

Stafford Slave Settlement

Cumberland Island National Seashore, Georgia



Masonry Materials Analysis and Testing

January 2020



BUILDING CONSERVATION ASSOCIATES INC.

Stafford Slave Settlement

Cumberland Island National Seashore, Georgia

Masonry Materials Analysis and Testing

Prepared For

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January 2020



BUILDING CONSERVATION ASSOCIATES INC.

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I.0 INTRODUCTION

At the request of Joseph K. Oppermann – Architect, P.A., Building Conservation Associates, Inc. (BCA) performed testing and analysis of multiple historic masonry materials removed from the Stafford Slave Settlement on Cumberland Island National Seashore in Georgia. The materials tested were removed from the remaining chimneys that are present at the ruins of the Stafford Slave Settlement. The chimneys are constructed of four primary masonry materials: tabby brick, red clay brick, mortar, and stucco/parging. The testing and analysis performed by BCA was limited to the tabby brick, red clay brick and mortar.

The materials testing is being performed as part of a larger project involving the structural stabilization of select chimneys that remain at the site. The work performed by BCA and presented in this report involved both physical testing and evaluation in the laboratory, as well as in situ visual assessment. The goal of the testing and evaluation was to document the physical properties of the historic masonry to guide certain aspects of the chimney stabilization project. The following report summarizes the findings of both the field observations and laboratory testing.

The report is organized by material (tabby brick, red clay brick and mortar), with sections on methodology as well as final conclusions and recommendations. All work required for the execution of this testing and evaluation was performed by Dorothy S. Krotzer, BCA Regional Director with assistance from Highbridge Materials Testing, Inc. (Highbridge). Highbridge submitted six separate reports as part of their laboratory analysis and testing, all of which are appended to this report. While this report summarizes Highbridge's findings and puts them in the context of the site, review of their in-depth and comprehensive reports is strongly recommended for a full understanding of the Stafford Slave Settlement's masonry materials.

2.0 METHODOLOGY

On 19-20 August 2019, BCA performed a site visit to Cumberland Island to remove masonry materials from the Stafford Slave Settlement for laboratory analysis and testing. A total of 21 individual material samples were removed, including several full brick units. A list of the samples is included on the following page (*Table 1*) and representative photographs of sample locations are included in *Images 1-16*. While on site, in addition to removing samples, BCA also examined the extant chimneys for typical conditions and patterns of deterioration. Observations from the site visit are summarized in Section 3.1 of this report.

All of the material samples removed by BCA were shipped to Highbridge. Once received, BCA and Highbridge collaborated to decide the type and extent of testing that should be performed in order to provide the most useful information to the National Park Service (NPS) and the project team. The testing regimen developed by BCA and Highbridge for the tabby brick, red clay brick and mortar is summarized below and the results are summarized in Section 3.0 of this report. For a detailed description of the methodology used for each testing procedure, see Highbridge's reports in *Appendices A- F* of this report.

It should be noted that the tabby brick does not fit any modern material category, so the test methods had to be adapted from several different standards.

Testing and Analysis of Tabby Brick

- *Compositional analysis of tabby brick.* This testing combined petrographic examination and chemical analysis to identify constituents, estimate proportions, and assess overall condition of the tabby brick. An acid digestion to extract an aggregate sample for description and gradation was also performed.
- *Gradation analysis of tabby brick aggregate.* Acid digestion was performed on three additional brick samples and the content and gradation of the acid-insoluble constituents compared. The reason for this analysis was because it was anticipated that there may be some variation in the tabby brick mix proportions.
- *Physical property testing of tabby brick.* This testing included compressive strength, absorption, and saturation coefficient determination on a sample of five brick specimens.
- *Qualitative identification of salts in tabby brick.* Identification of water-soluble salts present within the brick through x-ray diffraction analysis. Three samples were chosen for the analysis, two identified by BCA as distressed and one identified by BCA as sound.
- *Qualitative identification of clays in tabby brick.* X-ray diffraction analysis was performed on clays extracted from one brick sample to determine whether swelling varieties are present. This testing was performed in order to evaluate the possibility that the weathering of the tabby brick is the result of the swelling behavior of clay constituents during wetting/drying cycles.
- *Gradation analysis of local silt/clay.* Analysis of a sample of local sediments removed from the shore of the island was performed because it is suspected that this material may have been used in the tabby manufacture. The laboratory disaggregated this loosely consolidated

material and graded it through standard sieves. The color and gradation of the sediment was compared to the acid-insoluble material recovered from the tabby brick to see if there was any similarity.

Analysis of Mortar

- *Compositional analysis of masonry mortar.* This testing combined petrographic examination and chemical analysis to identify constituents, estimate proportions, and assess overall condition of the tabby brick bedding mortar. An acid digestion to extract an aggregate sample for description and gradation was also included.

Analysis of Red Clay Brick

- *Petrographic examination of red clay brick.* One sample of red clay brick was examined petrographically. The purpose of this petrographic examination is to evaluate the constituents and microstructural features of the brick and to assess any potential causes for deterioration.

Table I. Masonry Samples Removed

Sample No.	Chimney No.	Material Type	Description
Stafford.1	18	Tabby brick bedding mortar	Taken from interior side of chimney above lintel.
Stafford.2	11	Tabby brick bedding mortar	Taken from location of roof peak, area of mortar build-up, mortar continues into adjacent joint, (i.e. same material as mortar in joints).
Stafford.3	1	Tabby brick bedding mortar	Small sample from exterior mortar joint, west exterior face
Stafford.4	4	Parging	Parging does not appear to be original (different color than mortar original, evidence of soiling on face of mortar under parging).
Stafford.5	N/A – Sample Discarded		
Stafford.6	4	Red brick	Found on ground next to chimney, presumed to be from west surround of hearth.
Stafford.7	16	Tabby brick	East side of hearth, “f” marked on face
Stafford.8	1	Tabby brick	West side of hearth, interior-facing side of chimney, removed from middle wythe
Stafford.9	18	Tabby brick	Interior-facing side of chimney (same location as Stafford.1), original orientation of brick not clear.
Stafford.10	10	Tabby brick	Found in rubble pile next to chimney
Stafford.11	10	Tabby brick	Found in rubble pile next to chimney
Stafford.12	22	Tabby brick	Found in rubble pile next to chimney
Stafford.13	22	Tabby brick	Found in rubble pile next to chimney
Stafford.14	22	Tabby brick	Found in rubble pile next to chimney
Stafford.15	22	Tabby brick	Found in rubble pile next to chimney
Stafford.16	22	Tabby brick	Found in rubble pile next to chimney
Stafford.17	22	Red brick	Removed from back wall of hearth
Stafford.18	4	Tabby brick	Removed from west side of chimney, significant erosion of brick face
Stafford.19	3	Tabby brick	Removed from back exterior face of chimney, significant erosion of brick face
Stafford.20	16	Tabby brick	Removed from northwest corner of chimney, face only, “B” marked on back/interior of brick) mild erosion of brick face
Stafford.21	N/A	“clay rock” from shore	



Image 1. Typical intact chimney with replaced wood lintel. Note the use of red brick for the hearth and firebox and the use of tabby brick elsewhere.



Image 2. General setting of the majority of the chimneys, located in a shaded tree grove in approximately the middle of the island. Some chimneys were previously stabilized in 2008.



Image 3. Location of the sample Stafford. I.



Images 4 and 5. Location of the sample Stafford.2.

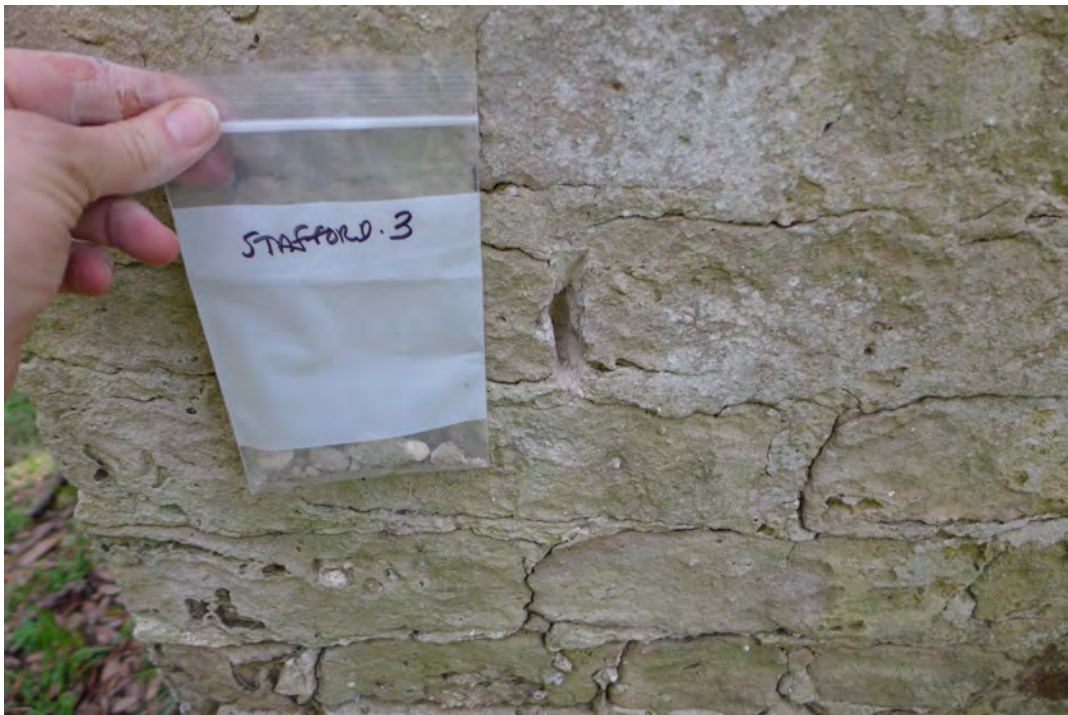


Image 6. Location of the sample Stafford.3.

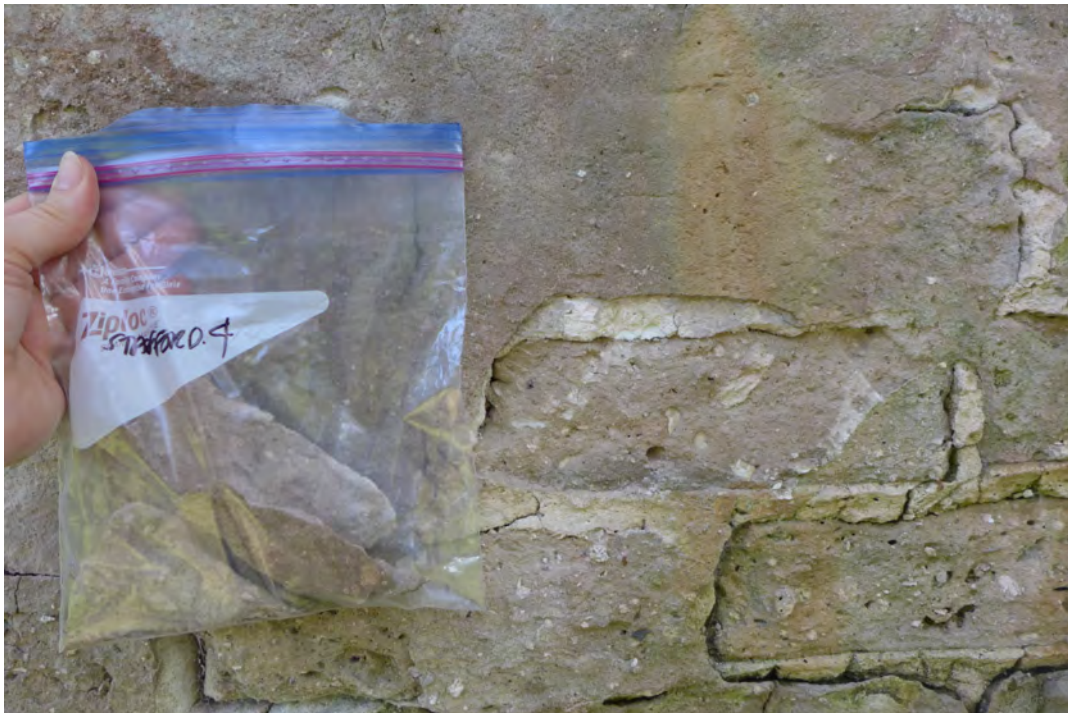


Image 7. Location of the sample Stafford.4.



Image 8. Location of the sample Stafford.6.



Image 9. Location of the sample Stafford.9.



Image 10. Location of the sample Stafford.17.



Image 11. Location of the sample Stafford.19.



Images 12 and 13. Location of the sample Stafford.18.



Images 14 and 15. Location of the sample Stafford.20.



Image 16. Location of the sample Stafford.21, the “clay rock” or deposited sediment found along the shore of the island.

3.0 SUMMARY OF FINDINGS

The chimneys of the Stafford Slave Settlement are constructed of four primary masonry materials: tabby brick (a cast product); red clay brick (a fired product); mortar; and stucco/parging. The parging is only present on some chimneys and is only partial where it does exist. It is unclear whether the parging, which is a similar brown color as the tabby brick, is original or added. The parging was not examined in detail as part of this study.

The findings summarized below are primarily derived from the results of the extensive laboratory analysis and testing performed by Highbridge (see *Appendices A-F*), with *Section 3.4* summarizing BCA's observations from the site visit.

3.1 Tabby Brick

The pale brown-colored tabby bricks at the Stafford Slave Settlement are handmade, cast products composed solely of non-hydraulic lime and sand. Unlike the more well-known tabby concrete, it does not include broken shells as a coarse aggregate addition, although numerous shell fragments are present in the brick and are readily observed. (*Images 7 and 11*) However, these shell fragments are interpreted to have originated from the burning of oyster shell to produce the lime used to make the brick, and not as intentional aggregate additions. These unburned shell fragments and other lime conclusions are fairly plentiful, making up between 7-10% of the brick sample examined. In general, the tabby brick is more like a coarse lime mortar than a true tabby.

The aggregate found in the tabby brick is a very fine and narrowly-graded natural quartz sand typical of Southern coastal lime mortars of the 19th century. There is a trace amount of silt, clay, and organic matter, which were probably part of the sand originally. It is this material, even in a small amount, that is responsible for the pale brown color of the brick. The sands for the four brick examined are all essentially the same. In addition, the color and gradation of the sand in the tabby brick matches that of the sands in both the sediment sample and the mortar sample analyzed as part of this study. This evidence indicates that the sands for both the tabby brick and mortar came from the same general geological deposit, most likely on Cumberland Island. (*Chart 1*) It is interesting to note that the original sediment material has a high percentage of dark-colored fines (approximately 12%), which must have been rinsed off prior to being used for the tabby brick and the mortar because the percentage of these fines in the brick and mortar are significantly lower.

The proportion of ingredients was also examined in four different tabby bricks and found to be incredibly consistent. The bricks are made of lime and sand in a proportion of 1 part lime: 1.5 parts sand, by volume, with the lime interpreted as a dry hydrate and not a putty. If interpreted as a lime putty, the proportions are 1 part lime : 1.8 parts sand. The consistency of proportions is unusual and striking. It is at a level usually found only in modern premixed mortars where batching is done in a controlled plant setting. This level of consistency could have been the result of the bricks being made from a single, large, well-mixed batch of lime and sand. Or, more likely, the brick manufacturing process involved careful measuring procedures. Either way, the proportion consistency indicates a fairly controlled and somewhat sophisticated means of manufacture for the tabby brick.

The petrographic examination of the tabby brick shows a material of good quality and no inherent material flaws. Its ingredients are well-mixed, adequately consolidated, and effectively

cured. The resulting product is highly cohesive. The binder is fully carbonated, as expected for the material and age. Typical of lime mortars, the tabby brick is soft and highly permeable. No deleterious effects from being in service were identified petrographically. The clay portion of the brick was extracted and analyzed to determine if they were of the swelling variety, which could contribute to the long-term erosion of the tabby brick. The analysis determined that swelling clays are not present in any appreciable concentration in the brick.

The physical properties of the tabby brick were also evaluated using a combination of test techniques and standards. The compressive strength of the brick ranges from 400 to 600 psi, which is in the range expected for a well-cured, non-hydraulic lime based mortar. For the compressive strength testing, the laboratory took cores in two directions from each of the five bricks to determine compressive strength. The reason for this was to determine if there was any significant strength anisotropy, since the tabby brick could potentially contain relatively flat shell fragments that would likely have been compacted in a direction perpendicular to the bed face during the casting process resulting in a plane of weakness. Anisotropy can impact how the bricks decay in service. The results of the testing indicate that there is no statistically significant difference between the two groups of cores tested (perpendicular and parallel), suggesting the brick ingredients were not strongly preferentially aligned during casting. Therefore, anisotropy is not a concern. One additional core sample was tested in each orientation under saturated conditions because it was also suspected that the tabby brick may be appreciably weaker when wet. The results indicate that the strengths while saturated are 60% to 70% that of the dry values.

Absorption values of the tabby brick are rather high, as expected for non-hydraulic lime-based mortars. Strength is more variable than absorption and there is no good correlation between the two. This suggests that the variations in strength are not directly controlled by porosity.

