Analyzing Mortars and Stuccos at the College of Charleston: A Comprehensive Approach

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This article presents an overview of methodologies currently available for mortar analysis and a suggested approach.

Introduction

Modern methods of investigation are essential to our exploration of traditional crafts and materials. When combined with historical research, techniques such as petrographic examination and instrumental analysis can help us understand how certain materials were manufactured, when and where they were used, and why they were selected for particular applications. Yet these techniques are underutilized in our field. Collaboration between conservator and materials scientist does not occur often enough, even though it can lead to a wealth of new information about the provenance of building materials.

This type of collaboration proved critical to understanding the history of material use for three historically significant buildings at the College of Charleston, in Charleston, South Carolina — Randolph Hall, Towell Library, and Porter's Lodge. In fact, the combination of extensive historical research and technical investigation revealed that the range of binders used in the mortar materials of these buildings represents a general trend in the historic availability of lime and cement products. This campus serves as a microcosm of sorts, representing the evolution of available binders for mortar materials in the United States. This discovery would not have been possible if historical research had not been performed first and if the materials scientist had not played a key role in the technical investigation.

Fig. 1. This 1902 photograph of the Cistern area of the College of Charleston shows Randolph Hall, with Towell Library, built in 1858, to the left. Randolph Hall, originally designed by William Strickland and referred to simply as the Main Building, was begun in 1828. Photograph by William H. Jackson, published in Gene Waddell, *Charleston Architecture* (Charleston: Wyrick & Company, 2003).

Project Background

The College of Charleston was founded in 1770 and became the country's first municipal college in 1836, when the City of Charleston assumed responsibility for its support. In 1970 it was incorporated into the South Carolina state-college system in order to serve a broader region. Although founded in the eighteenth century, much of the physical college campus is comprised of nineteenth-century buildings, some built specifically for the college and others constructed as residences and commercial buildings but absorbed as part of the school's expansion.

The heart of the college's campus, known as the Cistern because of the large underground cistern in its center, is comprised of three buildings and surrounded by a low masonry wall that is topped by an iron fence. The most conspicuous and emblematic of these three buildings is Randolph Hall, formerly known simply as the Main Building until its renaming in 1972 for former college president Harrison Randolph.[1] Randolph Hall was originally designed by William Strickland in 1828 but has

Fig. 2. William Strickland, design for Randolph Hall, 1828. Courtesy of Special Collections, College of Charleston Library.

been significantly modified through subsequent building campaigns.[2] The other two structures that comprise the Cistern area are Porter's Lodge, designed by Charleston architect Edward Brickell White and built in 1851, and Towell Library, designed in the Italian Renaissance Revival style by George Edward Walker and constructed in 1856.[3] All buildings are brick and stucco with stone trim (Fig. 1).

Randolph Hall, as it exists today, is very different from Strickland's original design — a simple plan executed in the "Rational Neoclassical" style with no portico and no wings (Fig. 2). Although depicted as a stuccoed building in Strickland's 1828 sketch, historical documentation indicates that Randolph Hall was not actually stuccoed until the 1850s. Less than 25 years after its construction, architect E. B. White was asked to expand the building, resulting in a remodeling in the Italian Renaissance Revival style. White's new program, implemented in 1851, included the addition of a portico, changes to the doors and windows, and the addition of flanking wings with Ionic pilasters. The building was also first stuccoed at this time.[4]

Thirty-five years after White's modifications, the Charleston earthquake of 1886 caused serious damage to Randolph Hall and required additional changes.[5] White's 1851 portico was damaged, and his wings had to be completely rebuilt, including the foundations. This work was overseen by one of Charleston's "gentleman architects," Dr. Gabriel Edward Manigault (Fig. 3). The wings were not rebuilt simultaneously. The east wing was rebuilt first, in 1888–89, and the west wing was rebuilt five years later, in 1894.[6] The rebuilt wings were intended to mimic White's 1850 design almost exactly, but the addition of curvilinear parapets gave the building more of an Italianate feel. The Randolph Hall of today exists much as it did after Manigault's final 1894 reconstruction work (Fig. 4).

Towell Library and Porter's Lodge, both built in the 1850s, escaped significant damage during the earthquake and have undergone no significant alterations since their original period of construction.

