0.06	2.49	0.11	3.22	41.47	100.00
Std. deviation		2.29	3.17	2.16	0.46	0.37	1.49	0.04	1.70	0.06	3.47	6.62	
Max.		12.56	43.67	6.87	1.37	1.18	5.29	0.15	4.75	0.25	11.97	51.74	
Min.		5.31	33.92	1.48	0.18	0.09	0.70	-0.02	0.60	0.05	0.77	33.14	

20130312 Amy Elizabeth Fort Sumter Iron

3/12/2013 4:28:10 PM





Comment:

Project: 20130312 Amy Elizabeth Fort Sumter Iron

Owner: INCA

Sample: A 14 Traverse rail

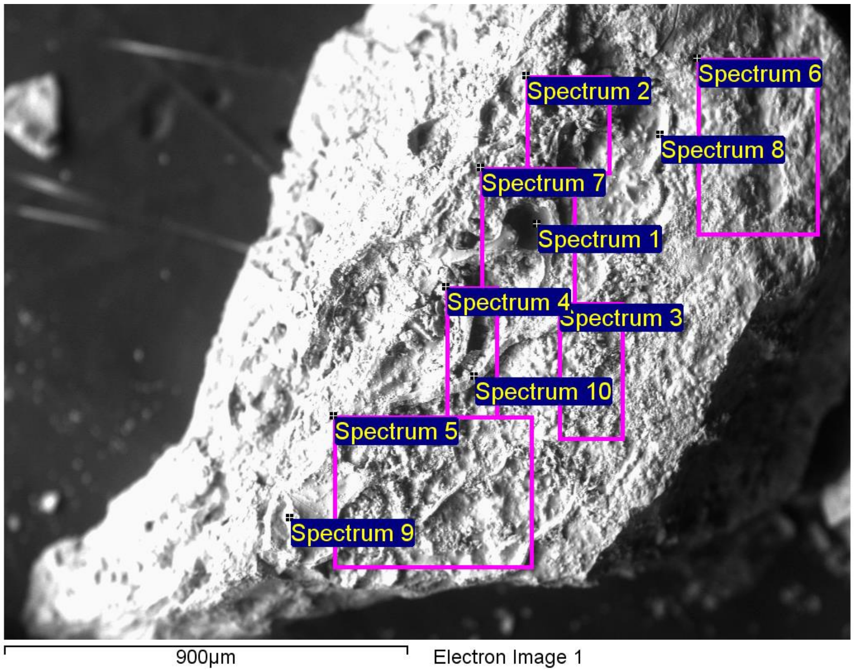
Type: Default

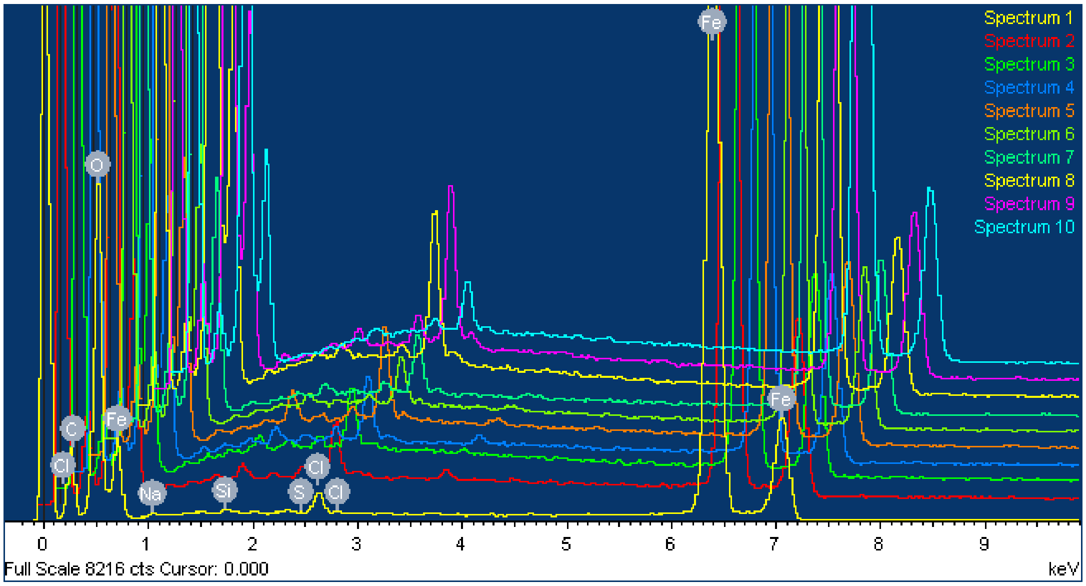
All results in weight%

Spectrum	In stats.	C	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Fe	Ni	Zn	Total
Spectrum 1	Yes	12.85	37.41	1.62	4.62	1.61	5.81	0.67	0.30	2.29	0.39	2.26	29.59	0.27	0.30	100.00
Spectrum 2	Yes	3.29	34.34	1.24	0.19	0.08	0.19	0.43	0.05	0.28	0.14	0.40	59.28	0.14	-0.04	100.00
Spectrum 3	Yes	2.95	37.42	1.29	0.13	0.13	0.14	0.26	0.04	0.35	0.14	0.13	56.85	0.13	0.03	100.00
Spectrum 4	Yes	23.86	33.50	1.10	0.05	0.03	0.68	0.17	0.03	0.54	0.09	0.12	39.29	0.54	-0.01	100.00
Spectrum 5	Yes	20.98	33.71	1.16	0.05	0.04	0.25	0.21	0.02	0.54	0.11	0.17	42.35	0.41	-0.01	100.00