The tabby brick were also tested for the presence of soluble salts. While salts were observed on the brick in several locations during the site visit, the quantity and type of salts was unknown. Knowing the type of salts present in masonry can help to identify the source(s), which can aid in eliminating the source when possible. Three tabby bricks were tested for salt content, two were in a deteriorated condition and one was in sound condition, provided as a control of sorts. The two bricks in deteriorated condition contain approximately 1% soluble salts by weight. The salts include halite (NaCl), niter (KNO_3) and darapskite ($\text{Na}_3(\text{SO}_4)(\text{NO}_3)(\text{H}_2\text{O})$). These types of salt are likely from a combination of seawater (the chloride and sulfate salts) and the decay products of naturally-occurring matter in the soil (the nitrate salts). They are typical of those expected to be associated with low-lying marine environments. The brick in good condition was also tested and found to contain very little salt. Although the salts could have been introduced through the sands used to make the tabby brick, it is more likely that they are the result of rising damp, migrating upward through capillary action from the underlying soil. The very low concentration of salts in the sound brick sample indicates that the salts are not present in the same quantity for all bricks, which would be the case if the salts were in the original brick mix.

The variety of salts documented in the two damaged brick are certainly capable of causing progressive decay of the brick matrix through repeated wetting and drying cycles. The sulfates would tend to be the most destructive, but none of the salts are considered innocuous. This makes sense when one considers that some of the most pronounced damage observed on site was at the edges or sides of the chimney bases, where wetting and drying cycles would occur more frequently. Because there is no evidence for the presence of swelling clays in the brick matrix, nor are there other common environmental factors such as freeze-thaw cycling that

would damage the tabby brick, it is possible that soluble salts are one of the more significant causes of erosion in the tabby brick.

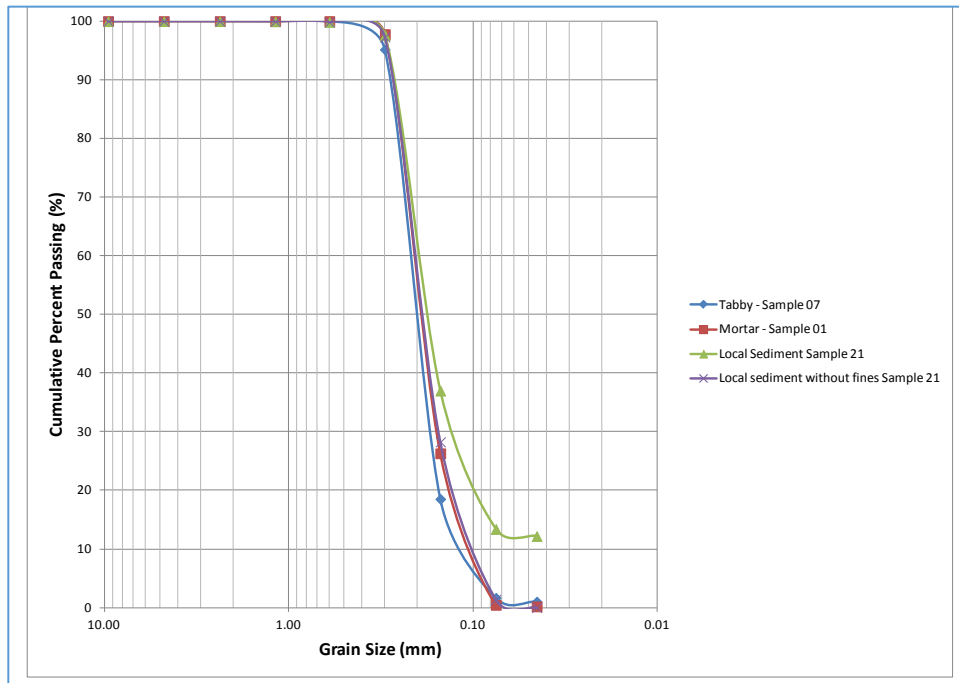


Chart I. This chart compares the sand profiles in the tabby brick (Sample 07), the bedding mortar (Sample 01), and the local sediment sample (Sample 21). Note that the profiles are essentially identical.

3.2 Red Clay Brick

The red clay bricks at Stafford Slave Settlement are hand-molded, fired bricks. The brick is uniform in texture with a purplish-red matrix and darker spots distributed evenly throughout the unit. The material is sandy-textured, highly permeable and well-fired. Microscopically, the brick is found to have approximately even volumes of sintered clay, fine temper, and micropores. The temper, which constitutes approximately 30% of the total brick volume, is a fine quartz sand that was a natural component of the brick clay. The ingredients are well-mixed and there is no streaking of the clay. The overall composition and microstructure of these red bricks are typical of many Southern coastal bricks of the nineteenth century.

There is only minor hairline cracking is evident in the brick and no significant secondary mineralizations. The red brick material is intact and sound.

3.3 Mortar

The mortar analyzed for the current study was removed from the tabby brick masonry. More specifically, it was removed from the interior (protected) side of Chimney 18 above the lintel. (*Image 3*) The mortar is off-white in color (Munsell code approximately 10YR 8/1) and contains visible lime particles and incompletely burned shell fragments. It is relatively uniform in appearance. Although it was not analyzed as part of this study, the parging on the interior of the chimneys appears to be the same white-colored mortar material.

Laboratory analysis determined that the mortar is a common lime mortar. The lime is a non-hydraulic fat (high calcium) lime prepared from oyster shell and apparently screened to remove coarser shell fragments. The aggregate is a very fine and narrowly graded natural quartz sand. It appears to be the same sand as documented in the tabby brick and the sediment deposit sample, but with the fines removed. The lack of these fines, which impart a brownish color to the sediment and the tabby brick, are what make the mortar white in color.

The proportions of ingredients in the mortar are estimated at 1 part lime : 1.4 parts sand by volume, with the lime calculated as a putty. If calculated as a dry hydrate, the proportions are 1 part lime : 1.1 parts sand, by volume. This is a fairly common proportioning for historical lime mortars, especially ones that contained narrowly graded sands such as the Stafford Slave Settlement tabby brick mortar. Such sands have high void contents and require a greater amount of binder to ensure thorough consolidation.

The materials were thoroughly mixed, adequately consolidated, and well-cured. There are no sand steaks or coarse binder inclusions. The resulting product is highly cohesive, though like the tabby brick, it maintains the softness and high permeability typical of lime mortars.

Discontinuous microscopic shrinkage cracks were observed, but this is typical of lime mortars (especially those with a relatively high sand content) and not considered a defect. The binder is fully carbonated as expected for the material and age. Aside from the normal shrinkage cracks, there is no physical distress of any kind identified petrographically.

3.4 Visual Observations from Site Visit

The condition of the masonry materials varies widely from chimney to chimney, and also on each individual chimney. However, in general, the tabby brick and the mortar exhibit the worst conditions. The red brick is generally in moderate to good condition. Typical material conditions observed for the tabby brick include: erosion, often severe and concave; cracking, through both brick units and mortar joints; and loss of entire units. The mortar shows signs of cracking in most joints, as well as separation of the mortar from the brick units in many locations. The mortar is also severely eroded in places, typically in locations where the tabby brick are also eroded. Salts were also observed on all of the masonry materials.

Although the conditions tend to be localized and somewhat random, some patterns of deterioration were observed. The most severe damage seems to be concentrated at the outside corners of the chimney bases, at the backs of the hearths, and in any location where a dense Portland cement re-pointing mortar or patching has been installed. In light of the information provided in the materials testing reports, this pattern makes sense. If cyclical wetting and drying of soluble salts is considered one of the primary causes of the severe tabby brick deterioration (namely erosion), then the pattern of eroded bricks at the bottom of the chimneys seems logical. The bricks at the bases of the chimneys are closer to the ground and the soluble salts are entering the brick masonry from the salt-laden ground moisture through rising damp and then hydrating or crystalizing (both of which cause damage to masonry). Damage from salts associated with rising damp tends to manifest themselves several inches or feet from the ground, depending on the type of salt and other environmental conditions, because this is the location where the salts are drying. The corners of the chimneys, which tend to exhibit some of the most extreme erosion, would tend to go through more frequent wetting and drying cycles than the rest of the chimneys, since they are exposed to air on two sides. The corners may also be more subjected to rain run-off from the “shoulders” of the chimneys, although this was not directly observed during the site visit.

The presence of Portland cement patches and repointing, although not prevalent, is also causing damage to the tabby brick where it does exist. The dense, impervious Portland cement material redirects moisture through the adjacent highly porous tabby brick and historic mortar, exacerbating their deterioration. Portland cements can also contain salts such as sulfates, which could also be entering the adjacent tabby brick masonry and contributing to their deterioration.

The loss of chimney stacks, which is a prevalent condition, is seen as a structural condition and not a material condition. However, where chimney stacks remain, the tabby brick tend to be in relatively good condition. This observation is consistent with the theory that the worst damage is occurring closer to the ground due to proximity to salt-laden ground moisture.



Image 17. The thin, brown-colored parging that is present on some of the chimneys (usually in partial form) is visible on this chimney.



Image 18. The exterior side of the hearth is typically in poor condition on most chimneys, as is visible in this photograph.



Image 19. This chimney clearly exhibits the typical deterioration pattern of eroded corners of the chimney base.



Image 20. Portland cement repair materials have caused deterioration in adjacent tabby brick.

4.0 CONCLUSIONS AND RECOMMENDATIONS

As a result of this study, the materials and properties of the primary masonry materials used to construct the chimneys of the Stafford Slave Settlement are much better understood. These materials include cast tabby bricks made of lime and sand, fired red clay bricks, and lime mortar. As documented by the analysis, the majority of these materials (the lime and sand used to make the mortar and the tabby brick, as well as the red brick) are typical of Southern coastal building materials of the 19th century. In addition, the ingredients for these materials (with the exception of the red clay brick) were most likely obtained from the island and manufactured on it as well. Of particular interest is the great consistency of ingredient proportions, or batching, exhibited by the tabby brick, which is unusual for a 19th century mortar material and more typical of contemporary industrial mixing. The proportion consistency indicates a fairly controlled and somewhat sophisticated means of manufacture for the tabby brick.

The results of the laboratory analysis, in tandem with the field assessment, indicate that all of the masonry materials used to construct the chimneys of the Stafford Slave Settlement are considered sound from a material perspective. When not exposed to external conditions such as salts, Portland cement repair materials or structural stresses, the tabby brick and mortar are in relatively good condition as individual building materials. Their composition and physical characteristics are not inherently flawed, and it is only when an external factor is introduced that they are damaged.

The fundamental good quality and sound composition of these materials affects the recommendations that are made for the repair and stabilization of the chimneys. Because they are not intrinsically flawed and do not contain any inherent deleterious ingredients or negative physical properties, replication of the materials can be considered.

The following recommendations for the masonry portions of the chimneys are made based on the findings of the field assessment and laboratory analysis:

1. Selective repointing, or as needed for structural stabilization and reconstruction.

Repointing of open or severely deteriorated mortar joints is recommended for the long-term preservation of the chimneys. Re-pointing and re-setting of tabby and red brick will also be required as part of any stabilization or reconstruction efforts associated with the current project. Because the mortar used for the chimneys is a fairly traditional high-calcium, non-hydraulic lime mortar that has performed adequately over its life, a replication mortar based on the original mortar is recommended with two adjustments.

First, the original sand used for the mortar is very fine and somewhat narrowly graded. It does not comply with modern masonry and gradation profiles as specified by ASTM C144. Therefore, the sand for the replication mortar should be fine-grained, similar in color, and graded to be similar to the original particle size distribution of the aggregate while meeting the requirements of ASTM C144.

Secondly, because a less fine sand and more well-graded sand will be used, a replication mix based on slightly more sand is recommended. While the original mortar ratio was 1 part lime putty to 1.4 parts sand, **the recommended replication mortar mix is 1 part lime putty: 2 parts sand (by volume)**. This mix is also more in line with current industry standards.

It should be noted that lime putty mortars require special precautions to ensure the proper installation and long-term durability. Because lime putty mortars take longer to cure and carbonate than lime-cement hybrid or hydraulic lime mortars (full carbonation of non-hydraulic lime can take years), it is important to protect the mortar during its initial cure. In order to ensure a proper cure, we recommend that the following precautions be taken when using lime putty mortars:

- Install at least 28 days prior to expected freezing temperatures to prevent the mortar from freezing. This should not be an issue on Cumberland Island, but is nonetheless important to note.
- Do not install during the hottest summer months when mortar may dry out prematurely.
- Do not install in areas of perpetual dampness.
- Protect from sun, wind and rain for at least 14 days.
- Moisten mortar and allow to dry in regular cycles during the initial cure to allow for carbonation.
- Best results will be obtained from a mason who is familiar with lime putty mortars, as their workability and working time differ from that of cement-lime hybrid mortars.

The lime putty manufacturer's precautions and recommended installation procedures should be consulted before beginning work.

2. Selective replacement of significantly deteriorated bricks, or as needed for structural stabilization and reconstruction.

Replacement of significantly damaged or deteriorated bricks, both tabby and red clay, is a significant part of any repair or stabilization effort for the chimneys. Fortunately, the tabby brick is a material that can be replicated fairly easily by hand and does not need to be made by a manufacturer. The original tabby brick, which were cast in molds or possibly shaped by hand, were composed of only lime and sand. New tabby bricks can be made that essentially replicates this mix. However, as with the replication mortar discussed above, two modifications to the original mix are needed: the use of a sand that matches the original as closely as possible while still meeting ASTM C144, and the use of slightly more sand than the original tabby brick. **The recommended mortar mix for the replication tabby brick is 1 part hydrated lime: 2 parts sand (by volume).** It should be noted that a dry hydrate is recommended for the tabby brick as opposed to a lime putty, which is what was used originally. The reason for this is that it will be much easier to thoroughly mix the required large batches of mortar for the tabby brick production if the mortar is initially mixed dry. Shrinkage will also be less of an issue if the dry hydrate is used instead of a putty, although some shrinkage is to be expected when casting these bricks of mortar.

The same considerations for working with lime-based mortars that are outlined above are also true for these tabby brick.

As for the red clay brick, these cannot be made by hand as they are a fired product. Instead, salvaged or newly manufactured bricks that visually match the original should be sourced. Fortunately, far fewer red clay replacement brick are needed than replacement tabby brick.

3. *Removal of Portland cement repair materials.* Existing Portland cement repair materials (parging, pointing) should be carefully removed and replaced with the recommended lime mortar above. The removal of the Portland cement materials will most likely damage the tabby and red clay brick masonry. However, the removal of this material is felt to be critical to the long-term preservation of the masonry and the long-term benefits of its removal are felt to outweigh any damage that might occur during the removal process.

4. *Accept rising damp of salt-laden ground moisture.* Although salts have been identified as one of the primary causes of the deterioration of the tabby brick and mortar, it is virtually impossible to eliminate this factor from affecting the masonry. All of the chimneys come into direct contact with the soil and elimination of the salts from the ground is not an option. While damp proof coursing to address the issue of rising damp exists (in both physical and chemical applications), it is not felt to be appropriate for this site. It is an invasive procedure with sometimes limited benefit. The success of damp-proof coursing, especially chemical, is not proven and the idea of introducing another material into these chimney assemblies does not seem prudent.

Appendix A

**“Report on Physical Properties of Tabby Brick”
(Highbridge Materials Consulting, Inc., 11/18/19)**

Report on Physical Properties of Tabby Brick

Stafford Slave Settlement, Cumberland Island
National Seashore, Chimney Stabilization
Cumberland Island, Camden County, GA



Prepared for
Building Conservation Associates, Inc.

Client ID
BUIL005

Report No.
SL1443-01

Report Date
11/18/19



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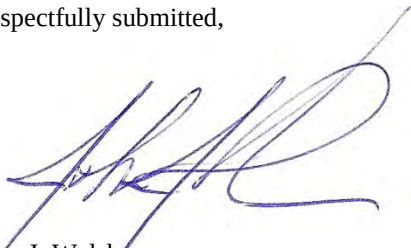
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Highbridge has performed its services in conformance with the care and skill ordinarily exercised by reputable members of the profession practicing under similar conditions at the same time. No other warranty of any kind, expressed or implied, in fact or by law, is made or intended. Interpretations and results are based strictly on samples provided and/or examined.

Cover Image

Photograph of a chimney structure at the Stafford Slave Settlement on Cumberland Island, GA courtesy of Ms. Dorothy Krotzer of Building Conservation Associates, October 2, 2019.

Respectfully submitted,



John J. Walsh
President/ Senior Petrographer
Highbridge Materials Consulting, Inc.

1. Executive Summary

This report presents compressive strength, absorption, and saturation coefficient values for tabby brick sampled from the Stafford Slave Settlement on Cumberland Island, GA. Five individual units were sampled for this testing and strength was performed in two orientations relative to the assumed casting direction. Testing was also performed in wet condition for Sample 12. Table 1.1 presents the average test results.

Table 1.1: Summary of Findings

Property	Average	Standard deviation
Dry compressive strength - perpendicular (psi)	480	110
Dry compressive strength - parallel (psi)	450	70
Wet compressive strength - perpendicular (psi)	310	n/a
Wet compressive strength - parallel (psi)	400	n/a
Cold water absorption (%)	18.0	1.1
Boiling water absorption (%)	26.3	0.8
Saturation coefficient	0.68	0.04

The following statements may be offered regarding the test data:

- Compressive strengths range from about 400 to 600 psi. This is in the range expected for a well-cured non-hydraulic lime-based mortar. It is worth noting that any spalling of the brick faces would occur in tension. A rule of thumb for brittle solids is that tensile strength should be about an order of magnitude less than compressive strength.
- A statistical analysis was performed on the strength testing performed perpendicular and parallel to the assumed casting direction (Appendix II). No statistically significant difference is identified between the two groups. This suggests that the constituents were not strongly preferentially aligned during casting.
- For Sample 12, companion cores were tested under saturated conditions. This results in strengths that are 60% to 76% of the dry values.
- Absorption values are rather high as expected for non-hydraulic lime-based mortars. The variance is small for both cold and boiling water absorption.
- A graphical plot of strength vs. absorption is presented in Section 6. Strength is more variable than absorption and there is no good correlation between the two. This suggests that the variations in strength are not directly controlled by porosity.