The importance of these buildings, both regionally and nationally, coupled with their relatively intact physical condition, demanded that a thorough documentation of their history be performed. A key part of this documentation involved recording their overall construction history, as well as the materials used to build them. This information was necessary in order to shed light on the intention of the original architects and builders, including their goals for the aesthetic properties of the final buildings, as well as to serve as a guide for contemporary preservation efforts.

Because of the need to understand and record the materials used to build Randolph Hall, Towell Library, and Porter's Lodge, extensive materials analysis was performed on all three buildings in 2006. Archival research was performed in tandem with the materials analysis, uncovering a wealth of written documentation and historic images that provided valuable insight into the buildings' appearance throughout history.

Among the materials analyzed as part of the documentation were the mortars and stuccos of each building. The aggregates, binders, and pozzolans found in mortar are almost entirely of geological materials. Aggregate is either obtained from natural sand deposits or processed from the crushing and screening of rock material. Binders, whether lime- or cement-based, are produced by burning limestone rock of variable purity and chemistry. Pozzolans are obtained directly from natural volcanic deposits, or glassy byproducts of the industrial processing of mineral resources are used. These masonry materials were subjected to a full range of laboratory analyses, including acid-digestion methods, instrumental analysis, and imaging (petrographic) techniques. This combination of techniques represents the best possible means for identifying the composition of mortar materials, and their use on this project allowed important discoveries to be made regarding the provenance and commercial availability of American limes and cements. This article provides a review of this approach to mortar analysis.

Review of Mortar-Analysis Methods

Standards that define appropriate analytical techniques for mortar exist and are slowly being accepted and utilized by the preservation industry.[7] However, more often various nonstandard methods are used, making it difficult for the conservator or architect to judge the validity of the results. The College of Charleston documentation project was viewed early on as an opportunity to utilize a "best practices" approach to mortar analysis, one that would use these existing standards. The techniques used in this approach can be grouped into three distinct categories: acid-digestion methods, instrumental techniques, and imaging methods.

Acid-digestion methods. These methods comprise all of those in which the mortar sample is digested in an acid solution, the Cliver process being the best known.[8] All methods are characterized by an effort to separate the sand from the binder and then calculate component weights by the amount of material dissolved. The advantages of these methods are that they are simple and inexpensive and that they can be performed by almost anyone, regardless of their scientific background. The disadvantage is that the methods are nothing more than algorithms in which a precise series of steps are followed and an answer is generated automatically without any informed judgment on the part of the analyst. Algorithms are wonderful things for computer programs, where numbers always behave in the same way. However, they are inappropriate in the material world, where components are diverse, material categories are arbitrary, and the unexpected should always be anticipated.

Fig. 3. Randolph Hall in 1887, following the Charleston earthquake. Note that the wings built in 1851 had to be completely removed but that the central portion of the building remained relatively unaffected. Photograph from George L. Cook, *Earthquake News, No. 129*, courtesy of Photographic Archives, South Caroliniana Library, University of South Carolina.

Fig. 4. Randolph Hall, 2006. Photograph by D. Krotzer.

Acid-digestion methods work best when it is already known that a mortar consists of a nonhydraulic lime, an aggregate not soluble in the chosen acid, and no pozzolans or pigments. Clearly, this is a severe limitation. Consider a natural-cement mortar containing coral sand, commonly found in nineteenth-century Gulf Coast construction. An acid digestion would leave nothing but a fine residue of unburned clays and silt from the natural cement, and the aggregate would be completely dissolved. By contrast, consider a lime mortar containing ground steel slag as a pozzolanic addition, a mortar commonly used in the southeastern United States during the early twentieth century. The lime would dissolve vigorously, and the copious slag grains would sink to the bottom of the beaker. The algorithm approach would identify this as an oversanded lime mortar with no hydraulic component. Without any other data, the analyst would be forced to accept this result instead of interpreting the findings to indicate the presence of a hydraulic slag cement binder. These examples represent the kind of misinterpretation that can occur when acid digestion is the sole technique used for analysis of historic mortars. In addition, because acid digestion was used as the primary examination tool in both of these examples, the binder component would be destroyed, preventing any further analysis of this crucial mortar component using other techniques.