Spectrum 6	Yes	20.37	33.37	1.28	0.03	0.13	0.20	0.18	0.05	0.59	0.10	0.17	43.30	0.23	0.00	100.00
Spectrum 7	Yes	14.48	33.09	2.05	-0.02	0.07	0.21	0.24	0.05	0.96	0.13	0.19	48.28	0.26	0.01	100.00
Spectrum 8	Yes	11.15	32.20	1.83	0.01	0.02	0.23	0.26	0.05	0.92	0.12	0.13	52.96	0.16	-0.05	100.00
Spectrum 9	Yes	17.73	34.16	1.32	0.03	0.00	0.34	0.19	0.03	0.64	0.10	0.16	44.84	0.40	0.06	100.00
Mean		14.18	34.36	1.43	0.56	0.24	0.90	0.29	0.07	0.79	0.15	0.42	46.30	0.28	0.03	100.00
Std. deviation		7.47	1.84	0.33	1.52	0.52	1.85	0.16	0.09	0.61	0.09	0.70	9.24	0.14	0.11	
Max.		23.86	37.42	2.05	4.62	1.61	5.81	0.67	0.30	2.29	0.39	2.26	59.28	0.54	0.30	
Min.		2.95	32.20	1.10	-0.02	0.00	0.14	0.17	0.02	0.28	0.09	0.12	29.59	0.13	-0.05	

20130312 Amy Elizabeth Fort Sumter Iron

3/12/2013 4:34:13 PM





Comment:

Project: 20130312 Amy Elizabeth Fort Sumter Iron

Owner: INCA

Sample: B 3 Pintel

Type: Default

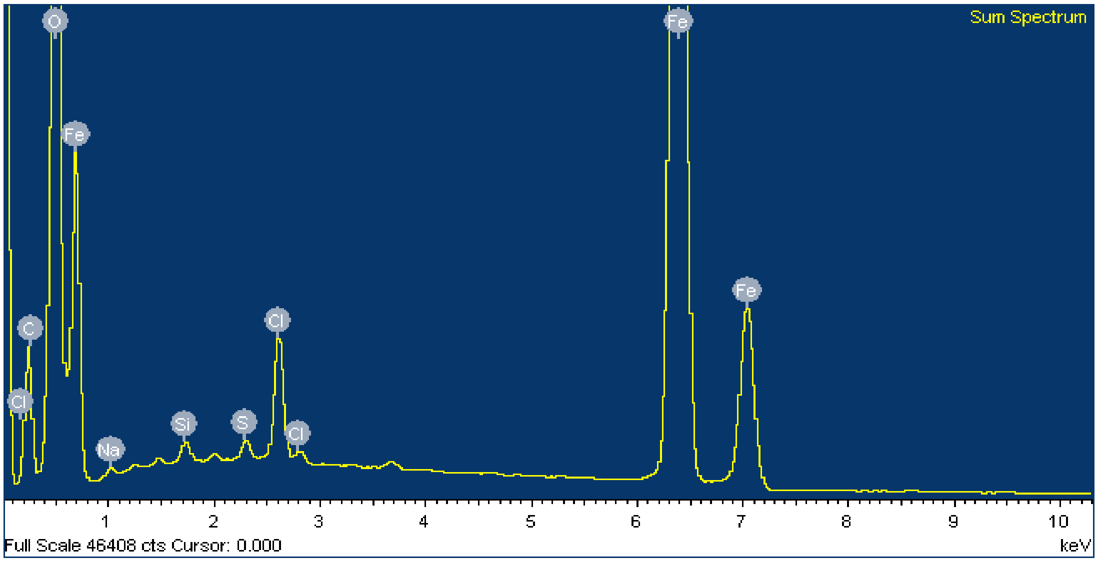
Processing option : All elements analysed (Normalised) - All results in weight%