2. Introduction

On August 27, 2019, Highbridge received a set of masonry samples from Ms. Dorothy Krotzer of Building Conservation Associates reported to have been sampled from chimney structures at the Stafford Slave Settlement on Cumberland Island, GA. A summary of the samples, their identifications, and locations is presented in Appendix III. It is understood from the client that the site represents the ruins of a 19th century slave housing settlement in which only the chimney structures survive. The chimneys are reported to have been constructed of tabby brick with red clay brick used for the hearth and firebox.

At Ms. Krotzer's request, laboratory testing is performed on the samples to provide information that may assist in an ongoing stabilization effort. The testing plan was developed in discussions between Ms. Krotzer and Mr. John Walsh of Highbridge. The plan was finalized in a telephone call on September 20 and includes the following:

1. Qualitative identification of salts in tabby brick

Surface erosions on tabby brick may be the result of salt hydration or crystallization. The client has requested an identification of water-soluble salts present within the brick through x-ray diffraction analysis. Three samples are chosen for the analysis, two the client has identified as distressed and one the client has identified as sound.

2. Qualitative identification of clays in tabby brick

Weathering of the tabby brick may also be the result of the swelling behavior of clay constituents during wetting/drying cycles. X-ray diffraction analysis will be performed on clays extracted from one brick sample to determine whether swelling varieties are present.

3. Compositional analysis of tabby brick

This testing combines petrographic examination and chemical analysis to identify constituents, estimate proportions, and assess overall condition of the tabby brick. An acid digestion to extract an aggregate sample for description and gradation is also included. One sample will be examined comprehensively.

4. Gradation analysis of tabby brick aggregate

It is anticipated that there may be some variation in the tabby brick mix proportions. Rather than examine several samples comprehensively, a less costly acid digestion will be performed on an additional three brick samples. The content and gradation of the acid-insoluble constituents will be compared.

5. Gradation analysis of local silt/clay

The client has provided a sample of local sediments from the shore of the island. It is suspected that this material may have been used in the tabby manufacture. The laboratory will disaggregate this loosely consolidated material and grade it through standard sieves. The color and gradation of the sediment will be compared to the acid-insoluble material recovered from the tabby brick.

6. Physical property testing of tabby brick

The testing includes compressive strength, absorption, and saturation coefficient determination on a sample of five brick specimens. Since the tabby brick potentially contains relatively flat shell fragments and would likely have been compacted in a direction perpendicular to the bed face, it is suspected that there could be significant strength anisotropy. If so, this might have a bearing on the manner in which the brick decays in service. The laboratory will take cores in two directions from each of the five bricks to determine compressive strength. It is also suspected that the tabby brick may be appreciably weaker when wet. One additional core sample will be tested in each orientation under saturated conditions.

7. Compositional analysis of masonry mortar

This testing combines petrographic examination and chemical analysis to identify constituents, estimate proportions, and assess overall condition of the tabby brick bedding mortar. An acid digestion to extract an aggregate sample for description and gradation is also included. One sample will be examined comprehensively.

8. Petrographic examination of red clay brick

One sample of red clay brick will be examined petrographically. The purpose of a petrographic examination is to evaluate the constituents and microstructural features of the brick and to assess any potential causes for deterioration observed by the client on site.

This report presents results of the physical properties of the tabby brick masonry units. Results for the other tests will be presented under separate cover when complete.

3. Methods of Examination

The tabby brick does not fit any modern standard material category. As such, test methods were adapted from several standards and optimized for the tabby.

Compressive strength testing was performed on five specimens chosen from rubble pile sample. Samples 10, 12, 13, 14, and 16 were selected for the testing. Since tabby brick is a cast material, there is the possibility of anisotropic mechanical properties due to the preferential alignment of elongate or plate-like particles during consolidation. In order to evaluate this, the laboratory chose to test compressive strength in two dimensions. A better statistical comparison could be made if the same population of five brick were used for comparison. Additionally, it was desired to test at least one specimen under saturated conditions in both orientations. This would allow an assessment of the worst possible conditions.

In order to achieve all of this, it was decided to take core samples from the bricks rather than cutting larger blocks. Cores were taken at 1.5" diameter on a drill press fitted with a diamond coring bit. For each brick, one core was taken perpendicular to the bed surface, and another parallel to the bed surface and perpendicular to the face. For Sample 12, an additional pair of cores were taken to test strength under saturated conditions. The perpendicular cores were labeled with an "E" suffix after the brick number. The parallel cores were labeled with an "A" suffix. A "W" was appended to the sample identifications for the cores intended to be tested under wet conditions.

The ends of each core were trimmed square to remove any irregularities. The cutting was done to keep the cores as close to a 2 : 1 length to diameter ratio without exceeding this ratio. Most of the preparation and conditioning from this point onward was done in partial accordance with ASTM C67, the standard for clay brick. All cores were dried to constant weight at 110°C for not less than 24 hours. A very thin application of shellac was applied to the cut surfaces. Just enough was applied to slow the absorption of mix water from the capping compound without achieving any penetration into the tabby. From here, the core ends were capped with a high-strength gypsum plaster and cured in a low temperature oven overnight. The cores for wet conditioning were further immersed in water for 48 hours prior to testing. All cores were tested to failure in a compression machine meeting the requirements of ASTM E4-16. The test results were rounded to the nearest 10 psi. No correction factors were applied to account for length to diameter ratios less than 1.75. This is not expected to result in any appreciable error.

The absorption and saturation coefficient testing was performed in general accordance with ASTM C67/C67M-19. Rectangular prisms were sawn from the portions of the tabby brick remaining after cores were sampled for strength testing. The faces of the prism were trimmed to remove any weathered or soiled material. The absorption method chosen includes the 24-hour cold water absorption followed by the 5-hour boiling water absorption. Calculation of the saturation coefficient is also included.

The following personnel contributed to the examination:

Technician: M. Pattie
Supervisors: H. Hartshorn
J. Walsh

4. Compressive Strength Testing

Table 4.1: Compressive Strength Results - Perpendicular Cores

Specimen ID	10E	12E	13E	14E	16E
Capped length (in.)	2.55	2.45	2.17	2.31	2.10
Diameter (in.)	1.47	1.48	1.48	1.48	1.48
Length/diameter ratio	1.73	1.66	1.47	1.56	1.42
Area (sq. in.)	1.71	1.72	1.71	1.71	1.71
Load (lbf)	1033	914	912	632	635
Compressive strength (psi)	610	530	530	370	370
Average (psi)	480				
Standard deviation (psi)	110				

Table 4.2: Compressive Strength Results - Parallel Cores

Specimen ID	10A	12A	13A	14A	16A
Capped length (in.)	2.76	2.94	2.95	2.94	2.96
Diameter (in.)	1.47	1.48	1.44	1.46	1.47
Length/diameter ratio	1.88	1.99	2.05	2.01	2.01
Area (sq. in.)	1.70	1.72	1.63	1.67	1.70
Load (lbf)	848	887	646	593	799
Compressive strength (psi)	500	520	400	350	470
Average (psi)	450				
Standard deviation (psi)	70				

Table 4.3: Compressive Strength Results - Wet-Conditioned Cores

Specimen ID	12EW	12AW
Capped length (in.)	2.60	2.95
Diameter (in.)	1.47	1.48
Length/diameter ratio	1.77	2.00
Area (sq. in.)	1.70	1.72
Load (lbf)	533	696
Compressive strength (psi)	310	400

5. Absorption and Saturation Coefficient Determination

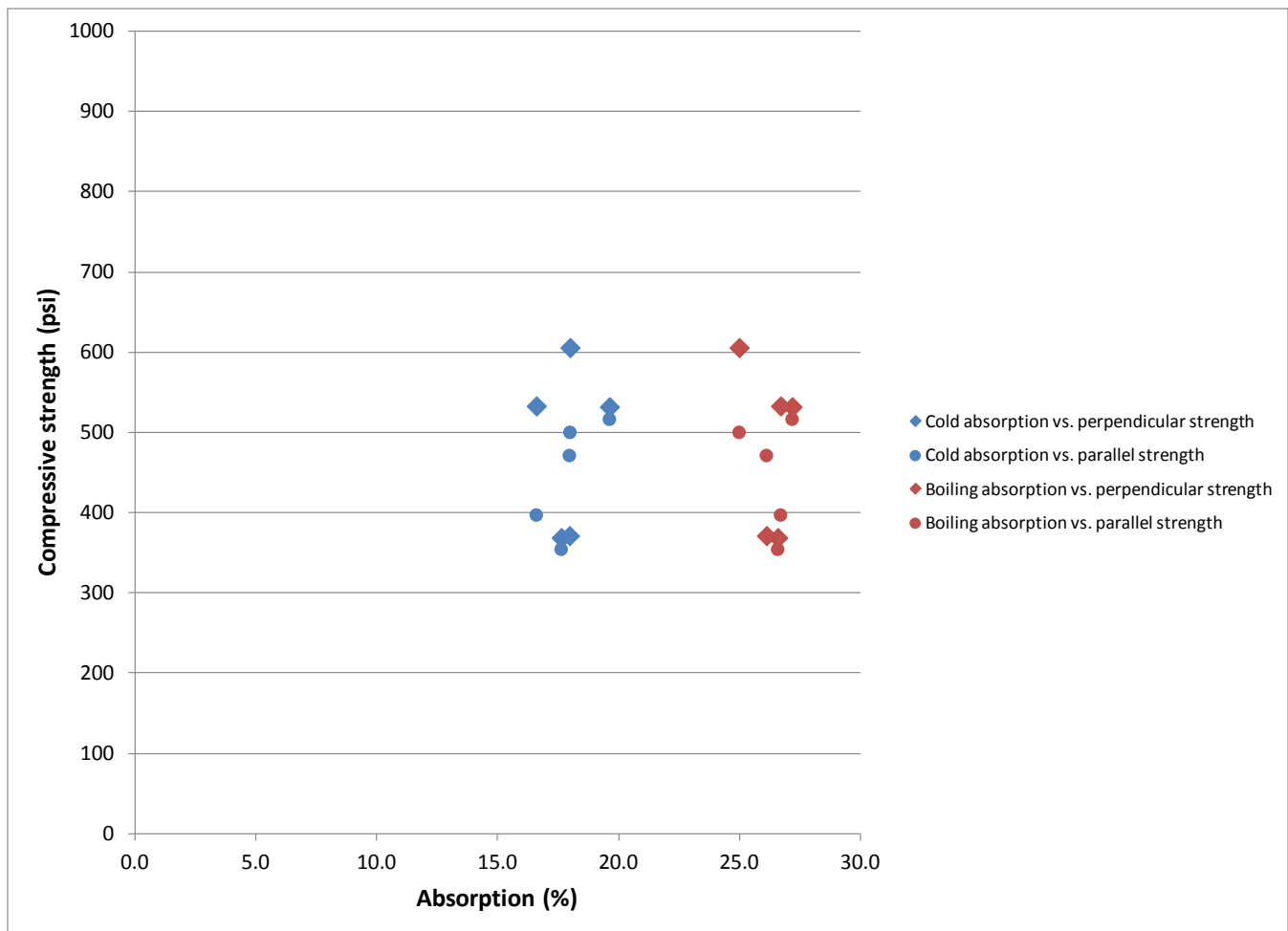
Table 5.1: Test Results

Specimen ID	Cold water absorption	Boiling water absorption	Saturation coefficient
	(%)	(%)	(no units)
10	18.0	25.0	0.72
12	19.6	27.2	0.72
13	16.6	26.7	0.62
14	17.6	26.6	0.66
16	18.0	26.1	0.69
Average	18.0	26.3	0.68
Standard deviation	1.1	0.8	0.04

6. Strength vs. Absorption Analysis

Chart 6.1: Relationship Between Absorption and Compressive Strength

The following graph plots the cold and boiling water absorption values against the compressive strength for the same test specimens. Each specimen was loaded perpendicular and parallel to the assumed casting direction of the tabby. The plot suggests that variations in compressive strength values do not appear to be related to the absorption or porosity of the material.



Appendix I: Photographs



Figure 1: Photographs of the tabby brick units from which compressive strength and absorption test specimens were prepared.

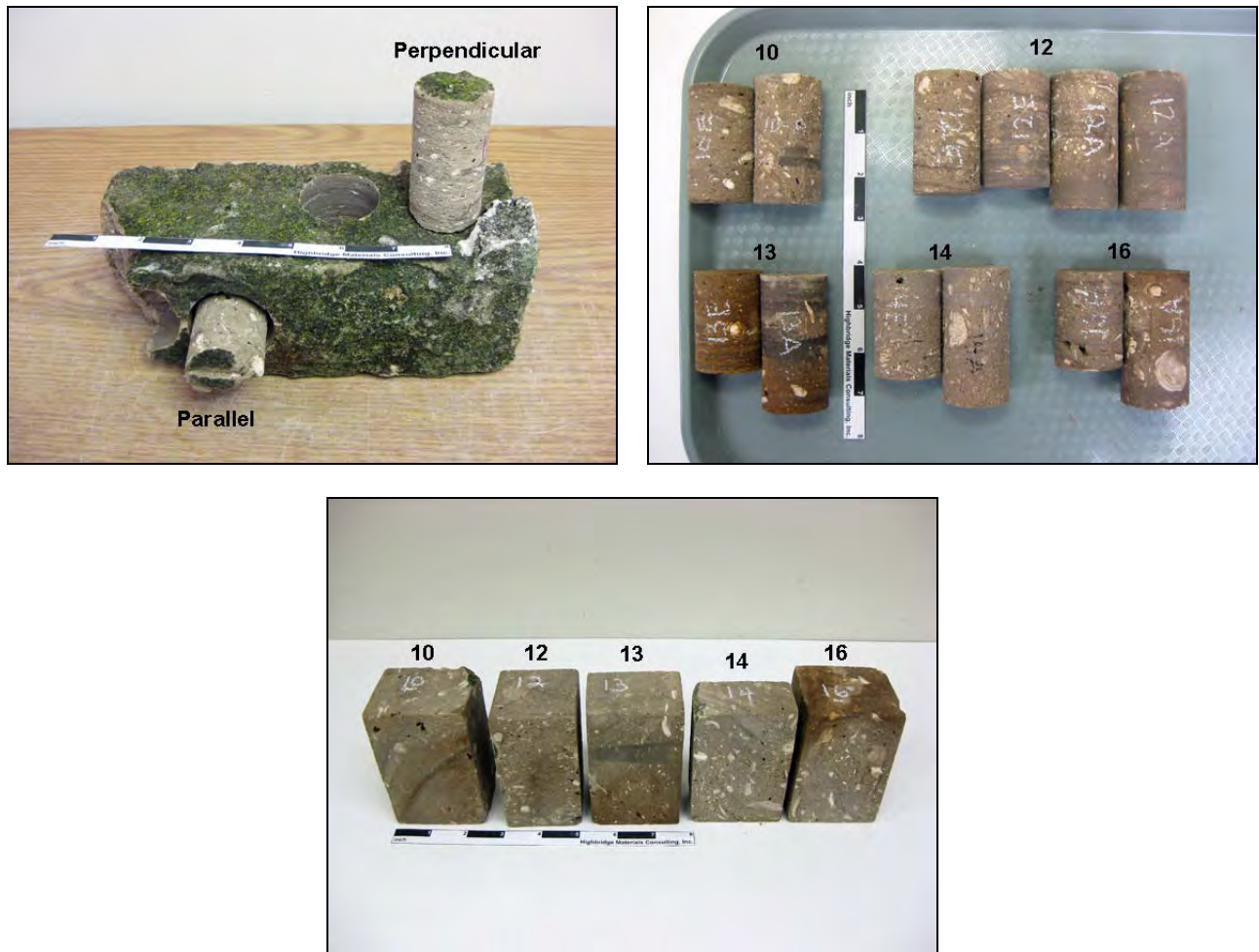


Figure 2: (Upper left) An example is shown of the coring used to produce compressive strength specimens. For most samples, one core was made perpendicular to the presumed casting direction and the other parallel to this direction. (Upper right) The compressive strength cores are shown after the ends had been trimmed but before the gypsum caps were applied. (Lower) The five sawn prisms used for absorption testing are shown.

Appendix II: Statistical Analysis

Compressive strength testing for each brick specimen was done in two different orientations. The following t-test illustrates that a statistically significant difference cannot be shown to exist between the averages of the two orientations.

Table II.1: Student's t-Test - Compressive Strength

	<i>Perpendicular</i>	<i>Parallel</i>
Mean	482.2044955	447.7078371
Variance	11365.328	4826.405211
Observations	5	5
Pearson Correlation	0.516514142	
Hypothesized Mean Difference	0	
df	4	
t Stat	0.834666643	
P(T<=t) one-tail	0.225427519	
t Critical one-tail	2.131846782	
P(T<=t) two-tail	0.450855038	

Appendix III: Sample Log

Table III.1: Summary of Received Samples

The laboratory has shortened the sample identifications for more convenient presentation in the reports. The shortened IDs are describe in the "HMC ID" column.