The acid-digestion method does have value, but when used alone, it is not sufficient to provide accurate identification of mortar components. Other methods are better suited for this purpose, and acid digestion is most appropriate when used as a follow-up to more rigorous analytical techniques. However, acid digestion can be useful when the analyst is faced with a large number of samples that are believed to have a similar composition. It can quickly and inexpensively establish characteristics such as sand gradation, color, and approximate content, allowing for a gross comparison of the samples. But again, the method does not serve well as a primary tool for identification and characterization.

This criticism is not new. As early as the 1980s, methods such as the Cliver process were being critically assessed, as indicated by this quote from a 1982 article in an *APT Bulletin* written by John Stewart and James Moore:

> "What were the materials and their proportions used…?" If the question is to be answered, it seems unlikely that simple chemical techniques will be the solution. As the nature of mortars is largely dependent on their mineralogical composition the solution may lie in crystallographic and petrological techniques.[9]

The limitations of the acid-digestion technique are well understood, and it is hoped that the adoption of more rigorous techniques may improve the analysis of historic mortars. Standards for a more thorough approach using instrumental and petrographic methods are becoming more widely utilized.

Instrumental techniques. A vast array of highly technical analytical instruments are currently available to the construction industry, many of which are routinely applied to mortar analyses. Commonly employed instruments include atomic-absorption spectrometers, which measure elemental composition, and X-ray diffractometers, which identify mineralogical components. These machines are capable of producing very precise data with excellent resolution, but there is no analytical instrument that can identify mortar components and determine proportions. This information can only be arrived at through interpretation by an experienced materials scientist. The instruments are simply tools used by the scientist to answer specific questions during an informed investigation. Careful subsampling must precede the instrumental analysis to isolate the components of interest and correct for expected interferences once these are identified by other methods. After the analysis, results must be interpreted based on an understanding of the technique's limitations.

The instrumental analyses fail when the analyst treats them as "black boxes," forcing the sample in one end of the machine and misunderstanding a precise result at the other end. A good example is the regular use of X-ray diffractometry (XRD) in mortar analysis. XRD bombards a powdered and randomly oriented sample with X-rays at various angles, then detects the regular spacing of atoms as the rays are diffracted by the crystal structure of the component minerals. These atomic spacings are compared to a computer database, and individual minerals are identified. Generally speaking, four or five of the most abundant minerals can be positively identified before the signals begin to overlap or become buried in the noise. Consider then a typical mortar sample where XRD is used to identify the original binder. The whole sample is crushed, and the resulting powder is loaded into the machine. A typical mortar may contain about 75 percent sand by weight, which may contain several dozen minerals. Three-quarters of the signal from the machine will simply be noise from the aggregate. In a cementitious mortar the unhydrated cement crystals may represent a small percentage of the binder, with the remainder being poorly crystalline hydrates or calcium carbonate, a result of normal environmental aging of the mortar. The critical evidence needed to identify the binder is the identification of the unhydrated cement minerals. These minerals may represent two or three mineral phases within several dozen phases and only a very small percentage of the total signal. Therefore, a tool like XRD is best suited for answering very specific questions about mineral phases in portions of the mortar that have been isolated by careful subsampling. XRD is not a tool to diagnose an entire mortar sample in order to generate precise information about overall composition or quantities of ingredients.

When performed by an informed analyst to answer specific questions, instrumental techniques are very effective. However, when treated as a "black box" approach, valuable information can rarely be obtained.

Imaging methods. Imaging, or petrographic, methods apply observational and microscopical examination to materials. Petrographic examination may involve a simple visual field survey or high-magnification imaging using an electron microscope. While these levels of examination may appear grossly different in sophistication, the fact that they involve direct observation of the subject distinguishes them clearly from the methods discussed above. Polarized light microscopy (PLM), which is often used to qualitatively identify components, examine textural relationships, and inform further instrumental analyses, lies between acid digestion and instrumental analyses.[10] Due to the primary use of PLM in petrographic examinations, PLM and petrography are nearly synonymous in mortar analysis. Like any other microscope, the PLM magnifies the subject. However, additional components in the light path take advantage of the fact that crystals refract light. Resulting interference patterns are used by the petrographer to quantify the optical properties of the constituent minerals, and these patterns allow for positive identification. Unlike XRD, where the sample is crushed and randomized, the petrographer observes the material in its intact state using mortar sections milled to transparency. There is no need to guess whether a particular mineral identification belongs to the binder, sand, or a secondary mineral deposit, because the textural context is included in the analysis.