Spectrum	In stats.	C	O	Na	Si	S	Cl	Fe	Total
Spectrum 1	Yes	12.58	23.52	0.20	0.09	0.04	0.63	62.93	100.00
Spectrum 2	Yes	8.74	29.28	0.16	0.20	0.14	0.80	60.68	100.00
Spectrum 3	Yes	6.04	31.66	0.13	0.18	0.15	0.77	61.08	100.00
Spectrum 4	Yes	7.51	30.22	0.23	0.19	0.14	0.88	60.83	100.00
Spectrum 5	Yes	7.84	31.94	0.17	0.41	0.14	1.26	58.25	100.00
Spectrum 6	Yes	8.04	35.16	0.19	0.15	0.09	0.67	55.70	100.00
Spectrum 7	Yes	8.07	31.78	0.15	0.16	0.15	0.94	58.73	100.00
Spectrum 8	Yes	6.44	41.91	0.12	0.16	0.14	1.85	49.38	100.00
Spectrum 9	Yes	8.75	38.15	0.31	0.21	0.33	1.93	50.32	100.00
Spectrum 10	Yes	5.24	31.09	0.07	0.13	0.15	0.74	62.58	100.00
Mean		7.92	32.47	0.17	0.19	0.15	1.05	58.05	100.00
Std. deviation		2.01	5.02	0.06	0.08	0.07	0.48	4.82	
Max.		12.58	41.91	0.31	0.41	0.33	1.93	62.93	
Min.		5.24	23.52	0.07	0.09	0.04	0.63	49.38	

20130312 Amy Elizabeth Fort Sumter Iron

3/12/2013 4:37:15 PM

Electron Image 1



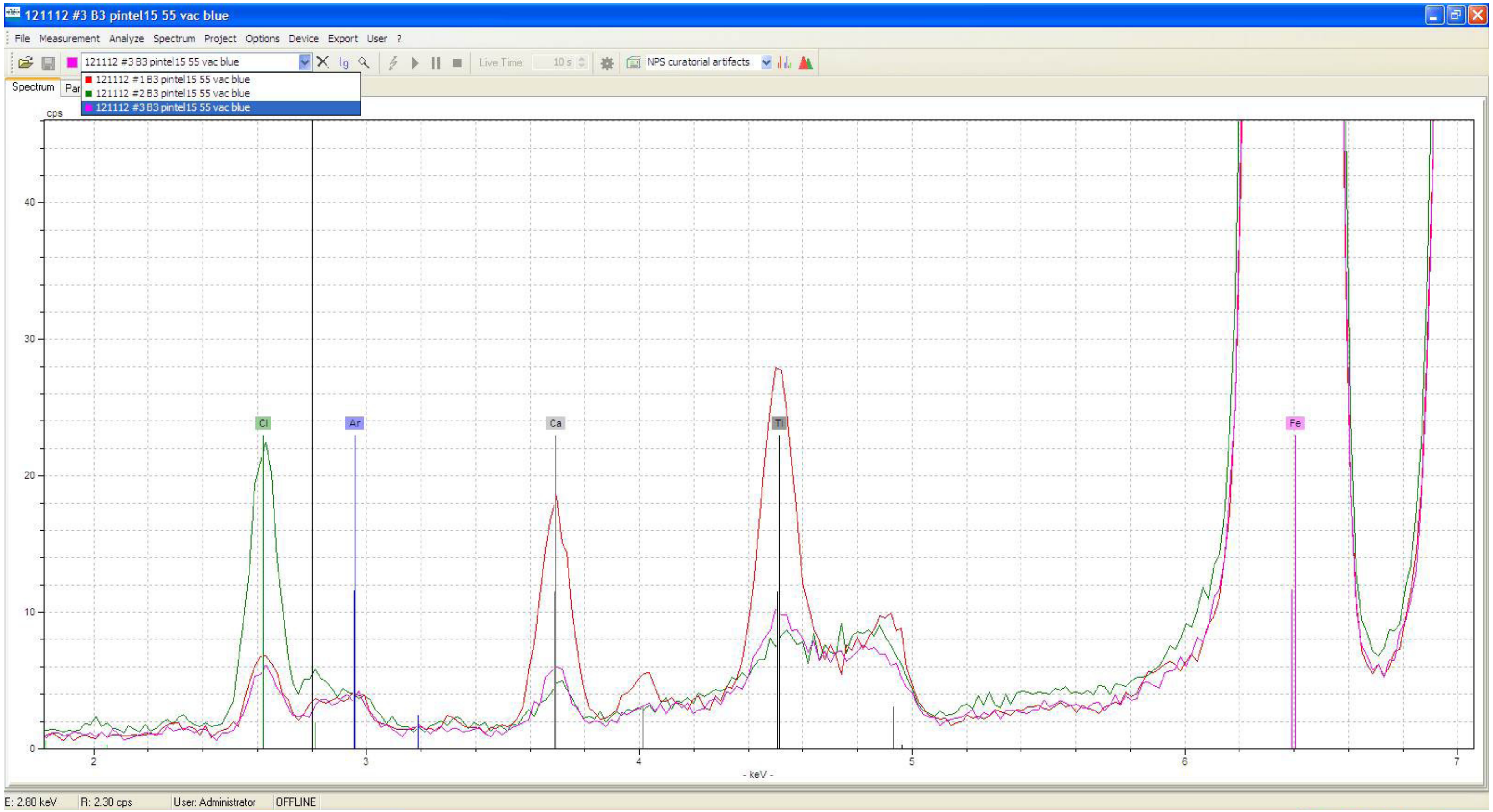
Comment:

Project: 20130312 Amy Elizabeth Fort Sumter Iron Owner: INCA	Sample: B 3 Pintel Type: Default

Processing option : All elements analysed (Normalised)

Spectrum	In stats.	C	O	Na	Si	S	Cl	Fe	Total
Sum Spectrum	Yes	10.29	34.88	0.20	0.23	0.20	1.49	52.71	100.00
Mean		10.29	34.88	0.20	0.23	0.20	1.49	52.71	100.00
Std. deviation		0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Max.		10.29	34.88	0.20	0.23	0.20	1.49	52.71	
Min.		10.29	34.88	0.20	0.23	0.20	1.49	52.71	

B1-3 Pintle Results - overall

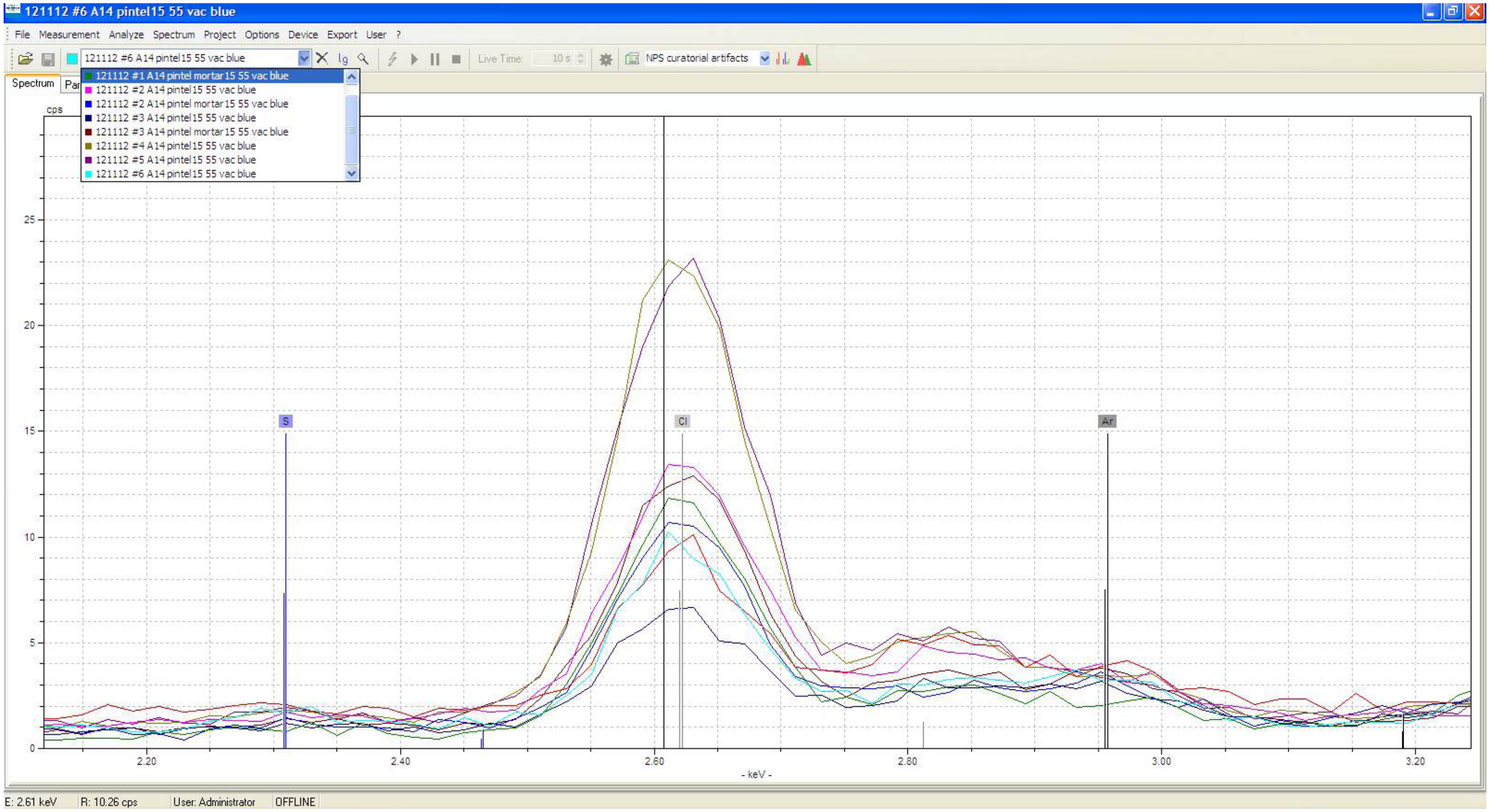


121112 #3 B3 pintel15 55 vac blue