Material	Client ID	Chimney No.	HMC ID	Client description	Testing
Tabby brick	Stafford.7	16	07	East side of hearth, "f" marked on face	Compositional analysis, clay identification
	Stafford.8	1	08	West side of hearth	
	Stafford.9	18	09	Interior-facing side of chimney (same location as Stafford.1), original orientation of brick not clear.	Soluble salt identification through XRD
	Stafford.10	10	10	Found in rubble pile next to chimney	Strength, absorption
	Stafford.11	10	11	Found in rubble pile next to chimney	
	Stafford.12	22	12	Found in rubble pile next to chimney	Strength, absorption
	Stafford.13	22	13	Found in rubble pile next to chimney	Strength, absorption
	Stafford.14	22	14	Found in rubble pile next to chimney	Strength, absorption
	Stafford.15	22	15	Found in rubble pile next to chimney	
	Stafford.16	22	16	Found in rubble pile next to chimney	Strength, absorption
	Stafford.18	4	18	Removed from west side of chimney, significant erosion of brick face.	Soluble salt identification through XRD
	Stafford.19	3	19	Removed from back exterior face of chimney, significant erosion of brick face.	Soluble salt identification through XRD
Red clay brick	Stafford.20	16	20	Removed from northwest corner of chimney, face only, "B" marked on back/interior of brick) mild erosion of brick face	
	Stafford.6	4	06	Found on ground next to chimney, presumed to be from west surround of hearth.	Petrographic examination
Tabby brick bedding mortar	Stafford.17	22	17	Removed from back wall of hearth	
	Stafford.1	18	01	Taken from interior side of chimney above lintel.	
	Stafford.2	11	02	Taken from location of roof peak, area of mortar build-up, mortar continues into adjacent joint (i.e., same material as mortar in joints).	Compositional analysis
Parging	Stafford.3	1	03	Small sample from exterior mortar joint.	
	Stafford.4	4	04	Parging does not appear to be original (different color than mortar original, evidence of soiling on face of mortar under parging).	
Clay	Stafford.4	n/a	21	"Clay rock" from shore	Gradation analysis

Notes:

1. The laboratory has shortened the sample identifications for more convenient presentation in the reports. The shortened IDs are describe in the "HMC ID" column.
2. Three additional tabby brick will be selected for limited insoluble residue testing to evaluate the type and content of siliceous aggregate. These samples have not been selected and the testing is not indicated in the table as of this writing.

Appendix B

**“Report on Tabby Brick Compositional Analysis”
(Highbridge Materials Consulting, Inc., 12/23/19)**

Report on Tabby Brick Compositional Analysis

Stafford Slave Settlement, Cumberland Island
National Seashore, Chimney Stabilization
Cumberland Island, Camden County, GA



Prepared for
Building Conservation Associates, Inc.

Client ID
BUIL005

Report No.
SL1443-03

Report Date
12/23/19



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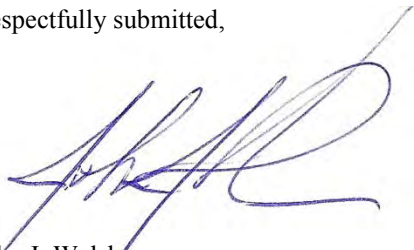
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Cover Image

Photograph of a chimney structure at the Stafford Slave Settlement on Cumberland Island, GA courtesy of Ms. Dorothy Krotzer of Building Conservation Associates, October 2, 2019.

Respectfully submitted,



John J. Walsh
President/ Senior Petrographer
Highbridge Materials Consulting, Inc.



Heather Hartshorn
Chemist/ Staff Scientist
Highbridge Materials Consulting, Inc.

1. Executive Summary

This report presents the compositional analysis of a cast tabby brick unit that has been sampled from a chimney ruin at the Stafford Slave Settlement on Cumberland Island, GA. The material is similar to tabby concrete but differs in that it does not include broken shells as a coarse aggregate addition. Instead, the material is a simple mixture of lime and sand, with a volume proportion estimated at 1 : 1.8. Any shell fragments present are interpreted to have originated from an unscreened derived from the burning of oyster shell. The aggregate is a very fine and narrowly graded natural quartz sand. A trace amount of silt, clay, and organic matter were probably part of the sand originally. This small amount of material is responsible for the pale brown color of the brick in contrast with the bright white color of the adjacent bedding mortar (Munsell color approximately 10YR 7/2). White lime inclusions and partially burned shell fragments contrast against the brown matrix. These particles are evenly distributed and not densely packed, having sizes usually less than 2 centimeters. All of the materials were well-mixed, adequately consolidated, and effectively cured. The resulting product is highly cohesive though it maintains the softness and high permeability typical of lime mortars. The binder is fully carbonated as expected for the material and age. No deleterious service effects are identified petrographically.

2. Introduction

On August 27, 2019, Highbridge received a set of masonry samples from Ms. Dorothy Krotzer of Building Conservation Associates reported to have been sampled from chimney structures at the Stafford Slave Settlement on Cumberland Island, GA. A summary of the samples, their identifications, and locations is presented in Appendix III. It is understood from the client that the site represents the ruins of a 19th century slave housing settlement in which only the chimney structures survive. The chimneys are reported to have been constructed of tabby brick with red clay brick used for the hearth and firebox.

At Ms. Krotzer's request, laboratory testing is performed on the samples to provide information that may assist in an ongoing stabilization effort. The testing plan was developed in discussions between Ms. Krotzer and Mr. John Walsh of Highbridge. The plan was finalized in a telephone call on September 20 and includes the following:

1. Qualitative identification of salts in tabby brick

Surface erosions on tabby brick may be the result of salt hydration or crystallization. The client has requested an identification of water-soluble salts present within the brick through x-ray diffraction analysis. Three samples are chosen for the analysis, two the client has identified as distressed and one the client has identified as sound.

2. Qualitative identification of clays in tabby brick

Weathering of the tabby brick may also be the result of the swelling behavior of clay constituents during wetting/drying cycles. X-ray diffraction analysis will be performed on clays extracted from one brick sample to determine whether swelling varieties are present.

3. Compositional analysis of tabby brick

This testing combines petrographic examination and chemical analysis to identify constituents, estimate proportions, and assess overall condition of the tabby brick. An acid digestion to extract an aggregate sample for description and gradation is also included. One sample will be examined comprehensively.

4. Gradation analysis of tabby brick aggregate

It is anticipated that there may be some variation in the tabby brick mix proportions. Rather than examine several samples comprehensively, a less costly acid digestion will be performed on an additional three brick samples. The content and gradation of the acid-insoluble constituents will be compared.

5. Gradation analysis of local silt/clay

The client has provided a sample of local sediments from the shore of the island. It is suspected that this material may have been used in the tabby manufacture. The laboratory will disaggregate this loosely consolidated material and grade it through standard sieves. The color and gradation of the sediment will be compared to the acid-insoluble material recovered from the tabby brick.

6. Physical property testing of tabby brick

The testing includes compressive strength, absorption, and saturation coefficient determination on a sample of five brick specimens. Since the tabby brick potentially contains relatively flat shell fragments and would likely have been compacted in a direction perpendicular to the bed face, it is suspected that there could be significant strength anisotropy. If so, this might have a bearing on the manner in which the brick decays in service. The laboratory will take cores in two directions from each of the five bricks to determine compressive strength. It is also suspected that the tabby brick may be appreciably weaker when wet. One additional core sample will be tested in each orientation under saturated conditions.

7. Compositional analysis of masonry mortar

This testing combines petrographic examination and chemical analysis to identify constituents, estimate proportions, and assess overall condition of the tabby brick bedding mortar. An acid digestion to extract an aggregate sample for description and gradation is also included. One sample will be examined comprehensively.

8. Petrographic examination of red clay brick

One sample of red clay brick will be examined petrographically. The purpose of a petrographic examination is to evaluate the constituents and microstructural features of the brick and to assess any potential causes for deterioration observed by the client on site.

This report presents results of the tabby brick compositional analysis including an x-ray diffraction analysis of extracted acid-insoluble fines. Also included are the gradation analyses for the local silty clay deposit, and sands extracted from several additional tabby brick samples for comparison. Results for the other tests will be presented under separate cover when complete.

3. Methods of Examination

The petrographic examination was conducted in accordance with the standard practices contained within ASTM C1324-15. Data collection is performed or supervised by a degreed geologist who by nature of their education is qualified to operate the analytical equipment employed. Analysis and interpretation is performed or directed by a supervising petrographer who satisfies the qualifications as specified in Section 4 of ASTM C856-18a.

Chemical analysis was performed in general accordance with the procedures outlined in ASTM C1324-15. Water, carbon dioxide, and aggregate weight percentages are determined gravimetrically. Oxide weight percentages are determined by inductively coupled plasma - optical emission spectroscopy (ICP-OES). While ASTM classifies C1324 as a test method, it is intended to serve as a guideline for qualified practitioners with ample experience in the various materials under consideration. Section 10.2 indicates the need for discretion on the part of the laboratory to ensure that methods are tailored to specific mortar compositions. As such, Highbridge chooses specific digestion methods, supplementary tests, instrumentation protocols, and mathematical models to best characterize each individual mortar under consideration. Many of these are proprietary methods that have been researched internally.

Organic impurities testing was not part of the original testing scope. This testing was performed in general accordance with methods described in ASTM C40/C40M-19. The sample size and reagent volume were prepared in an approximate manner without attention to those required by the standard.

The following personnel contributed to the examination:

Technician:	M. Pattie
Chemist:	H. Hartshorn
Petrographer:	J. Walsh

4. Petrographic Findings and Discussion

4.1 - Aggregate Materials

The aggregate in the tabby brick is a natural sand consisting almost entirely of quartz. There are a variety of traces including the ZTR index minerals and metamorphic mineral grains. All of the aggregate constituents are hard, non-porous, and durable for use in masonry mortars. The sand extracted through acid digestion is semi-translucent and uniform in appearance. The sand is buff in color after removing any loose silt or clay (Munsell code approximately 10YR 6.5/2). The aggregate is sharp-textured with equidimensional particles that are subangular in shape on average. The extracted sand was graded through a standard sieve set and the results are presented in Section 5. The sand is very fine-grained and somewhat narrowly graded. About 75% of the sand is retained between the No. 50 and No. 100 sieves, and about 17% between the No. 100 and No. 200 sieves. The particle size distribution would not comply with modern masonry sand gradation profiles as specified by ASTM C33/C33M-18. However, as described for the bedding mortar in Highbridge Report No. SL1443-02, the fine gradation is typical of Southern coastal lime mortars of the nineteenth century.

Sands were extracted from an additional three tabby brick samples for comparison (Section 5). The gradation profiles are virtually the same for the four tabby brick samples (Chart 5.1). There are slight differences between the sands from the tabby brick and the mortar. However, the gradations are quite similar overall and it is clear that all derive from the same general geological deposit. The absence of phosphate traces in Sample 07 suggests that the sands probably did not derive from the same exact sedimentary layer.

The sand colors are within the same approximate palette though there is some variation. The sand in Sample 07 is the palest of the group but not nearly as pale as the sand extracted from the bedding mortar. The sand in Samples 09 and 19 are a little darker, and the sand from Sample 13 is a little richer in color. It is notable that the hand samples received for Samples 13 and 16 exhibited some reddish discoloration. The color differences are believed to relate to slight variations in minor organic contaminants originally present in the sand. If these impurities were part of the lime, it is unlikely that they would be so tenaciously adhered to every sand particle.

Though not part of the testing scope, the presence of organic impurities was checked by borrowing methods from ASTM C40. An acid-insoluble fraction was recovered from Sample 07 (tabby brick) and Sample 01 (bedding mortar). A dilute hydrochloric acid was used and then decanted after the digestion. Sample 21 representing the local sediment was simply disaggregated by hand. All three samples were then digested for 24 hours in a 1N NaOH solution. The color of the supernatant liquid was compared against Gardner color standards as an indicator of organic content. As described in Highbridge Report No. SL1443-02, the bedding mortar solution had a color equivalent to Gardner No. 5. This indicates a low organic content. In contrast, the supernatant solution for the tabby brick sample had a Gardner color of No. 11. This indicates a moderate organic content. Still, the solution over the local sediment had a Gardner color of No. 14 indicating an even higher organic content. With respect to the tabby brick sample, it is possible that the sand originally contained a higher abundance of organic impurities, but that some of this organic matter had broken down through alkaline hydrolysis in the high pH environment of the cast brick.

Silt and clay extracted from the brick through acid digestion represents 1% of the total aggregate weight. This is estimated by the weight of material passing a No. 325 sieve (Table 5.2a). The other tabby bricks have fines contents between 1.4% and 2.3% by weight. The darker color of these fines suggests that a significant proportion of these consist of the organic impurities identified through alkaline digestion. Interestingly, the local sediment contains over 12% fines. This suggests that if the same aggregate source was used for the brick, there may have been some rinsing of the sand before use. However, this was not as thorough as that performed for the bedding mortar. The other possibility is that the fines in the tabby brick derive from coarser shells in the unscreened lime. However, as described above, the fines content appears to influence the sand color in a manner that should only happen if both were originally part of the same deposit. Whatever the case, the presence and abundance of these fines are responsible for the color differences between the brick and mortar.

4.2 - Binder Materials

The binder is a non-hydraulic, fat lime manufactured predominantly from oyster shells. It was possible to estimate the lime composition through the chemical analysis and this estimate is presented in Table 6.2. The estimate for the bedding mortar sample described in Highbridge Report No. SL1443-02 is also included for comparison. The lime in the tabby brick has a high purity with a CaO content greater than 94% by weight. A hydraulicity index of only 0.04 and a cementation index of 0.08 indicates that there was no appreciable hydraulicity of any kind. Nevertheless, the SiO₂ and Al₂O₃ contents are about three times higher than they are in the bedding mortar sample. This is probably due to the fact that the lime in the bedding mortar was screened, and this may have removed coarser impurities. However, it is also possible that the elevated SiO₂ and Al₂O₃ is derived from the partial decomposition of clays in the sand, either through long exposure in the initially uncarbonated lime or through the acidification used in the chemical analysis.

The hardened lime paste is homogeneously distributed with a high capillary porosity typical of lime mortars. There are no shrinkage cracks observed, and this may be due to the stabilizing influence of the minor clay. The paste has a somewhat microgranular texture. This probably indicates that parts of the lime had become dry during slaking, before sufficient water was added to fully plasticize the mass.

A moderate quantity of lime inclusions and unburned shell fragments are distributed throughout the matrix. Most are oyster shell fragments though there appears to be a very minor quantity of other molluscan forms in this and other samples. The various shells and coarse lime inclusions represent about 7.5-10% of the volume in Sample 07. A visual review of the other dozen brick samples suggests similar quantities with a maximum content of perhaps 15% (±). While it is not always easy to distinguish burned from unburned shells visually, unburned shells identified petrographically in Sample 07 represent a minor quantity of the visible inclusions. It is interpreted here that the slaked lime was unscreened, and the entire mass was mixed with the sand to produce a mortar. If correct, there is technically no separate addition of broken shells. Of course, it is also possible that the lime was screened and then a portion of the coarser screenings was measured and added back to the mixture. However, the relatively minor quantity of shell fragments seems inconsistent with an intentional addition. The brick composition is not the same as that typically understood to represent tabby. Instead, it is more similar to a coarse lime mortar.

The size and microstructural qualities of the inclusions are varied. The microgranular parts of the binder include slaked and carbonated lime grains as fine as 0.02 millimeters. Thermal disaggregation of the shells during calcination has produced a minor quantity of very fine calcite or aragonite crystals in this same approximate size range. These are streaky in distribution and rarely that abundant even locally. Coarser grains that are visible in hand sample range in size from about 0.5 millimeters to several centimeters. Most are no greater than 2 centimeters in this particular sample, but nearly whole shell fragments up to about 4 centimeters are occasionally observed in the other tabby brick samples. When viewed petrographically, some shell fragments that appear unburned actually exhibit microscopic calcination spots that have since slaked and carbonated. Fully fired shell particles usually exhibit open partings that correspond to lamination structures in the original shell.

There is also a moderate concentration of burned quartz and clay associated with the lime. These represent impurities originally adhered to the oyster shells when fired. This is demonstrated by the presence of both unburned and lightly burned linings remaining on some of the fired shell fragments. There are also thin arcuate flakes of calcined impurities that retain the negative impression of the shell surface. The quartz is usually observed as several grains fused together with a transparent colorless glass. The calcined clays are more variable in texture though there are some high-fired clinkered particles observed petrographically.

Finally, there is a minor concentration of carbonaceous particulates distributed throughout the lime binder. These represent residues of the fuel used to calcine the lime. Most are texturally nondescript. However, a low proportion exhibits a cellular texture indicative of wood cinder.

4.3 - Component Proportions

Chemical analysis was used to estimate the component proportions, and these results are presented in Section 6. Calculating the lime as the equivalent of a modern dry hydrate, the lime to sand ratio is estimated at 1 : 1.5 by volume. This is about 35% sandier than the bedding mortar examined for Highbridge Report No. SL1443-02. A few more notes are warranted regarding the calculations. A little more elaboration on these points is offered in Section 4.2 of the bedding mortar report.

- When the lime is calculated as a putty, the lime to aggregate volume ratio decreases to 1 : 1.8.
- Weight ratios are more accurate and are presented in Table 6.3.
- The estimated sand content is inclusive of silt and clay. A separate weight percentage is given for these components in Table 6.3, but the volume ratio is not significantly affected either way.

Acid-insoluble residues were determined for three additional tabby brick samples to evaluate the consistency of the mix proportioning (Table 5.1). The residue represents the sand, silt, clay, and any remaining organic impurities. Since the lime has a simple composition, and all the lime is likely carbonated, differences in this one measurement should be linearly proportional with differences in original sand to binder ratios. In fact, there is a remarkable consistency between the four samples with residue weights ranging from 63.2% to 63.8%. Of course, it is possible that these four brick samples were prepared from the same batch of lime. This seems unlikely since the bricks were sampled from four different chimneys. But even if these represent the same batch, this would suggest an excellent blending of the ingredients.

The consistency between the four samples is at a level usually only found in modern premixed mortars where batching is performed in a plant setting. Most modern field mixes have sand content variations that are at least 2% by weight. This is often the case even when mortar boxes are used to improve the batching consistency. The author is at a loss to explain these findings. If these four samples are not from the same well-mixed lime batch, the builders may have used some type of careful measuring procedure that is not obvious from the material samples alone.