Only imaging methods such as PLM are capable of positively identifying binder materials. The key lies in the presence of preserved grains of partially or fully unreacted binder, or relicts, that are almost invariably present microscopically, even in mortars several centuries old. In some cases the relicts are present as trace components within the matrix. When using instrumental methods such as XRD, the mineral constituents of the relict must be present in an amount sufficient to produce a signal greater than the noise. If not, the measured peaks may not be as high as those produced by random error in the equipment, and the results will be affected. In samples where the binder relicts are present in trace quantities, petrography is the only method that is insensitive to the signal-to-noise-ratio problem. The binder relicts may represent less than one tenth of a percent of the total mortar volume, but once observed through a thorough visual scan of the microscopic section, the surrounding components can be ignored and the critical grain examined in detail. Yet, even where binder relicts are abundant, individual mineral phases may be difficult to interpret using instrumental methods such as XRD. For example, brownmillerite is a weakly hydraulic iron-bearing phase that is present in most types of hydraulic cement. Without visually observing the texture and context of the mineral, it is difficult to interpret the nature of the suspected cement. The iron phase can be observed petrographically as either an interstitial mineral surrounding well-crystallized calcium silicates (as would be the case in a portland cement) or as linings around calcined carbonate (as in a natural cement). The visual context of the petrographic methods provides information that cannot be generated by bulk analytical methods.

Petrographic methods are used extensively in other branches of construction-materials analysis but have been only marginally accepted by the building-preservation industry as a mortar-analysis technique. Of course, finding a qualified petrographer who is versed in the examination of historic building materials is crucial. A conversation with a petrographer prior to commissioning a mortar analysis, as well as an examination of examples of his or her work, should be sufficient to establish that person's experience in construction-materials history and analysis. Geologists trained in the history of materials manufacture who use petrography can provide important information on mineral processing that cannot be provided by an architect or conservator using simple bench-top methods, such as acid digestion.[11]

Positive identification of binder components, as well as the identification of sand and other materials such as pozzolans, are well within the capabilities of PLM. The main limitation of the petrographic methods is that they are qualitative in nature, with only some exceptions. However, when petrography is used as the starting point for choosing appropriate sample preparations for quantitative instrumental analysis and interpreting the behavior of samples separated by acid-digestion methods, it is possible to determine the original mortar-mixture proportions with some

Fig. 5. Randolph Hall, area of bricks and mortar behind stucco that was exposed as part of testing. Samples of both mortar and stucco were removed from this location for laboratory analysis. Photograph by D. Krotzer.

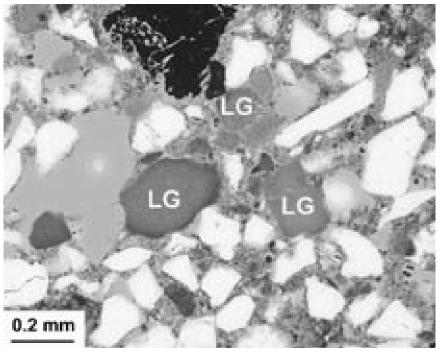

Fig. 6. Mortar samples removed from the brick masonry of the three buildings were identified as common lime mortars. In this photomicrograph of one such mortar, the relict lime grains (LG) are easily distinguished from the surrounding binder matrix by their distinct boundaries, even though both the grains and matrix are composed of calcium carbonate. The grain interiors are simple in mineralogy and microtexture, and no hydraulic species are detected. Photograph by J. Walsh.

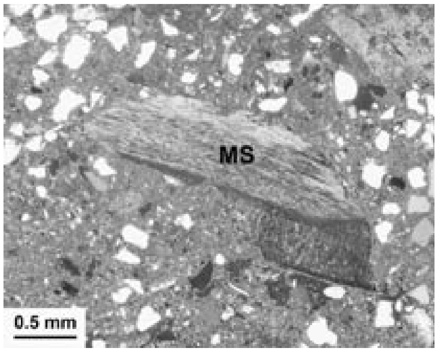

Fig. 7. In petrography, mineralogical materials are observed directly under high magnification. Additionally, since many calcined products retain microstructural evidence of the original rock from which the lime or cement was produced, the method is capable of establishing binder sources. In this photomicrograph of a lime mortar removed from the brickwork of the 1828 portion of Randolph Hall, a lightly burned mollusk shell (MS) with a characteristic herringbone texture indicates an oyster-shell source for the lime. Photograph by J. Walsh.

accuracy. Yet, if the analyst is instructed only to provide data toward a replication mix, then little more than mix components and proportions should be expected. Even where petrographic methods are being appropriately utilized, a great deal of historically significant information may be neglected when the petrographer is not aware of the history of the structure and made a part of the conservation team.