- 🟥 121112 #1 B3 pintel15 55 vac blue
- 🟩 121112 #2 B3 pintel15 55 vac blue
- ■ 121112 #3 B3 pintel15 55 vac blue

E: 2.80 keV | R: 2.30 cps | User: Administrator | OFFLINE

B1-3 Pintle Results -
detail showing chlorine



121112 #6 A14 pintel15 55 vac blue

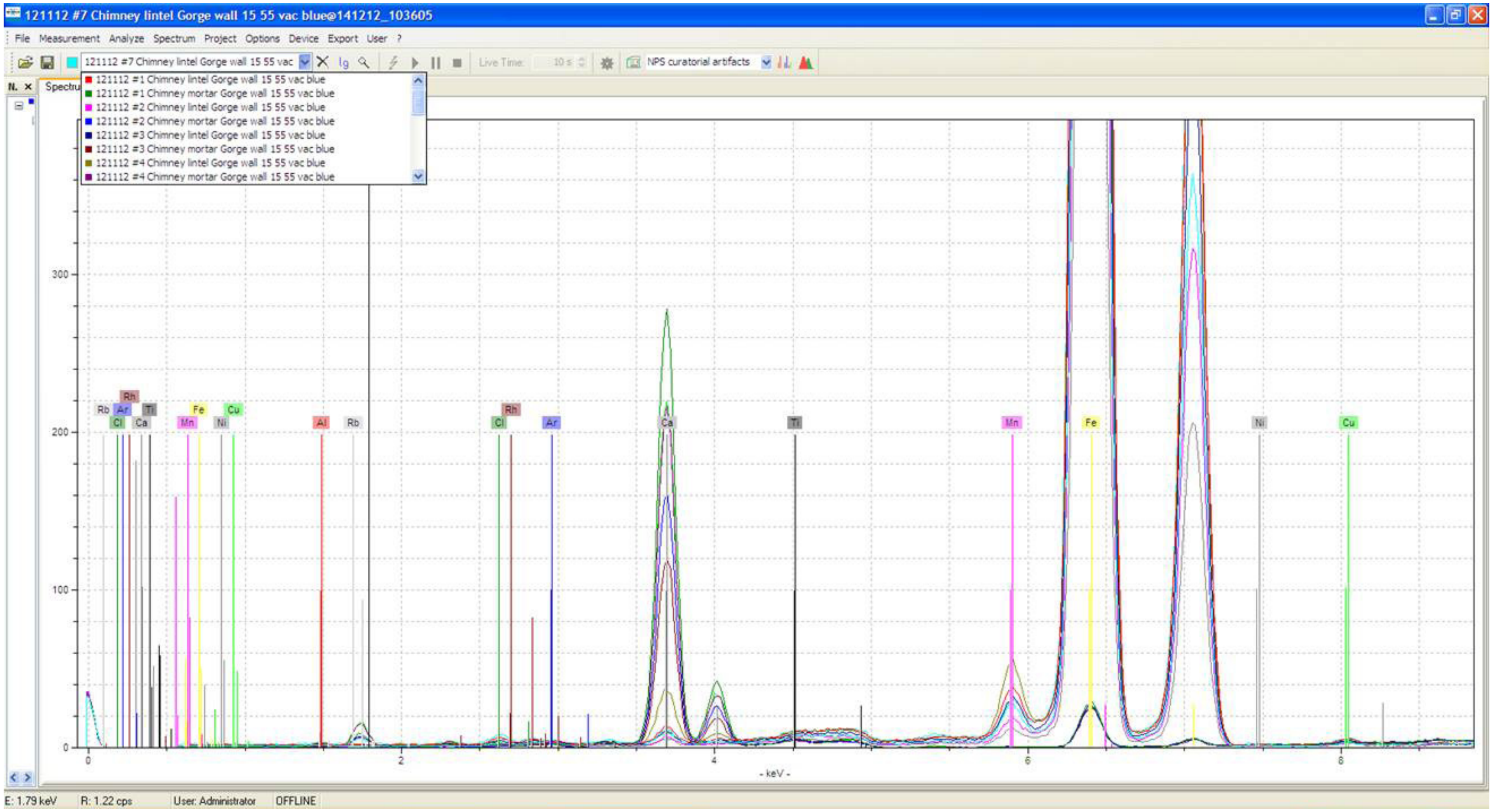
121112 #1 A14 pintel mortar15 55 vac blue
121112 #2 A14 pintel15 55 vac blue
121112 #2 A14 pintel mortar15 55 vac blue
121112 #3 A14 pintel15 55 vac blue
121112 #3 A14 pintel mortar15 55 vac blue
121112 #4 A14 pintel15 55 vac blue
121112 #5 A14 pintel15 55 vac blue
121112 #6 A14 pintel15 55 vac blue