4.4 - Mixing and Casting

Despite the presence of unscreened lime, the constituents of the brick were very well-blended. The shape of the molded brick appears to have been irregular when cast. Either way, the mortar is well compacted and consolidated into the mold. The total air content is estimated at 8-12% by volume though most voids are less than 0.5 millimeters in diameter. Visible consolidation voids are not at all abundant and rarely more than a few millimeters in size. There is no significant alignment of anisotropic constituents. Had the material been more similar to tabby concrete, there would be an expectation of shells lying mostly horizontally with respect to the original casting direction. This would generally result in anisotropic physical properties such as weaker strengths when loaded parallel to the horizontal plane. In this case, the relatively few underburned shell fragments are randomly oriented within the matrix. Strength tests performed on several samples in two orientations confirm that there is no significant anisotropy (Highbridge Report SL1443-01).

4.5 - Condition and Service Performance

The qualitative properties of the mortar are typical for the composition, and similar to those of the bedding mortar. The paste is soft and highly water permeable. However, the brick is indurate and exhibits no friability. A qualitative survey of the other dozen samples suggests that the materials are consistent in quality with no obvious deficiencies.

Little physical distress is observed in this particular sample. Petrographically, there is an absence of any type of cracking including microscopic shrinkage cracks. Visually, there is only a softening of arrises without any discrete damage. Similarly, there is little evidence for chemical distress. The binder is fully carbonated but this is a normal and desirable consequence of curing. No secondary mineralizations are visible in hand sample and no salt deposits are identified petrographically within the pores of the mortar matrix. Of course, it is likely that there are submicroscopic salts within the capillary pores of the brick that are not visible petrographically. Qualitative salt analysis was performed for three other brick samples (Highbridge Report SL1443-05). Though this particular sample was not included in that testing, the client has identified Samples 07, 08, and 09 as intact. Though some chloride and sulfate salts are detected in Sample 09, the total salt content is only about 0.15% by weight. While this is not negligible, it is at a level where it is possible for no concentrated deposition to be visible either visually or microscopically.

5. Aggregate Sieve Analysis

Aggregate sieve analysis was done as part of the comprehensive analysis for Sample 07. The laboratory also recommended checking the consistency in mix proportioning between several samples without going through the expense of a full analysis for each additional sample. Performing the sieve analysis on three additional samples allowed the laboratory to estimate any differences in sand content relative to Sample 07, and to compare the appearance and gradation of the constituent sands. The laboratory chose Samples 09, 13, and 19 for this analysis. Preliminary testing suggested that there was some color variation in the sands and this was well represented by these three samples. The samples also appeared to have different sand and clay contents based on the digestion of small subsamples. Finally, the four brick samples were recovered by the client from four different chimneys.

For the tabby brick, aggregate analysis was performed by digesting the samples in an acid sufficient to dissolve the binder. The materials were examined visually and microscopically to ensure that all recovered material represents sand rather than undigested binder components. In all samples, most of the few grains recovered above the No. 30 sieve were identified as fused quartz. These represent impurities from the lime and were removed from the gradation analyses. There is certainly a very small concentration of these impurities in the finer sieve sizes but it is impracticable to extract them from the rest of the sand. Similarly there are traces of fine cinder from the lime production that cannot be conveniently separated. In any case, these combined factors represent an insignificant error. In contrast, there is a moderate concentration of incompletely burned shell fragments from the lime that behave as aggregate. These were all dissolved in the acid digestion and are not represented in the analysis below. The visual impact of shell fragments is discussed in the findings section.

The sand samples were also compared to weakly consolidated local sediment sampled from the shore by the client (Sample 21). A subsample of this material was physically disaggregated and graded for evaluation.

Table 5.1: Weight Percentage and Color of Acid-Extracted Sand and Fines

Sample ID	Chimney No.	Weight %	Sand color		Fines color	
			Visual color	Munsell code	Visual color	Munsell code
07	16	63.8	Buff	~10YR 6.5/2	Dark gray	~10YR 3.75/1
09	18	63.4	Light brown	~10YR 5.5/2.5	Dark gray	~10YR 3.75/1
13	22	63.6	Medium brown	~10YR 5/3	Dark gray	~10YR 3.5/1.5
19	3	63.2	Light brown	~10YR 5/2.5	Dark gray	~10YR 3.75/1
21	n/a	n/a	Buff	~10YR 6.5/2	Pale brown	~10YR 6.25/3

Table 5.2a: Acid Digestion Data - Weight Retained (grams)

	07	09	13	19	21	21 fines excluded
No. 16	0.00	0.00	0.00	0.00	0.02	0.02
No. 30	0.00	0.00	0.00	0.00	0.05	0.05
No. 50	0.33	0.30	0.30	0.26	1.13	1.13
No. 100	5.19	4.66	4.87	4.78	30.73	30.73
No. 200	1.14	1.35	1.39	1.29	11.95	11.95
No. 325	0.04	0.04	0.03	0.04	0.61	0.61
Pan	0.07	0.09	0.13	0.15	6.17	0.00

Table 5.2b: Acid Digestion Data - Cumulative Percentage Passing

	07	09	13	19	21	21 fines excluded
No. 16	100.0	100.0	100.0	100.0	100.0	100.0
No. 30	100.0	100.0	100.0	100.0	99.9	99.9
No. 50	95.2	95.3	95.5	96.0	97.6	97.3
No. 100	18.5	23.0	23.1	22.6	37.0	28.2
No. 200	1.7	2.0	2.4	2.8	13.4	1.4
No. 325	1.0	1.4	1.9	2.3	12.2	0.0

Table 5.2c: Acid Digestion Data - Cumulative Percentage Retained

	07	09	13	19	21	21 fines excluded
No. 16	0.0	0.0	0.0	0.0	0.0	0.0
No. 30	0.0	0.0	0.0	0.0	0.1	0.1
No. 50	4.8	4.7	4.5	4.0	2.4	2.7
No. 100	81.5	77.0	76.9	77.4	63.0	71.8
No. 200	98.3	98.0	97.6	97.2	86.6	98.6
No. 325	99.0	98.6	98.1	97.7	87.8	100.0
Fineness modulus	0.86	0.82	0.81	0.81	0.66	0.75

Chart 5.1: Aggregate Sieve Analysis

The following chart presents the particle size distribution curves for the sand samples extracted from the four tabby bricks. The chart plots the data from Table 5.2b.

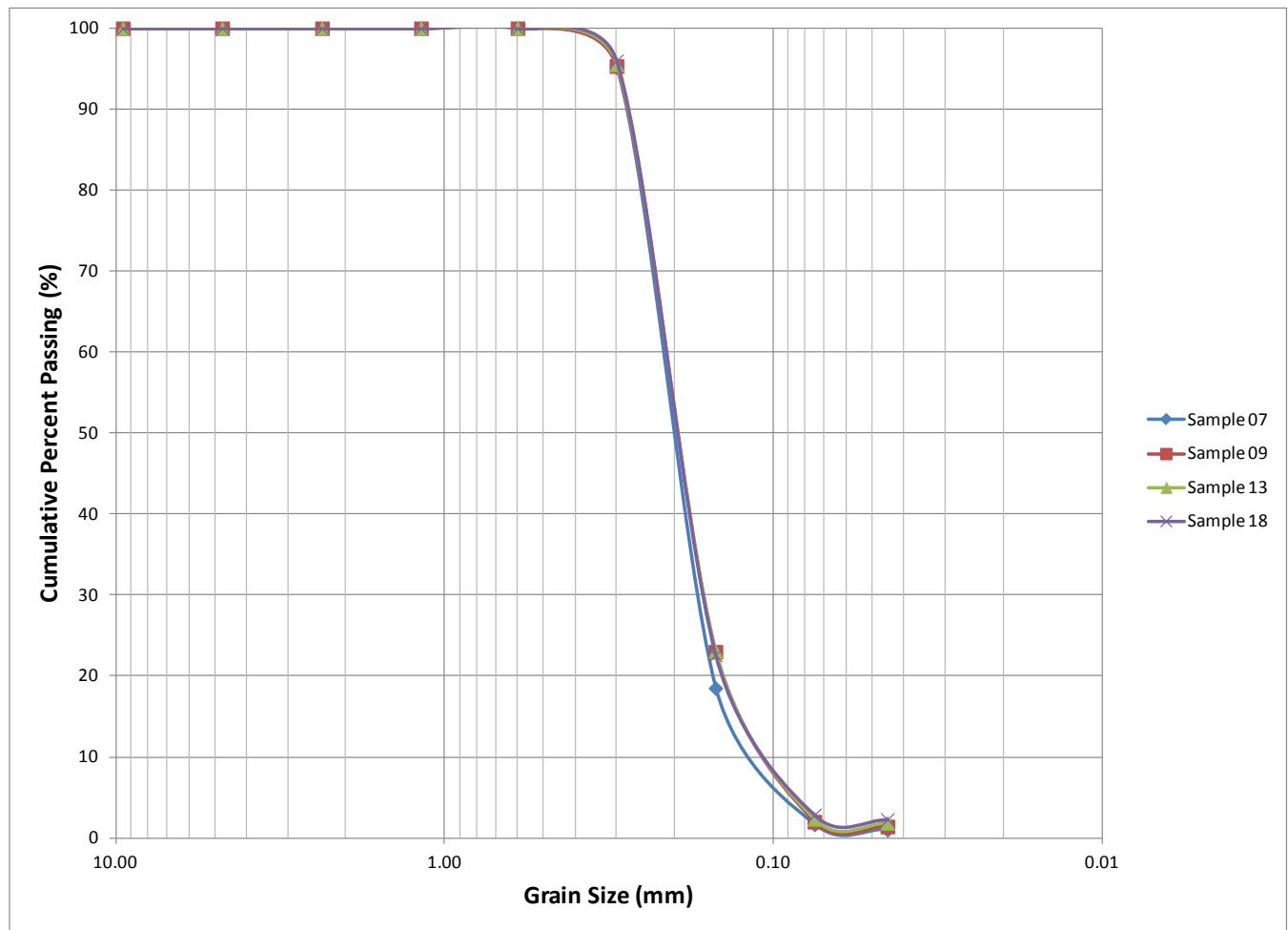
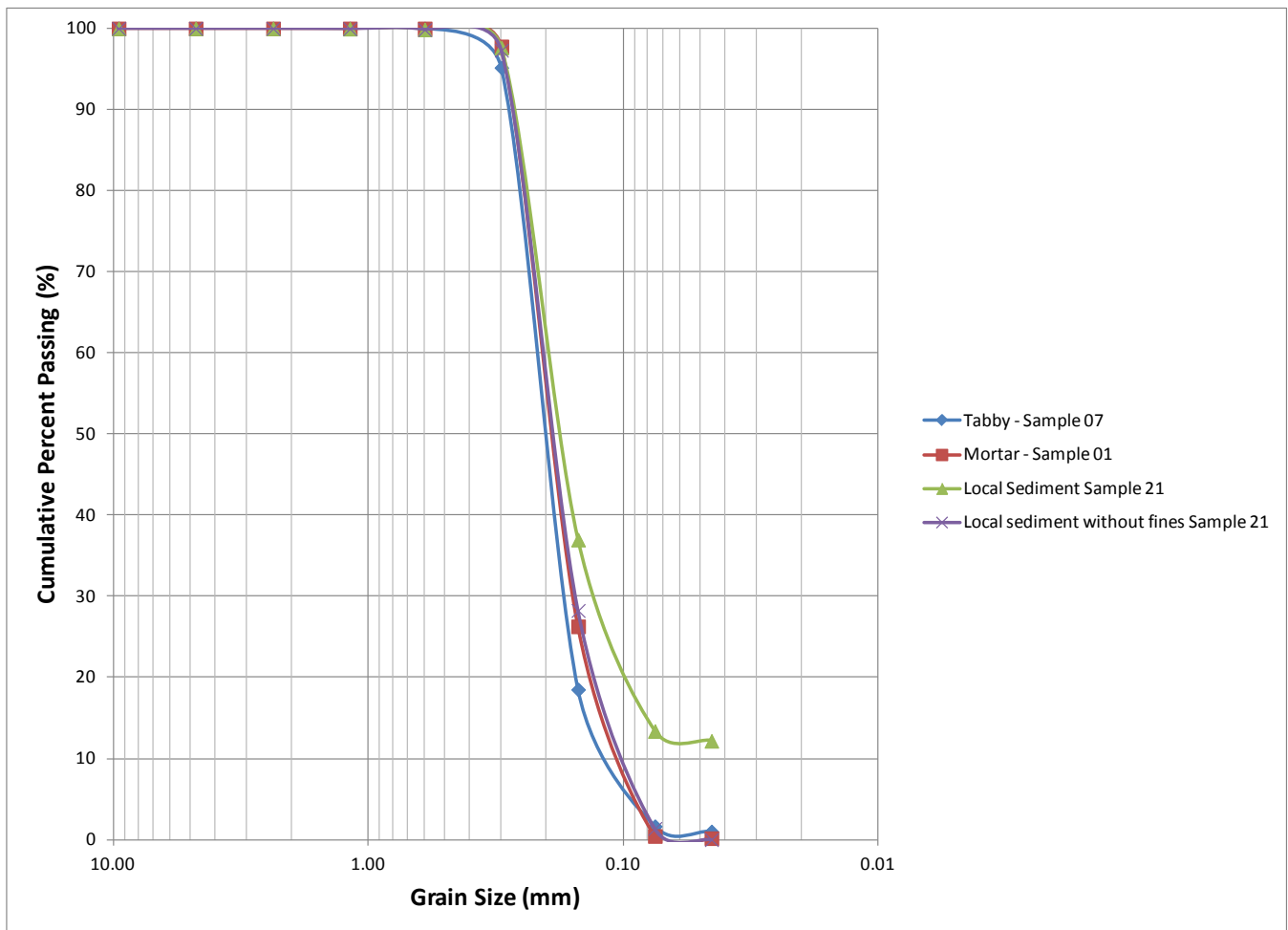


Chart 5.2: Aggregate Sieve Analysis

This chart compares the sand profiles of the tabby brick (Sample 07) and the bedding mortar evaluated for Highbridge Report SL1443-02 (Sample 01). The local sediment in Sample 21 is also plotted here. One curve represents the complete material and the other curve represents the material with the fines passing a No. 325 sieve removed.



6. Chemical Analysis

Table 6.1: Chemical Analysis Results

Sample ID	07
Component (wgt. %)	
SiO ₂	0.33
CaO	16.60
MgO	0.14
Al ₂ O ₃	0.32
Fe ₂ O ₃	0.06
Insoluble residue	66.73
LOI to 110°C	0.20
LOI 110°C-550°C	1.16
LOI 550°C-950°C	13.26
Measured Totals	98.80

Table 6.2: Estimated Original Lime Chemistry

The binder consists of non-hydraulic lime with no other additives. As such, the lime chemistry is estimated from the acid-soluble oxide chemistry presented in Table 6.1. The five major oxides in the binder are normalized to a 99% weight yield. This normalizes the lime to a dry weight basis and is equivalent to the pre-slaked condition. The residual 1% is assumed to represent trace unmeasured constituents. Important ratios are calculated directly from the data. The reported indices are calculated as follows:

Hydraulicity index = $(\text{SiO}_2 + \text{Al}_2\text{O}_3) / \text{CaO}$

Cementation index = $(2.8 \cdot \text{SiO}_2 + 1.1 \cdot \text{Al}_2\text{O}_3 + 0.7 \cdot \text{Fe}_2\text{O}_3) / (\text{CaO} + 1.4 \cdot \text{MgO})$.

The estimate is shown in comparison to an estimate made for the bedding mortar. The composition estimated for the brick is richer in SiO₂ and Al₂O₃. It is suspected that this may represent some influence from clay incorporated in the sand. As such, there may be a small error in the estimate.

Sample ID	01 - Mortar	07 - Brick
Component (wgt. %)		
SiO ₂	0.7	1.9
CaO	96.4	94.2
MgO	1.0	0.8
Al ₂ O ₃	0.6	1.8
Fe ₂ O ₃	0.2	0.3
Other	1.0	1.0
CaO/MgO ratio	92.1	117.3
Hydraulicity Index	0.01	0.04
Cementation Index	0.03	0.08

Table 6.3: Calculated Components

Sample ID	07
Component	
Lime expressed as dry hydrate (wgt. %)	25.5
Sand (wgt. %)	73.7
Silt and clay (wgt. %)	0.7
Lime : aggregate ratio (by volume with lime as dry hydrate)	1 : 1.5
Lime : aggregate ratio (by volume with lime as putty)	1 : 1.8

Notes:

- The lime weight is calculated by mathematically converting the measured CaO and MgO to their respective hydroxides by molecular weight conversion. The three other measured oxides are assumed to represent minor impurities in the lime and are added directly to the calculated hydroxides. This represents the lime as a hydrate. The measured insoluble residue largely represents the natural aggregate with only trace impurities from the binder. The acid digestion used to extract the sand sample (Section 5) is used to partition this residue value into sand and fines (silt and clay). The weight percentage of material passing the No. 325 in the extracted sample is considered to be silt and clay, and this percentage is multiplied by the chemically-measured acid-insoluble residue. The lime, sand, and fines weights are all normalized to 100% to return the materials to a dry weight basis. Since the amount of clay is shown to be negligible, the fines are included with the aggregate for the purposes of calculating a lime to aggregate ratio. The volumetric ratios are calculated assuming bulk densities for nonhydraulic lime and damp, loose sand of 40 lbs./ft.³ and 80 lbs./ft.³, respectively. Another calculation is provided assuming the lime in putty form. This assumes a unit of dry lime hydrate will lose approximately 20% of its volume when mixed to the consistency of a stiff paste.