Case Study

For the College of Charleston project, the petrographer was made a key member of the project team. All information gained from the archival research and field investigation was shared in order to provide a context for the laboratory analysis and to ensure that the most informed results were achieved.

Guided by the history of these buildings, samples of mortar and stucco were removed from key areas in order to document the materials used to construct each building (Fig. 5). Preliminary visual examination of brick-mortar samples suggested superficial similarities among materials used in the three buildings. Each of the mortars was pale yellow in color and very soft and friable and contained chunks of white lime particles visible to the naked eye. Laboratory analysis confirmed that three mortars were indeed similar, containing a very porous binder matrix and a large amount of sharp, uniformly sized siliceous sand. Microscopic lime grains were detected petrographically in all samples. A close examination of the lime-grain interiors revealed an absence of hydraulic mineralogies, and all were identified as nonhydraulic limes (Fig. 6).

These mortars would appear to be good candidates for analysis through simple acid-digestion techniques. Nonhydraulic lime dissolves readily in a dilute acid, leaving behind the acid-insoluble sand for careful examination. The weight proportions of the lime and sand could be determined by comparing the weight of the residual sand to that of the original sample. Original volume proportions could be estimated, provided appropriate bulk densities are used to convert the weight percentages to volumes. However, petrographic examination reveals subtle differences that provide interesting evidence for the source of the lime in each sample. Lime products are calcined, or burned, at a relatively low temperature that is still sufficient to drive off the bound carbon dioxide. In many cases, either the original microfabric of the limestone rock or the trace silicate minerals are partially preserved after calcination. Since these textures are familiar to geologists, the original rock source for the lime can often be established.

The mortar sample removed from Randolph Hall, the earliest of the three buildings, contains evidence of a lime that was produced from oyster or mollusk shells. Viewed petrographically, the sample of this 1828 mortar contains fine-grained broken mollusk shells that appear to have been heated, or calcined, as part of the lime-production process. Figure 7 shows the characteristic herringbone pattern indicative of mollusk shells. This image suggests not only that this mortar is based on high-calcium lime but also that this lime was derived from the calcination of shells. However, mortars removed from the two buildings dating to the 1850s, Porter's Lodge and Towell Library, indicate the use of a lime burned from a rock source, rather than shells. Although the mortar looks superficially very similar to that of Randolph Hall, the lime binder in these later mortars contains relict minerals within the residual binder grains that suggest that the lime was derived from a marble source. These include relatively coarse-grained micas and amphiboles that would never be found in a sedimentary limestone (Fig. 8).

This shift in material usage was discussed in 1886 by G. E. Manigault, the architect who rebuilt Randolph Hall after the Charleston earthquake, when he mentioned the character and durability of Strickland's original construction materials:

> This lime was invariably made from oyster shells, which were gathered at the mouths of the various rivers and inlets. The industry of burning lime from shells was an important one, and continued so until the cheaper stone limes from the Northern States were introduced, and the home-made article gradually was driven out of the market. This did not occur, however, until about the year 1838…[12]

Laboratory analysis of the mortars of the Cistern-area buildings supports Manigault's statement. The evidence indicates that the lime shifted from locally available oyster-shell lime to "imported" rock-based lime sometime between 1828 and 1851. This change may have been the result of a shift in commercial availability, cost, or a preference for lime produced from stone instead of shells.

The analysis of historic stuccos produced similar findings. Examination of stucco samples removed from different sections of Randolph Hall revealed interesting information about availability of lime and cement materials in the Charleston region in the late-nineteenth and early-twentieth centuries, an availability that seems to mirror that of the United States as a whole.