Live Time: 10 s

NPS curatorial artifacts

E: 2.61 keV
R: 10.26 cps
User: Administrator
OFFLINE

Gorge Wall Lintel Results - overall

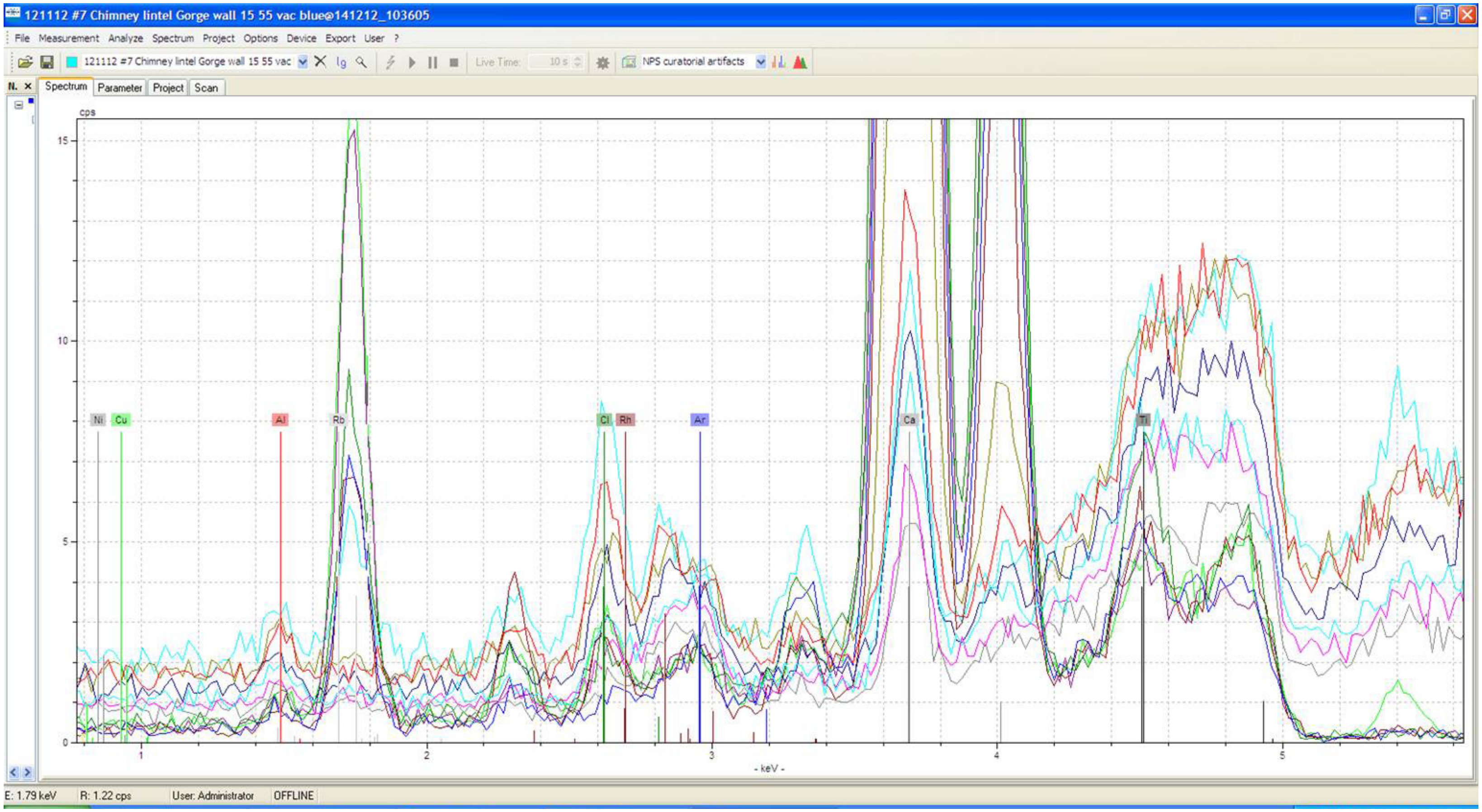


121112 #7 Chimney lintel Gorge wall 15 55 vac blue@141212_103605

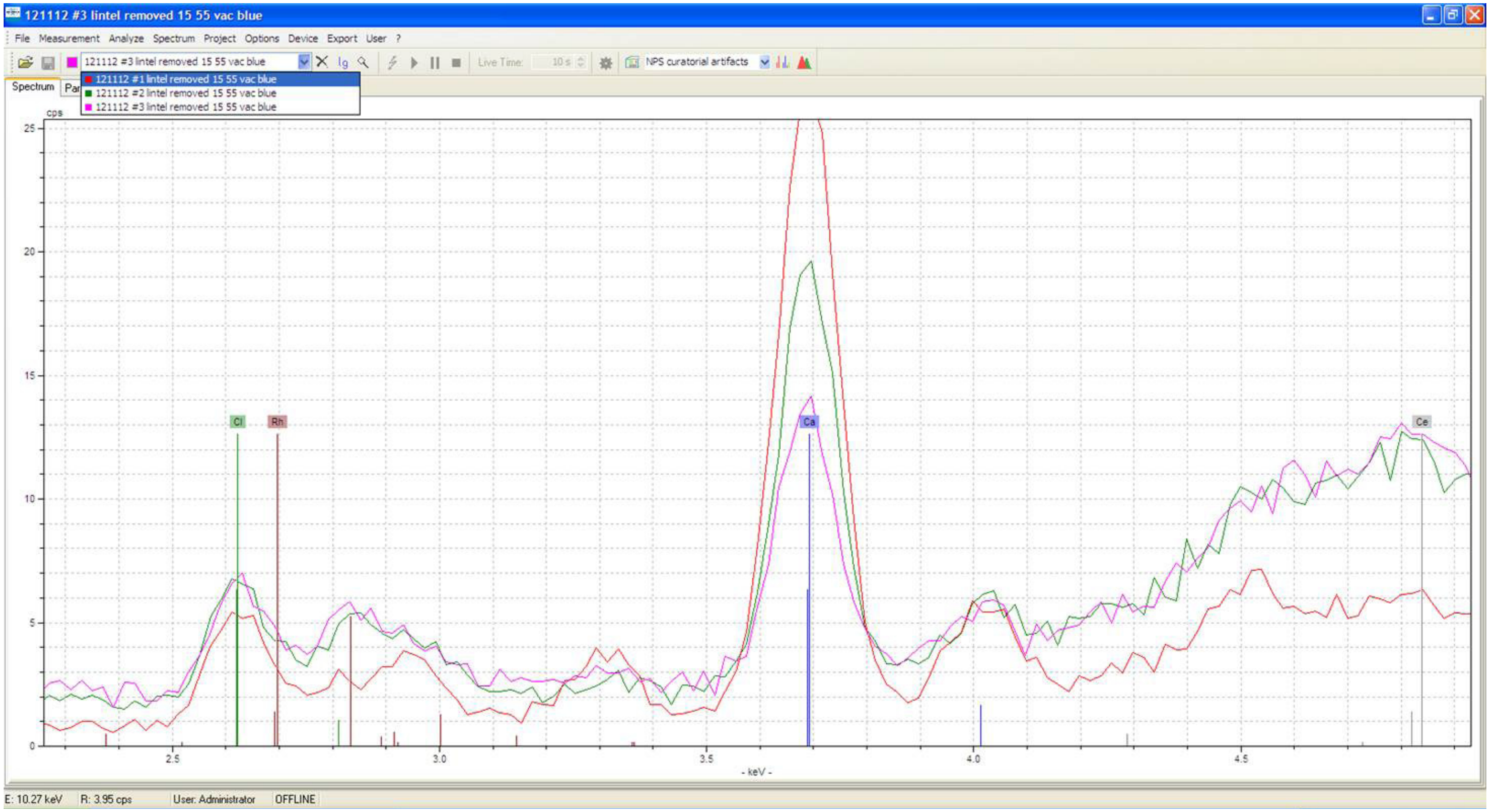
- 🟥 121112 #1 Chimney lintel Gorge wall 15 55 vac blue
- 🟩 121112 #1 Chimney mortar Gorge wall 15 55 vac blue
- ■ 121112 #2 Chimney lintel Gorge wall 15 55 vac blue
- 🟦 121112 #2 Chimney mortar Gorge wall 15 55 vac blue
- ■ 121112 #3 Chimney lintel Gorge wall 15 55 vac blue
- ■ 121112 #3 Chimney mortar Gorge wall 15 55 vac blue
- ■ 121112 #4 Chimney lintel Gorge wall 15 55 vac blue
- ■ 121112 #4 Chimney mortar Gorge wall 15 55 vac blue