Appendix I: Visual Description of Sample as Received

Sample ID	Sample 07 – Tabby Brick
Description	The sample is a complete brick unit with a somewhat irregular shape. The nominal dimensions are approximately 9-1/4" x 4" x 2-1/2" to 3".
Surfaces	One bed surface is fairly planar and unbroken. This mortar on this side forms a tabular cap about 5/8" thick. It is suspected that this was the screeded face that required a second lift of mortar to fill the mold. The opposite bed surface is highly irregular and lumpy. There are some tool marks on this surface that consist of shallow, non-regular grooves radiating from a center point. The marks give the appearance of the impression that would form from a wrinkled plastic bag caught in the mortar at a point near the brick center. There appears to be a small dab of masonry mortar adhered to the irregular face but this is not certain due to the similarity of the materials. The bed faces are partially coated with biogrowth. The faces and head surfaces are more completely coated.
Hardness / Friability	The paste is soft but the mortar is cohesive and nonfriable.
Appearance	Fresh surfaces have a dull luster and are very pale brown in color (Munsell code approximately 10YR 7/2).
Other details	No cracks, efflorescence, or mineral deposits are visible in hand sample.
Water absorptivity	The matrix is rapidly water absorptive.

Sample ID	Sample 21 – Local sediment
Description	The sample consists of 260 grams of clean, brown, silty clay as rounded and sometimes pitted lumps. The material is cohesive but not sticky, even when wet. The material can be disaggregated with moderate finger pressure.
Appearance	The material is uniform in appearance with a dull luster and a brown color (Munsell code approximately 10YR 5.5/3).

Appendix II: Photographs and Photomicrographs

Microscopic examination is performed on an Olympus BX-51 polarized/reflected light microscope and a Bausch and Lomb Stereozoom 7 stereoscopic microscope. Both microscopes are fitted with an Olympus DP-11 digital camera. The stereoscopic microscope is used for simple magnification. Sample types examined under this microscope include fractured surfaces, fine constituents extracted through chemical or physical means, or honed or polished cross sections. The polarized light microscope (PLM) magnifies but also employs principals of optical crystallography. The most common sample preparation for the PLM is the petrographic thin section. For this preparation, cross-sectioned samples are mounted to glass slides and are milled to a thickness sufficient to allow light to be transmitted through the material. These are usually prepared without water and with minimal heat to avoid altering minerals that are water or temperature-sensitive. In many cases, the samples are impregnated with a low-viscosity, blue-dyed epoxy. When so treated, blue areas represent some type of void space (e.g., air-voids, capillary pores, cracks, etc.). The polarized light photomicrographs are taken using a variety of optical settings chosen to best demonstrate the feature(s) of interest. These are distinguished as follows:

Plane polarized light (abbreviated as PPL)

This method uses the refractive power of different constituents to produce an artificial sense of surface relief. Otherwise, the method is the closest to a simple magnification of the material. The setting is often used to demonstrate granular relationships or microstructure. Pore spaces and cracks are observable with this setting if the blue-dyed epoxy is used.

Conoscopic polarized light (abbreviated as CPL)

In this setting, the transmitted light is condensed just before passing through the thin section. The method tends to bring colors or finer particulates into higher contrast at the expense of image sharpness. The setting is often used to image grain boundary failures in dimension stone, pigment particulates in binders, or gel phases in the micropores of cement pastes.

Cross polarized light (abbreviated as XPL)

The setting places the thin section between two pieces of polarizing film oriented at 90° to one another. In isotropic materials (e.g., glasses, simple salts), all light is absorbed and the materials appear black. In anisotropic crystals, two light rays traveling at different speeds are produced within the thin section and these offset waves interfere at the upper polarizing film. The interference produces a color that can be used to calculate properties of the crystal structure and aid in identification of mineral species. In essence, the colors are artificial. It should be noted that color is a function of orientation and color differences do not necessarily indicate material differences.

Compensator plates

When in XPL mode, full-wave or quarter-wave compensator plates may be inserted into the light path to add or subtract interference. Technically, these methods are used to calculate properties of the crystal structure. However, they can also be used to alter the image appearance to help improve contrast between different constituents. They can also reveal preferred orientations in some materials (e.g., oriented residual crystallinity in fired ceramics).

Scale bars are included with all photomicrographs. In higher magnification images, the μm symbol represents microns. One micron is equal to 0.001 millimeter.



Figure 1: (Left) Photograph of the tabby brick samples provided to Highbridge for various testing. Sample 07 was used for this compositional analysis. Samples 09, 13, and 19 was used for supplemental information. (Right) The client also provided a sample of the local sediment. This was compared to the sands extracted from the brick units.



Figure 2: Photographs of Sample 07 used by the laboratory for the compositional analysis of the tabby brick. The whole brick is shown obliquely in the left image. A close-up of one bed surface is shown at right. There is an unusual set of tool marks on this surface



Figure 3: The texture of the tabby brick is shown in these images of sawn and ground cross sections. The right image is a close-up with a scale bar having units in centimeters. The matrix is a pale brown color likely due to the inclusion of trace organic impurities in the sand. Unscreened fragments of partly burned shell are evenly dispersed throughout the brick without producing a grain anisotropy.

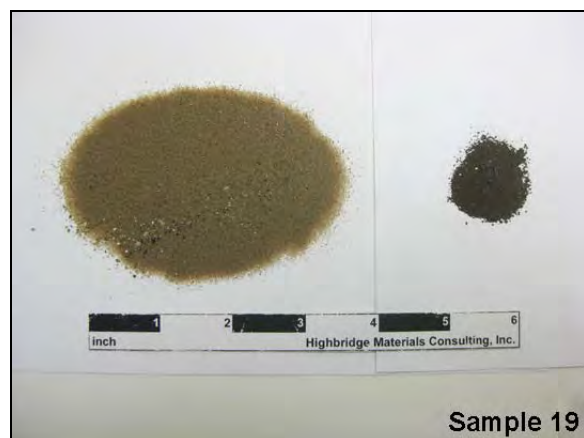
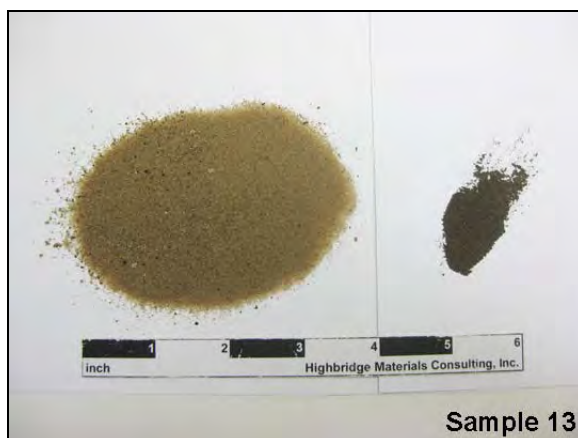
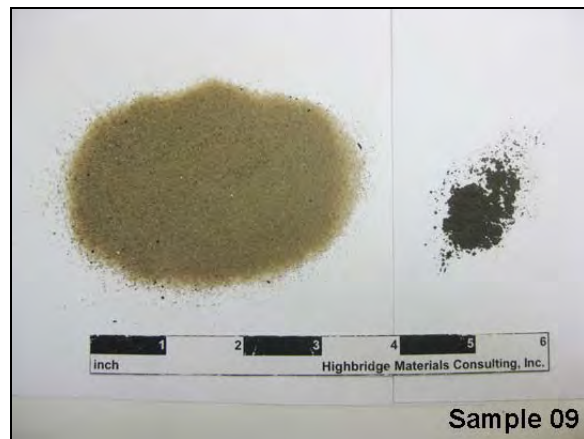
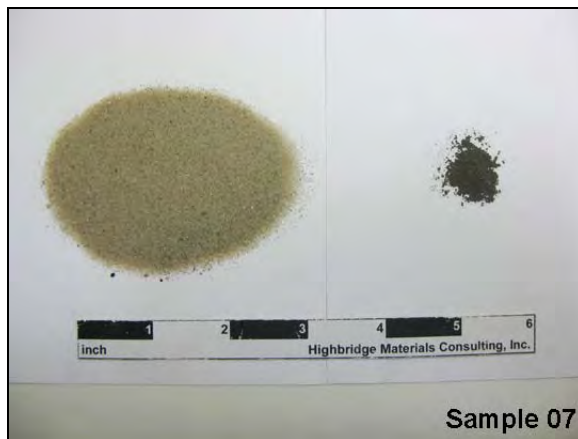


Figure 4: Photographs of the aggregate are shown after being extracted through acid digestion. In each image, the sand is shown to the left, and the silt and clay to the right. It is suspected that the latter also contains some organic matter. Note that the sand colors vary slightly while the color of the fines is somewhat consistent. Sample 21 represents the local sediment collected by the client. The fines content is much higher in this sample and the color does not differ from that of the sand.

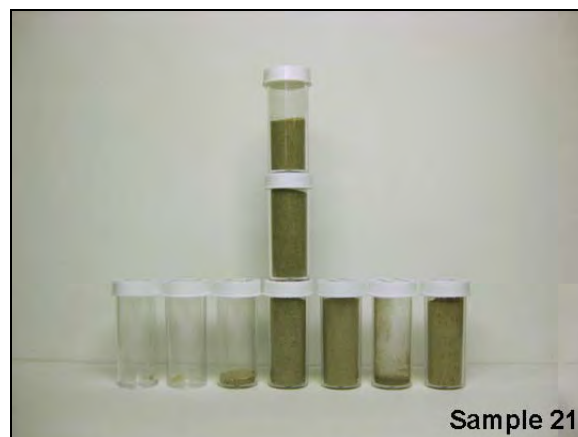
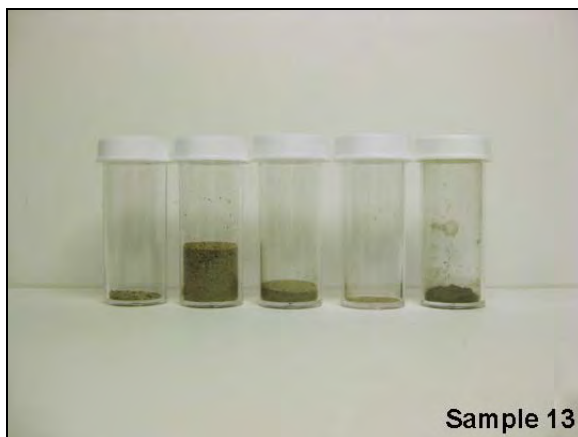
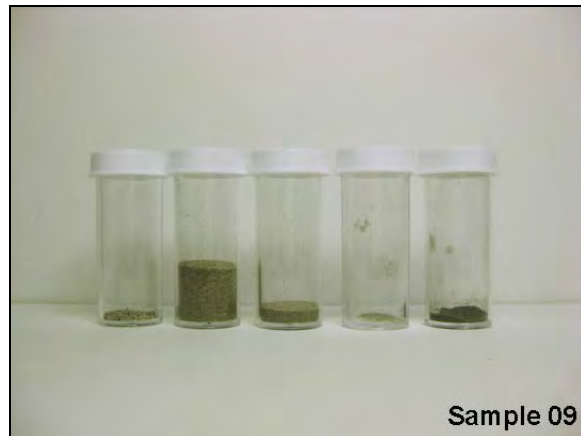
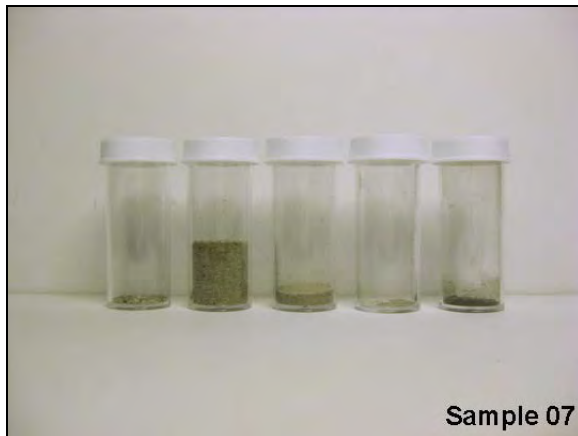


Figure 5: The extracted sand and fines shown in Figure 4 are shown here after gradation through a standard sieve stack. The sands are all fine and somewhat narrowly graded. The gradations are nearly identical.

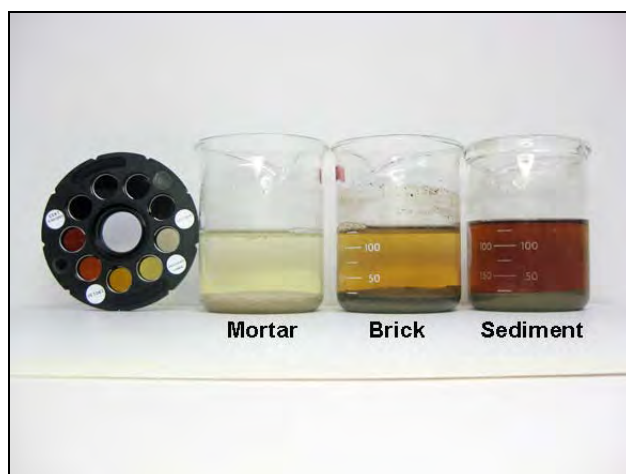


Figure 6: A simple organic impurities test was performed on the sands from the bedding mortar and the tabby brick (Samples 01 and 07 respectively). The local sediment was similarly examined (Sample 21). The color of the supernatant solution after a 24-hour base digestion is indicative of the organic content. The color is compared to the Gardner standard. The glass standard used for the comparison is shown at the left of the image.

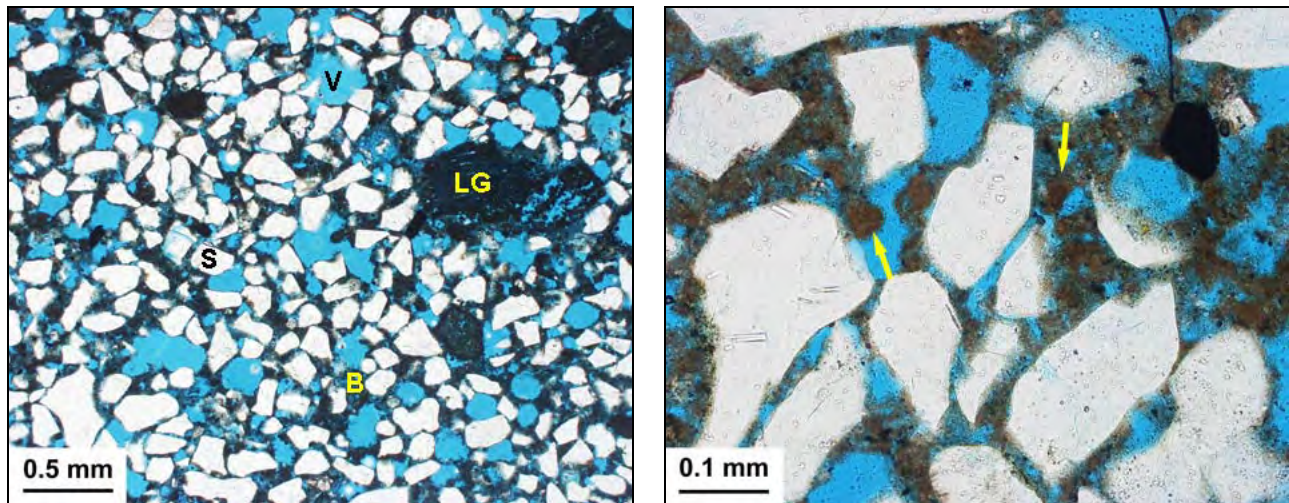


Figure 7: PPL photomicrographs illustrating the microtexture of the mortar. A lower magnification view is shown at left and a higher magnification view is shown at right. The binder (B) is highly permeable as shown by the strong absorption of blue-dyed epoxy used in the sample preparation. The arrows indicate microgranules of cured lime that suggest that the binder was not brought to full plasticity all at once. The sand (S) is sharp-textured and densely distributed throughout the matrix. Fine lime grains are distributed throughout the matrix (LG). While the mortar was well compacted into the mold, there is still a moderate concentration of microscopic voids (V).