Samples of stucco were removed from two portions of Randolph Hall — White's 1851 stucco campaign and Manigault's stucco campaign of 1888 (because the building was not stuccoed until the 1850s, there was no Strickland-era stucco to sample). Results of the laboratory analysis indicate that the stucco sample from the 1851 Randolph Hall is a sanded, natural-cement mortar. Like limes, natural cements are produced by calcination. The original rock microtexture is preserved in natural-cement residuals. Characteristic features of American natural cements include fine rhombic shapes of calcined dolomite surrounded by rims of recrystallized iron-bearing minerals.[13] Also common are disseminated quartz silt grains surrounded by rims of hydraulic product. Petrographic analysis revealed these forms in abundance in the 1851 stucco (Fig. 9). Additionally, it was possible to determine that no lime has been added to the stuccos, as thin-section observations revealed no distinctive lime grains within the cementitious matrix.

A natural cement is defined as a cement that is derived from the burning of a single source of highly impure limestone. It is the natural but fortuitously distributed impurities that give the cement the characteristic of hydraulicity, or the ability to set by reaction with water. Portland cements differ from natural cements in that the distribution of impurities required to produce the hydraulic properties are created by artificially blending multiple rock types in carefully balanced proportions and heating the finely ground mixture at high temperature to produce a hydraulic cement. Natural-cement-based mortars and stuccos were quite common in the mid- to late nineteenth century, and the raw materials would have been readily available at the time of White's alteration of Randolph Hall.

The conscious decision to use a hydraulic material for the stucco at Randolph Hall is documented in the college's archives. In 1839 a special committee of the board of trustees recommended "that the building, for its preservation, as well as improvement, requires to be rough cast, or covered with Roman cement."[14] Roman cement was a European product, a commercially processed natural cement, which was available in the U.S. by the early nineteenth century. Despite the recommendation, money for the work was not raised until 1850, and the building was not stuccoed until 1851. During these 12 years there was a major shift in the availability of cement in the United States. By 1850 American natural cements were being produced as far south as Georgia, and historical literature hints at the use of this cement in the Charleston area by 1852.[15]

Whether the newer American cements were used in the stucco instead of the European Roman cement was an interesting question that was addressed through careful laboratory analysis. One of the major differences between American and European natural cements is the magnesium content of the source rock. Generally speaking, European cements were high in calcium, while the majority of American cements were instead dolomitic, or rich in magnesium. In order to determine the origin of the binder used in the stucco, the samples were analyzed chemically using atomic-absorption spectroscopy. The sequence of the analysis was critical to its success. First, the petrographic examination was performed to qualitatively identify all components, and the sample was then carefully prepared to isolate the binder fraction before performing the atomic-absorption spectroscopy. Petrographic examination of the sand revealed no significant acid-soluble species, allowing for a more aggressive acid digestion to completely decompose the binder. The residuals from the digestion were then checked petrographically to ensure that no binder matrix remained. The original petrographic examination also revealed that no other binder components, pigments, or pozzolans were present, meaning that the measured chemistry would represent that of the original natural cement. The analysis yielded high magnesium contents and magnesium-to-silica ratios typical of those reported historically for American cements.[16] The presence of an American natural cement was conclusive, and this same natural cement was found on Towell Library and Porter's Lodge, also dating to the 1850s. The cement identified in this stucco demonstrates that domestically manufactured natural cement was readily available in Charleston by the 1850s.

The second Randolph Hall stucco sample, removed from the 1888 addition, was noticeably harder and denser than the 1851 stucco. Petrographic and chemical analysis helped to explain why the later stucco seemed to be so different. The analysis indicated that it was not a natural-cement-based stucco but was instead a pure portland-cement-and-sand-based mortar with no lime component. Unlike the binders in the lime and the natural-cement samples, the binder relicts of the later stucco displayed complete obliteration of original rock fabric and complete crystallization of hydraulic minerals. This type of recrystallization is known as clinkering and indicates burning at relatively high temperatures. Portland cement is produced by clinkering, and the minerals identified in the later stucco are typical of those found in modern portland cements. However, the textures observed petrographically are quite different from any typically found in twentieth-century cements (Fig. 10). The unusually large size of belite crystals suggest long burn

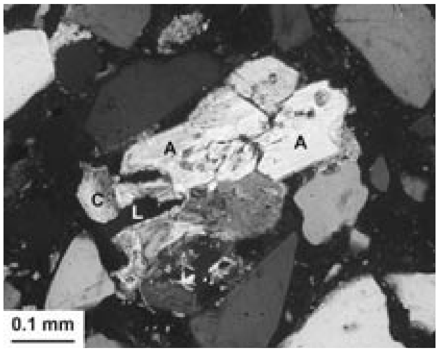

Fig. 8. The lime grain shown in this photomicrograph of a sample of brick mortar removed from Porter's Lodge contains lime (L), calcite (C), and a silicate mineral called amphibole (A). Amphibole is a high-temperature mineral not found in either oyster shells or sedimentary limestone. However, it is a common mineral in marble. This evidence indicates a marble lime source for the brick mortars of Towell Library and Porter's Lodge, which date from 1856 and 1851, respectively.