E: 1.79 keV R: 1.22 cps User: Administrator OFFLINE

Gorge Wall Lintel Results-
detail showing chlorine



Left Flank Lintel Results - overall



121112 #3 lintel removed 15 55 vac blue

121112 #3 lintel removed 15 55 vac blue

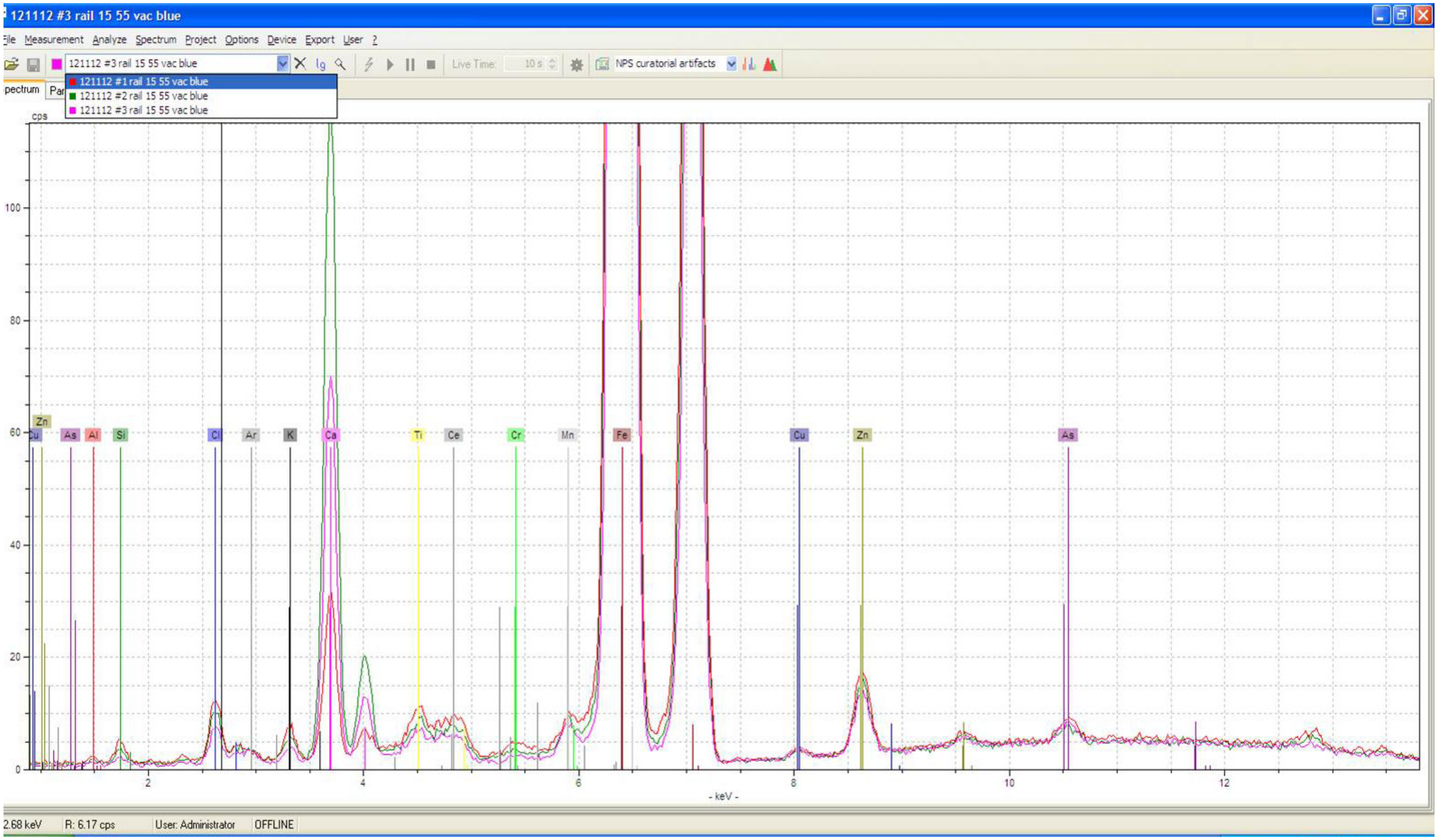
- 🟥 121112 #1 lintel removed 15 55 vac blue
- 🟩 121112 #2 lintel removed 15 55 vac blue
- 🟪 121112 #3 lintel removed 15 55 vac blue

Live Time: 10 s

NPS curatorial artifacts

E: 10.27 keV R: 3.95 cps User: Administrator OFFLINE

Traverse Rails Results - overall



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