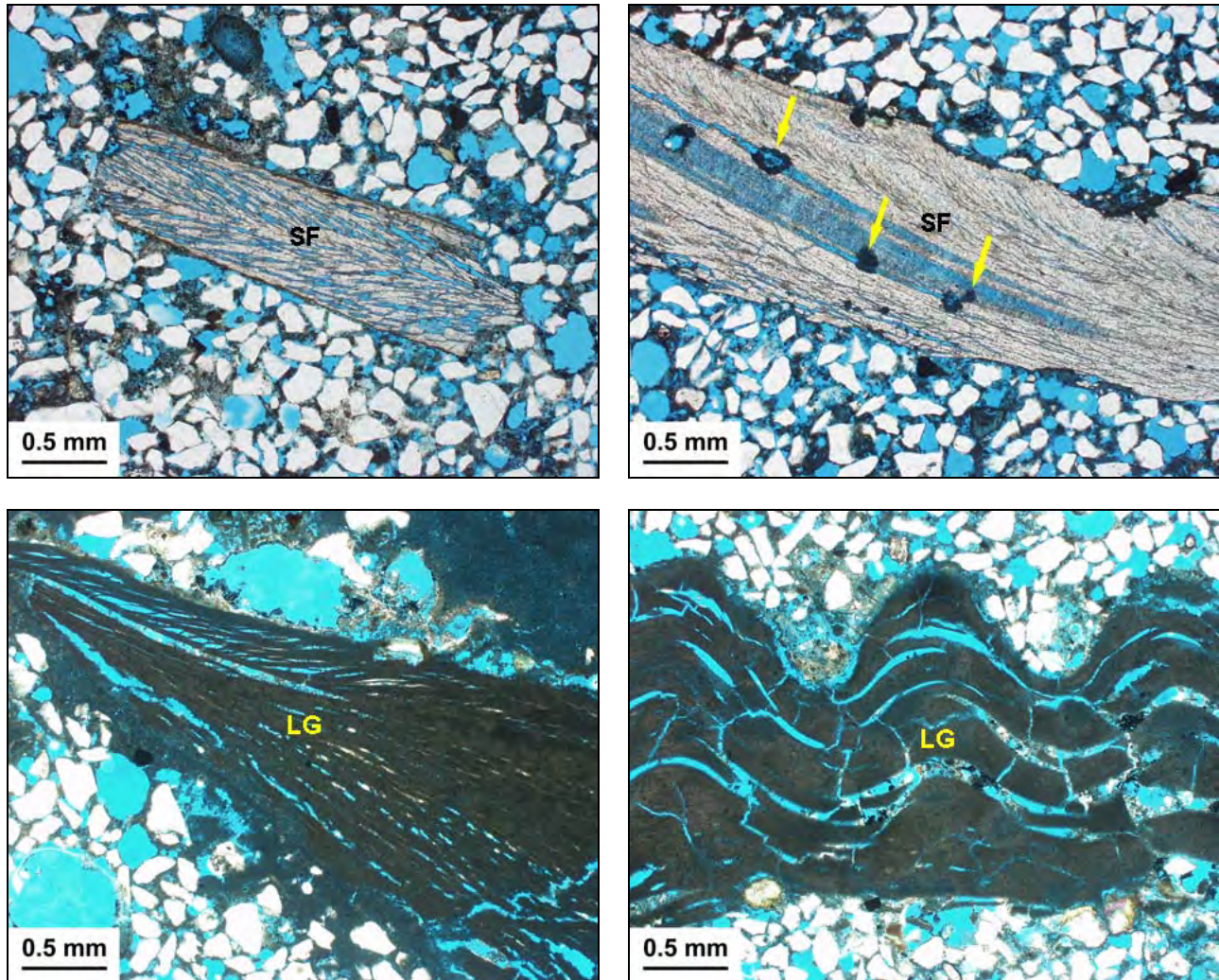


Figure 8: PPL photomicrographs illustrating the quality of the fired lime. (Upper left) Unburned shell fragments (SF) are typically plate-like and no more than a few millimeters in length. (Upper right) Even where apparently unburned, fine spots of carbonated lime within the shells indicate that they were fired. These are not simply crushed shell fragments. (Lower images) Fully carbonated lime grains (LG) often contain evidence of the shell source. Both images show microscopic partings within the lime grains (LG) that correspond to microtextures originally present within the shell. The grain at left is typical of oyster shell. The grain at right appears to represent some type of scallop shell.

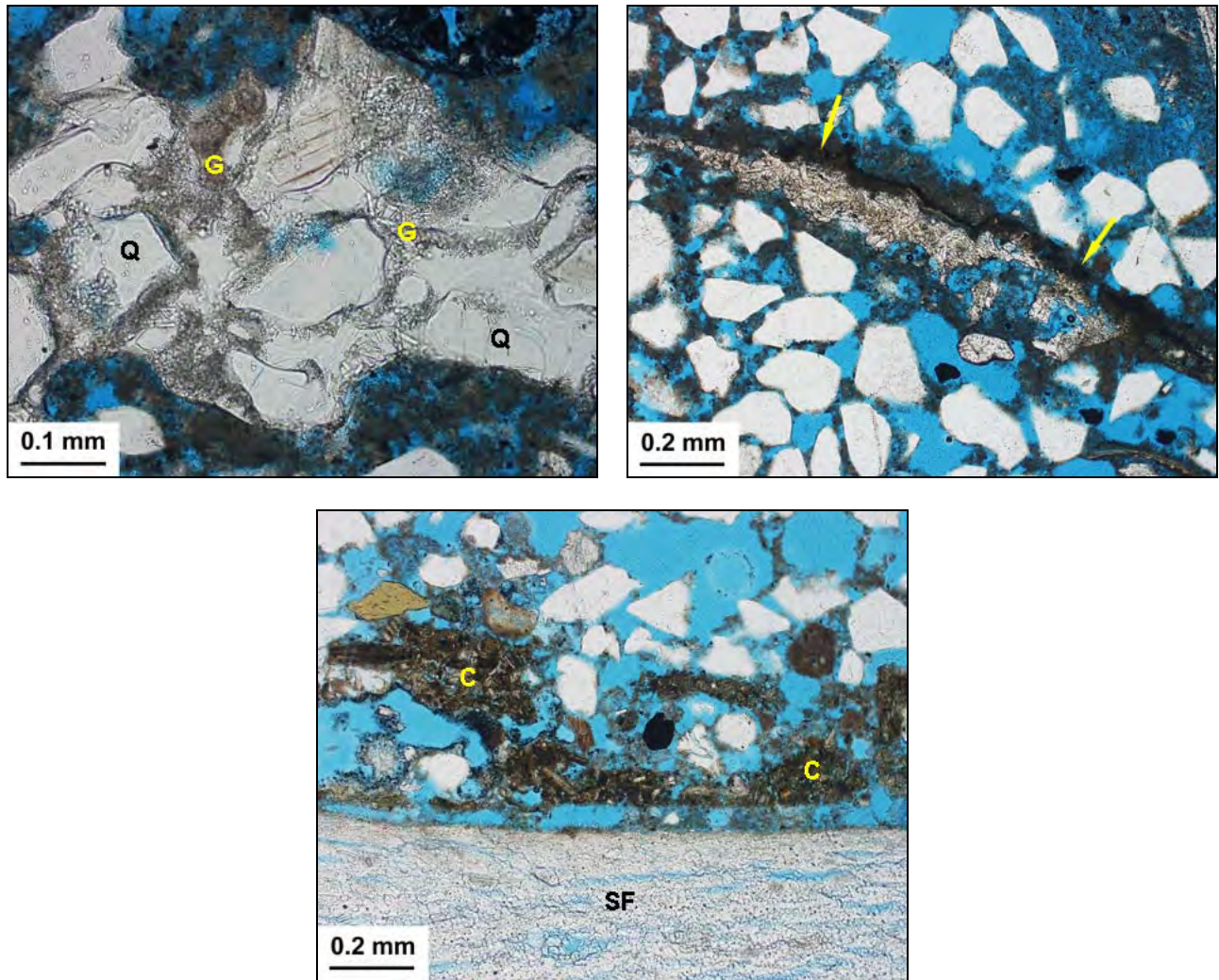


Figure 9: Minor impurities are also associated with the lime. These represent variously fired sand and clay residues originally adhered to the shell surfaces. (Upper left PPL image) A cluster of quartz particles (Q) are fused together with glass (G). (Upper right PPL image) The arrows indicate a thin arcuate flake of clinkered clay that maintains the negative impression of the original shell. (Lower PPL image) A residue of lightly burned clay (C) is adhered to the surface of a shell fragment (SF). This provides evidence for the source of the various impurities otherwise distributed throughout the binder.

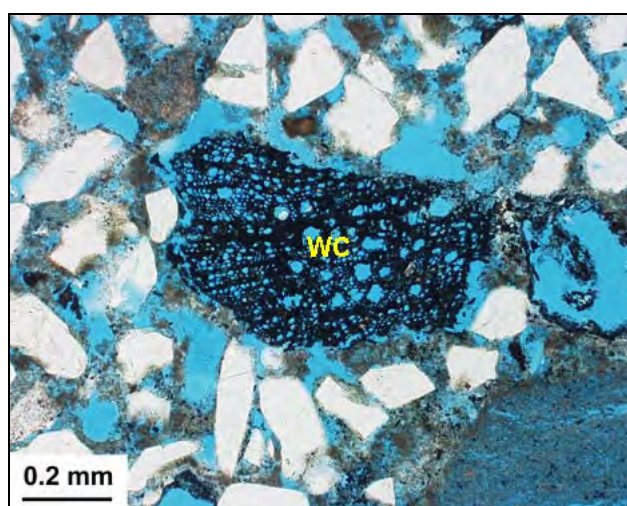


Figure 10: PPL photomicrograph. Traces of wood cinder (WC) represent relicts from the fuel used to calcine the lime.

Appendix III: Sample Log

Table III.1: Summary of Received Samples

The laboratory has shortened the sample identifications for more convenient presentation in the reports. The shortened IDs are describe in the "HMC ID" column.

Material	Client ID	Chimney No.	HMC ID	Client description	Testing
Tabby brick	Stafford.7	16	07	East side of hearth, "f" marked on face	Compositional analysis, clay identification
	Stafford.8	1	08	West side of hearth	
	Stafford.9	18	09	Interior-facing side of chimney (same location as Stafford.1), original orientation of brick not clear.	Soluble salt identification through XRD
	Stafford.10	10	10	Found in rubble pile next to chimney	Strength, absorption
	Stafford.11	10	11	Found in rubble pile next to chimney	
	Stafford.12	22	12	Found in rubble pile next to chimney	Strength, absorption
	Stafford.13	22	13	Found in rubble pile next to chimney	Strength, absorption
	Stafford.14	22	14	Found in rubble pile next to chimney	Strength, absorption
	Stafford.15	22	15	Found in rubble pile next to chimney	
	Stafford.16	22	16	Found in rubble pile next to chimney	Strength, absorption
	Stafford.18	4	18	Removed from west side of chimney, significant erosion of brick face.	Soluble salt identification through XRD
	Stafford.19	3	19	Removed from back exterior face of chimney, significant erosion of brick face.	Soluble salt identification through XRD
Red clay brick	Stafford.20	16	20	Removed from northwest corner of chimney, face only, "B" marked on back/interior of brick) mild erosion of brick face	
	Stafford.6	4	06	Found on ground next to chimney, presumed to be from west surround of hearth.	Petrographic examination
Tabby brick bedding mortar	Stafford.17	22	17	Removed from back wall of hearth	
	Stafford.1	18	01	Taken from interior side of chimney above lintel.	
	Stafford.2	11	02	Taken from location of roof peak, area of mortar build-up, mortar continues into adjacent joint (i.e., same material as mortar in joints).	Compositional analysis
Parging	Stafford.3	1	03	Small sample from exterior mortar joint.	
	Stafford.4	4	04	Parging does not appear to be original (different color than mortar original, evidence of soiling on face of mortar under parging).	
Clay	Stafford.4	n/a	21	"Clay rock" from shore	Gradation analysis

Notes:

1. The laboratory has shortened the sample identifications for more convenient presentation in the reports. The shortened IDs are describe in the "HMC ID" column.
2. Three additional tabby brick will be selected for limited insoluble residue testing to evaluate the type and content of siliceous aggregate. These samples have not been selected and the testing is not indicated in the table as of this writing.

Appendix C

“Report on Mortar Compositional Analysis” (Highbridge Materials Consulting, Inc., 12/23/19)

Report on Mortar Compositional Analysis

Stafford Slave Settlement, Cumberland Island
National Seashore, Chimney Stabilization
Cumberland Island, Camden County, GA



Prepared for
Building Conservation Associates, Inc.

Client ID
BUIL005

Report No.
SL1443-02

Report Date
12/23/19



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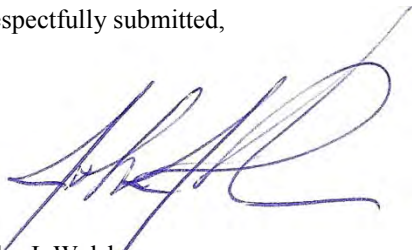
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Cover Image

Photograph of a chimney structure at the Stafford Slave Settlement on Cumberland Island, GA courtesy of Ms. Dorothy Krotzer of Building Conservation Associates, October 2, 2019.

Respectfully submitted,



John J. Walsh
President/ Senior Petrographer
Highbridge Materials Consulting, Inc.



Heather Hartshorn
Chemist/ Staff Scientist
Highbridge Materials Consulting, Inc.

1. Executive Summary

This report presents a compositional analysis on tabby brick mortar sampled from the interior side of a chimney at the Stafford Slave Settlement on Cumberland Island, GA. The material is a common lime mortar that is relatively uniform in appearance with a nearly white color where fresh (Munsell code approximately 10YR 8/1). The lime is a non-hydraulic fat lime prepared from oyster shell and probably screened to remove coarser shell fragments. The aggregate is a very fine and narrowly graded natural quartz sand. The proportions are estimated at 1 : 1.4 by volume with the lime calculated as a putty. The materials were thoroughly mixed, adequately consolidated, and well-cured. The resulting product is highly cohesive though it maintains the softness and high permeability typical of lime mortars. The binder is fully carbonated as expected for the material and age. No deleterious service effects are identified petrographically.

2. Introduction

On August 27, 2019, Highbridge received a set of masonry samples from Ms. Dorothy Krotzer of Building Conservation Associates reported to have been sampled from chimney structures at the Stafford Slave Settlement on Cumberland Island, GA. A summary of the samples, their identifications, and locations is presented in Appendix III. It is understood from the client that the site represents the ruins of a 19th century slave housing settlement in which only the chimney structures survive. The chimneys are reported to have been constructed of tabby brick with red clay brick used for the hearth and firebox.

At Ms. Krotzer's request, laboratory testing is performed on the samples to provide information that may assist in an ongoing stabilization effort. The testing plan was developed in discussions between Ms. Krotzer and Mr. John Walsh of Highbridge. The plan was finalized in a telephone call on September 20 and includes the following:

1. Qualitative identification of salts in tabby brick

Surface erosions on tabby brick may be the result of salt hydration or crystallization. The client has requested an identification of water-soluble salts present within the brick through x-ray diffraction analysis. Three samples are chosen for the analysis, two the client has identified as distressed and one the client has identified as sound.

2. Qualitative identification of clays in tabby brick

Weathering of the tabby brick may also be the result of the swelling behavior of clay constituents during wetting/drying cycles. X-ray diffraction analysis will be performed on clays extracted from one brick sample to determine whether swelling varieties are present.

3. Compositional analysis of tabby brick

This testing combines petrographic examination and chemical analysis to identify constituents, estimate proportions, and assess overall condition of the tabby brick. An acid digestion to extract an aggregate sample for description and gradation is also included. One sample will be examined comprehensively.

4. Gradation analysis of tabby brick aggregate

It is anticipated that there may be some variation in the tabby brick mix proportions. Rather than examine several samples comprehensively, a less costly acid digestion will be performed on an additional three brick samples. The content and gradation of the acid-insoluble constituents will be compared.

5. Gradation analysis of local silt/clay

The client has provided a sample of local sediments from the shore of the island. It is suspected that this material may have been used in the tabby manufacture. The laboratory will disaggregate this loosely consolidated material and grade it through standard sieves. The color and gradation of the sediment will be compared to the acid-insoluble material recovered from the tabby brick.

6. Physical property testing of tabby brick

The testing includes compressive strength, absorption, and saturation coefficient determination on a sample of five brick specimens. Since the tabby brick potentially contains relatively flat shell fragments and would likely have been compacted in a direction perpendicular to the bed face, it is suspected that there could be significant strength anisotropy. If so, this might have a bearing on the manner in which the brick decays in service. The laboratory will take cores in two directions from each of the five bricks to determine compressive strength. It is also suspected that the tabby brick may be appreciably weaker when wet. One additional core sample will be tested in each orientation under saturated conditions.

7. Compositional analysis of masonry mortar

This testing combines petrographic examination and chemical analysis to identify constituents, estimate proportions, and assess overall condition of the tabby brick bedding mortar. An acid digestion to extract an aggregate sample for description and gradation is also included. One sample will be examined comprehensively.

8. Petrographic examination of red clay brick

One sample of red clay brick will be examined petrographically. The purpose of a petrographic examination is to evaluate the constituents and microstructural features of the brick and to assess any potential causes for deterioration observed by the client on site.

This report presents results of the mortar compositional analysis. Results for the other tests will be presented under separate cover when complete.

3. Methods of Examination

The petrographic examination was conducted in accordance with the standard practices contained within ASTM C1324-15. Data collection is performed or supervised by a degreed geologist who by nature of their education is qualified to operate the analytical equipment employed. Analysis and interpretation is performed or directed by a supervising petrographer who satisfies the qualifications as specified in Section 4 of ASTM C856-18a.

Chemical analysis was performed in general accordance with the procedures outlined in ASTM C1324-15. Water, carbon dioxide, and aggregate weight percentages are determined gravimetrically. Oxide weight percentages are determined by inductively coupled plasma - optical emission spectroscopy (ICP-OES). While ASTM classifies C1324 as a test method, it is intended to serve as a guideline for qualified practitioners with ample experience in the various materials under consideration. Section 10.2 indicates the need for discretion on the part of the laboratory to ensure that methods are tailored to specific mortar compositions. As such, Highbridge chooses specific digestion methods, supplementary tests, instrumentation protocols, and mathematical models to best characterize each individual mortar under consideration. Many of these are proprietary methods that have been researched internally.

Organic impurities testing was not part of the original testing scope. This testing was performed in general accordance with methods described in ASTM C40/C40M-19. The sample size and reagent volume were prepared in an approximate manner without attention to those required by the standard.

The following personnel contributed to the examination:

Technician:	M. Pattie
Chemist:	H. Hartshorn
Petrographer:	J. Walsh

4. Petrographic Findings and Discussion

4.1 - Materials

The aggregate is a clean natural sand consisting almost entirely of quartz. Fine phosphate grains are present in trace quantity, but are more abundant than the other trace constituents. The other traces include microcline, zircon, amphibole, kyanite, epidote, staurolite, and some undifferentiated minerals. There is a very minor quantity of silt and clay associated with the sand (~0.2% by weight), but no significant clay coatings or friable lumps. A roughly executed organic impurities test was performed on a sand sample extracted from the mortar through digestion in dilute hydrochloric acid. The insoluble residue was further digested in 1N NaOH for 24 hours, and the supernatant liquid had a color equivalent to Gardner Color Standard No. 5. This would suggest a low content of organic impurities and certainly less than that suspected in the tabby brick of otherwise similar composition. Overall, the mortar aggregate is considered hard, non-porous, and durable for use in masonry mortar.