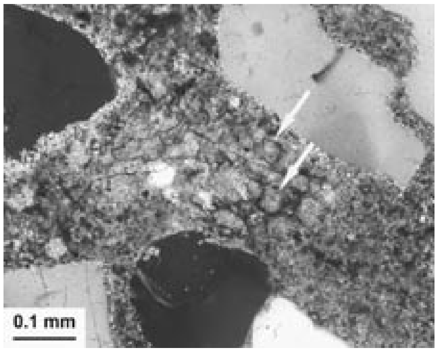

Fig. 9. All stuccos examined at the three buildings at the College of Charleston were identified as pure natural-cement mortars. Rhombic-shaped, calcined dolomite grains surrounded by iron-bearing ferrite (arrows) are textures typically found in American natural cements. Careful choice of chemical procedures following the petrographic examination allowed for a determination of the original binder chemistry. The high magnesium content, among other chemical signatures, provided conclusive evidence that the cement was an American product. Photograph by J. Walsh.

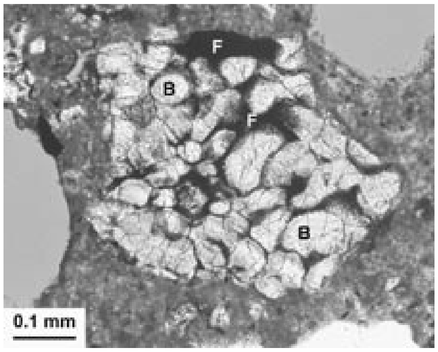

Fig. 10. The binder relicts detected in this sample of stucco removed from the 1888 portion of Randolph Hall displayed complete obliteration and recrystallization of the original rock texture. Coarse-grained belite (B) surrounded by interstitial ferrite (F) is shown in this photomicrograph. The coarseness of the belite, as well as variation in colors observed in other binder relicts, suggests variable kiln conditions. The cement textures are atypical of twentieth-century cements and are more typical of cements from the 1870s and 1880s. Photograph by J. Walsh.

times in the kiln, but high variability in the sizes suggests inconsistent kiln temperatures. The deep amber color of many of the crystals is indicative of slow cooling rates. The distinctive quality of the cement relicts are consistent with those often found in cements domestically produced in the 1870s and 1880s, a date which meshes well with the 1888 date of construction for the east wing of Randolph Hall.

Restoration of the Cistern-area buildings is currently being planned and is expected to begin in the spring of 2009. This work will involve some degree of repointing and stuccoing. Fortunately, the results of the extensive research and analysis presented in this article will allow for informed decisions about replication mix and performance requirements of new materials.

Conclusion

In order to yield accurate, thorough, and useful information, mortar analysis should be undertaken by a team consisting of both an architectural conservator and a material scientist. In this case the conservator performed historical research and physical investigation, which in turn generated questions about the materials used to construct the building and how they have performed. The materials scientist, a petrographer-geologist, performed focused analysis and testing in order to answer questions raised by the conservator. This type of collaboration is essential if new information regarding the history of construction materials and their usage is to be generated and documented.

This case study represents an example of this type of collaboration. The success of the project at the College of Charleston was based largely on three key factors that should be considered by any person performing or commissioning mortar analysis. First, establishing a historical context for the building, as well as its overall construction chronology, is an important step in understanding what materials one might expect to find. Secondly, collaboration and discussion between a conservator and a materials scientist is essential to fully documenting mortar materials. Only a petrographer trained to identify natural cements, high-calcium limes, and hydraulic materials can interpret samples of mortar and stucco to a level of specificity that will reveal important information about historical usage of masonry building materials. Lastly, pointed questions about a mortar's composition must be asked by the conservator and the analyst. These questions should be guided by the historical research and physical observations both on site and in the lab.

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