The sand extracted through acid digestion is semi-translucent and uniform in appearance. The color is a light yellowish gray (Munsell code approximately 2.5Y 7/1.5). The aggregate is sharp-textured with equidimensional particles that are subangular in shape on average. The extracted sand was graded through a standard sieve set and the results are presented in Section 5. The sand is very fine-grained and somewhat narrowly graded. About 75% of the sand is retained between the No. 50 and No. 100 sieves, and about 25% between the No. 100 and No. 200 sieves. The rather sharp truncation below the No. 200 mesh suggests that the aggregate may have been washed prior to use. The particle size distribution would not comply with modern masonry sand gradation profiles as specified by ASTM C33/C33M-18. However, the fine gradation was typical of Southern coastal lime mortars of the nineteenth century. It is noted that the mortar aggregate gradation is very similar to that of the local sediment represented by Sample 21 once the fines are removed from this material. The color of the mortar sand is paler, but this may be related to the breakdown of submicroscopic organic coatings on the sand once in contact with the highly alkaline lime paste.

The binder is identified as a non-hydraulic, high-calcium fat lime manufactured from oyster shells. It was possible to estimate the composition of the original lime through the chemical analysis and this estimate is presented in Table 6.2. The lime has a high purity with a CaO content greater than 96% by dry unslaked weight. The hardened lime paste is homogeneously distributed with a high capillary porosity and a moderate concentration of microscopic shrinkage cracks. The porosity and cracking are both typical of lime mortars. Discrete lime inclusions are moderately abundant although comparison with the tabby brick suggests that the lime for the mortar was screened to remove any particles larger than a few millimeters. Approximately half of the particulates represent incompletely burned shells. Where unburned, there is not a lot of evidence for the shells having been fired. However, there is a moderate to moderately low concentration of very fine carbonate crystals caused by disaggregation of the shells during calcination. These fines are distributed throughout the paste but are locally variable in concentration. Where fully-burned lime particles are evident, these are fully carbonated and sometimes include partings that are coincident with structures present in the original shell. There is also a moderate concentration of fused quartz grains along with lesser calcined clay and more completely fired aluminous clinker. These all represent silt and clay that originally lined the surfaces of the oyster shells before firing. In fact, there are a number of examples where the fired impurities retain the arcuate impression of the underlying shell. There are also a couple of examples observed petrographically where lime and fired impurities are adhered to one another.

4.2 - Component Proportions

Chemical analysis was used to estimate the component proportions, and these results are presented in Section 6. Calculating the lime as the equivalent of a modern dry hydrate, the lime to sand ratio is estimated at 1 : 1.1 by volume. This was a fairly common proportioning for historical lime mortars, especially ones that contained narrowly graded sands. Such sands have high void contents and require a greater amount of binder to ensure thorough consolidation.

The lime is calculated as a dry hydrate. However, it is clear that the lime was burned from local shell, and the construction predates the commercial availability of prepackaged dry hydrates. Nevertheless, the calculation of the lime as a dry hydrate is convenient because it does not have to take into account the mix water used in a lime putty. Still, if it is assumed that a volume of dry hydrate will lose approximately 20% of its volume when water is added to produce a putty of stiff consistency, then the lime to sand ratio is calculated at 1 : 1.4 by volume.

It should be noted that where volume proportions are given, these are based on estimated original bulk densities of the materials. In Table 6.3, estimates are given for both dry hydrated lime and lime putty. However, limes are subject to great variation in volume due to factors such as settling or “fluffing” in dry powders and mix water content in putties. Furthermore, the assumed sand density is based on that of a more broadly graded aggregate. Table 6.3 also presents the weight percentages of dry ingredients (dry hydrated lime and sand). These are more accurate as they represent direct measurements of material mass. Of course, this discussion may be academic as the client may choose to design a repair mortar using materials other than common lime. The findings of a mortar analysis are best used to constrain possible repair designs rather than as a prescription for a specific formulation.

It should also be noted that the estimated sand content is inclusive of a minor abundance of silt and clay. A separate weight percentage is reported in Table 6.3 for these constituents. However, these do not have a significant impact on the calculated binder to sand ratios whether or not they are included as part of the total aggregate.

4.3 - Condition and Service Performance

Based on the sample provide for examination, the mortar constituents were well mixed and there are no sand streaks or coarse binder inclusions. There are no local variations in microporosity that would suggest heterogeneous incorporation of original mix water. The mortar is compact and relatively well consolidated with an air content estimated at 7-10% by volume. Voids are mostly deformed spherical pores with sizes mostly finer than 0.5 millimeters in diameter.

The qualitative properties of the mortar are typical for the composition. The paste is soft and highly water permeable. However, the high degree of cohesion is indicative of a well-prepared and cured mixture. There is a moderate concentration of fine polygonal and discontinuous microscopic shrinkage cracks throughout the cured lime paste. These are typical of lime mortars, especially those with lower sand contents. The cracks are considered dormant and do not have a significant impact on the quality of the cured mortar.

The mortar is fully carbonated and this is a normal and desirable consequence of curing. There are no other mineralizations indicative of deleterious chemical attack on the mixture. Aside from the normal shrinkage cracking, there is no physical distress of any kind identified petrographically.

5. Aggregate Sieve Analysis

Aggregate analysis was performed by digesting the sample in an acid sufficient to dissolve the binder. The material was examined visually and microscopically to ensure that all recovered material represents sand rather than undigested binder components. Two grains captured on the No. 30 sieve are identified as fused quartz. These represent impurities from the lime and were removed from the gradation analysis. There is certainly a very small concentration of these impurities in the finer sieve sizes but it is impracticable to extract them from the rest of the sand. Similarly there are traces of fine cinder from the lime production that cannot be conveniently separated. In any case, these combined factors represent an insignificant error. In contrast, there is a minor concentration of incompletely burned shell fragments from the lime that behave as an aggregate. These were all dissolved in the acid digestion and are not represented in the analysis below. However, these are too minor to have any visual impact. The error associated with their exclusion from the gradation analysis is also negligible.

A qualitative description of the sand is given in the discussion above, and the recovered sample is returned to the client. The sample size is significantly smaller than would be required to perform a sieve analysis on fresh aggregate materials as per ASTM C136, and some small errors should be expected.

Table 5.1: Acid Digestion Data

	Retention (g)	Cumulative passing (%)	Cumulative retained (%)
No. 4	0.00	100.0	0.0
No. 8	0.00	100.0	0.0
No. 16	0.00	100.0	0.0
No. 30	0.00	100.0	0.0
No. 50	0.14	97.8	2.2
No. 100	4.48	26.3	73.7
No. 200	1.62	0.4	99.6
No. 325	0.02	0.2	99.8
Pan	0.01	0.0	100.0
Fineness Modulus			0.76

6. Chemical Analysis

Table 6.1: Chemical Analysis Results

Sample ID	01
Component (wgt. %)	
SiO ₂	0.15
CaO	19.78
MgO	0.21
Al ₂ O ₃	0.13
Fe ₂ O ₃	0.05
Insoluble residue	61.35
LOI to 110°C	0.35
LOI 110°C-550°C	1.26
LOI 550°C-950°C	15.51
Measured Totals	98.79

Table 6.2: Estimated Original Lime Chemistry

The binder consists of non-hydraulic lime with no other additives. As such, the lime chemistry is estimated from the acid-soluble oxide chemistry presented in Table 6.1. The five major oxides in the binder are normalized to a 99% weight yield. This normalizes the lime to a dry weight basis and is equivalent to the pre-slaked condition. The residual 1% is assumed to represent trace unmeasured constituents. Important ratios are calculated directly from the data. The reported indices are calculated as follows:

$$\text{Hydraulicity index} = (\text{SiO}_2 + \text{Al}_2\text{O}_3) / \text{CaO}$$

$$\text{Cementation index} = (2.8 \cdot \text{SiO}_2 + 1.1 \cdot \text{Al}_2\text{O}_3 + 0.7 \cdot \text{Fe}_2\text{O}_3) / (\text{CaO} + 1.4 \cdot \text{MgO}).$$

Sample ID	01
Component (wgt. %)	
SiO ₂	0.7
CaO	96.4
MgO	1.0
Al ₂ O ₃	0.6
Fe ₂ O ₃	0.2
Other	1.0
CaO/MgO ratio	92.1
Hydraulicity Index	0.01
Cementation Index	0.03

Table 6.3: Calculated Components

Sample ID	01
Component	
Lime expressed as dry hydrate (wgt. %)	30.4
Sand (wgt. %)	69.5
Silt and clay (wgt. %)	0.1
Lime : aggregate ratio (by volume with lime as dry hydrate)	1 : 1.1
Lime : aggregate ratio (by volume with lime as putty)	1 : 1.4

Notes:

- The lime weight is calculated by mathematically converting the measured CaO and MgO to their respective hydroxides by molecular weight conversion. The three other measured oxides are assumed to represent minor impurities in the lime and are added directly to the calculated hydroxides. This represents the lime as a hydrate. The measured insoluble residue largely represents the natural aggregate with only trace impurities from the binder. The acid digestion used to extract the sand sample (Section 5) is used to partition this residue value into sand and fines (silt and clay). The weight percentage of material passing the No. 325 in the extracted sample is considered to be silt and clay, and this percentage is multiplied by the chemically-measured acid-insoluble residue. The lime, sand, and fines weights are all normalized to 100% to return the materials to a dry weight basis. Since the amount of clay is shown to be negligible, the fines are included with the aggregate for the purposes of calculating a lime to aggregate ratio. The volumetric ratios are calculated assuming bulk densities for nonhydraulic lime and damp, loose sand of 40 lbs./ft.³ and 80 lbs./ft.³, respectively. Another calculation is provided assuming the lime in putty form. This assumes a unit of dry lime hydrate will lose approximately 20% of its volume when mixed to the consistency of a stiff paste.

Appendix I: Visual Description of Sample as Received

Sample ID	Sample 01
Description	The sample consists of five large bedding mortar pieces weighing a total of 294 grams.
Surfaces	Bed surfaces are roughly planar and compact with a fine sandy texture.
Hardness / Friability	The paste is soft but the mortar is cohesive and nonfriable.
Appearance	Fresh surfaces have a moderately dull luster and a nearly white color (Munsell code approximately 10YR 8/1).
Other details	No cracks, efflorescence, or mineral deposits are visible in hand sample. There is a moderately high concentration of white binder inclusions up to a maximum size of several millimeters in diameter. There is a low abundance of light gray shell fragments also at the millimeter scale.
Water absorptivity	The matrix is highly water absorptive.

Appendix II: Photographs and Photomicrographs

Microscopic examination is performed on an Olympus BX-51 polarized/reflected light microscope and a Bausch and Lomb Stereozoom 7 stereoscopic microscope. Both microscopes are fitted with an Olympus DP-11 digital camera. The stereoscopic microscope is used for simple magnification. Sample types examined under this microscope include fractured surfaces, fine constituents extracted through chemical or physical means, or honed or polished cross sections. The polarized light microscope (PLM) magnifies but also employs principals of optical crystallography. The most common sample preparation for the PLM is the petrographic thin section. For this preparation, cross-sectioned samples are mounted to glass slides and are milled to a thickness sufficient to allow light to be transmitted through the material. These are usually prepared without water and with minimal heat to avoid altering minerals that are water or temperature-sensitive. In many cases, the samples are impregnated with a low-viscosity, blue-dyed epoxy. When so treated, blue areas represent some type of void space (e.g., air-voids, capillary pores, cracks, etc.). The polarized light photomicrographs are taken using a variety of optical settings chosen to best demonstrate the feature(s) of interest. These are distinguished as follows:

Plane polarized light (abbreviated as PPL)

This method uses the refractive power of different constituents to produce an artificial sense of surface relief. Otherwise, the method is the closest to a simple magnification of the material. The setting is often used to demonstrate granular relationships or microstructure. Pore spaces and cracks are observable with this setting if the blue-dyed epoxy is used.

Conoscopic polarized light (abbreviated as CPL)

In this setting, the transmitted light is condensed just before passing through the thin section. The method tends to bring colors or finer particulates into higher contrast at the expense of image sharpness. The setting is often used to image grain boundary failures in dimension stone, pigment particulates in binders, or gel phases in the micropores of cement pastes.

Cross polarized light (abbreviated as XPL)

The setting places the thin section between two pieces of polarizing film oriented at 90° to one another. In isotropic materials (e.g., glasses, simple salts), all light is absorbed and the materials appear black. In anisotropic crystals, two light rays traveling at different speeds are produced within the thin section and these offset waves interfere at the upper polarizing film. The interference produces a color that can be used to calculate properties of the crystal structure and aid in identification of mineral species. In essence, the colors are artificial. It should be noted that color is a function of orientation and color differences do not necessarily indicate material differences.

Compensator plates

When in XPL mode, full-wave or quarter-wave compensator plates may be inserted into the light path to add or subtract interference. Technically, these methods are used to calculate properties of the crystal structure. However, they can also be used to alter the image appearance to help improve contrast between different constituents. They can also reveal preferred orientations in some materials (e.g., oriented residual crystallinity in fired ceramics).

Scale bars are included with all photomicrographs. In higher magnification images, the μm symbol represents microns. One micron is equal to 0.001 millimeter.



Figure 1: Photographs of the mortar sample received by Highbridge for examination. The total sample is shown at left. A fractured surface is shown at right. The arrows illustrate undispersed lime grains and incompletely burned shell fragments.

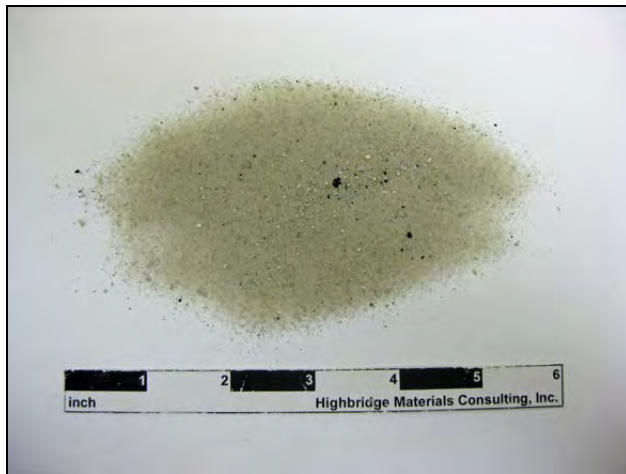


Figure 2: Photographs of the aggregate extracted through acid digestion. The total extraction is shown at left. The sand is uniform and light yellowish-gray in color. At right, the sand is shown after grading through a standard sieve stack. The sand is very fine and somewhat narrowly graded.

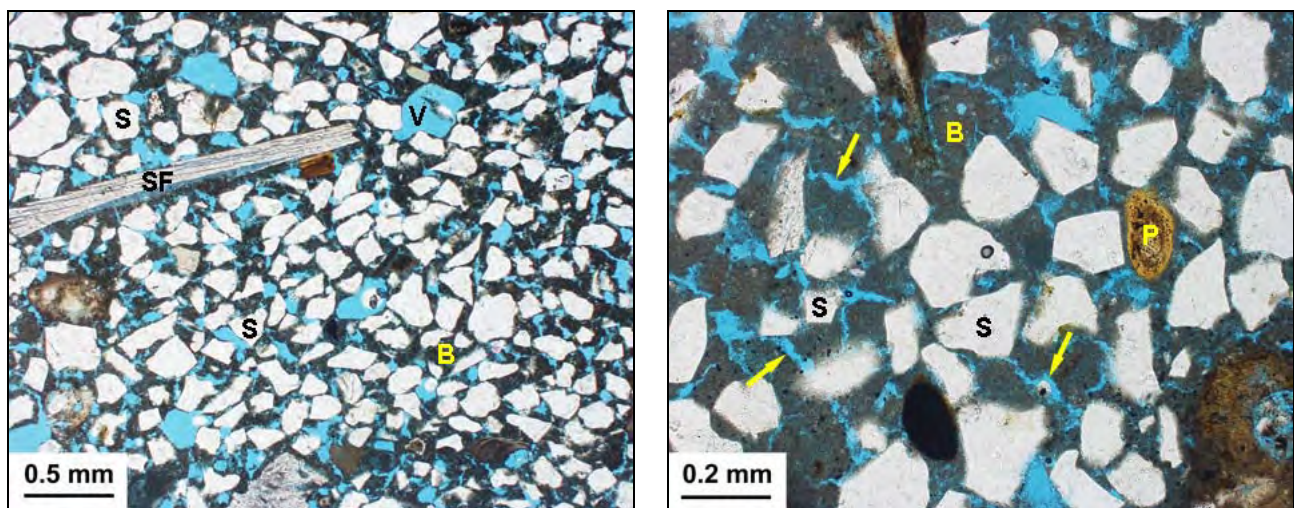


Figure 3: PPL photomicrographs illustrating the microtexture of the mortar. A lower magnification view is shown at left and a higher magnification view is shown at right. The binder (B) is highly permeable as shown by the strong absorption of blue-dyed epoxy used in the sample preparation. The arrows indicate microscopic shrinkage cracks that are typical of lime-based mortars. The sand (S) is sharp-textured and densely distributed throughout the matrix. Phosphate grains (P) are distinctive trace constituents. Incompletely burned shell fragments (SF) also behave as aggregate though these are only moderately abundant. The mortar is well consolidated and voids (V) are not concentrated.

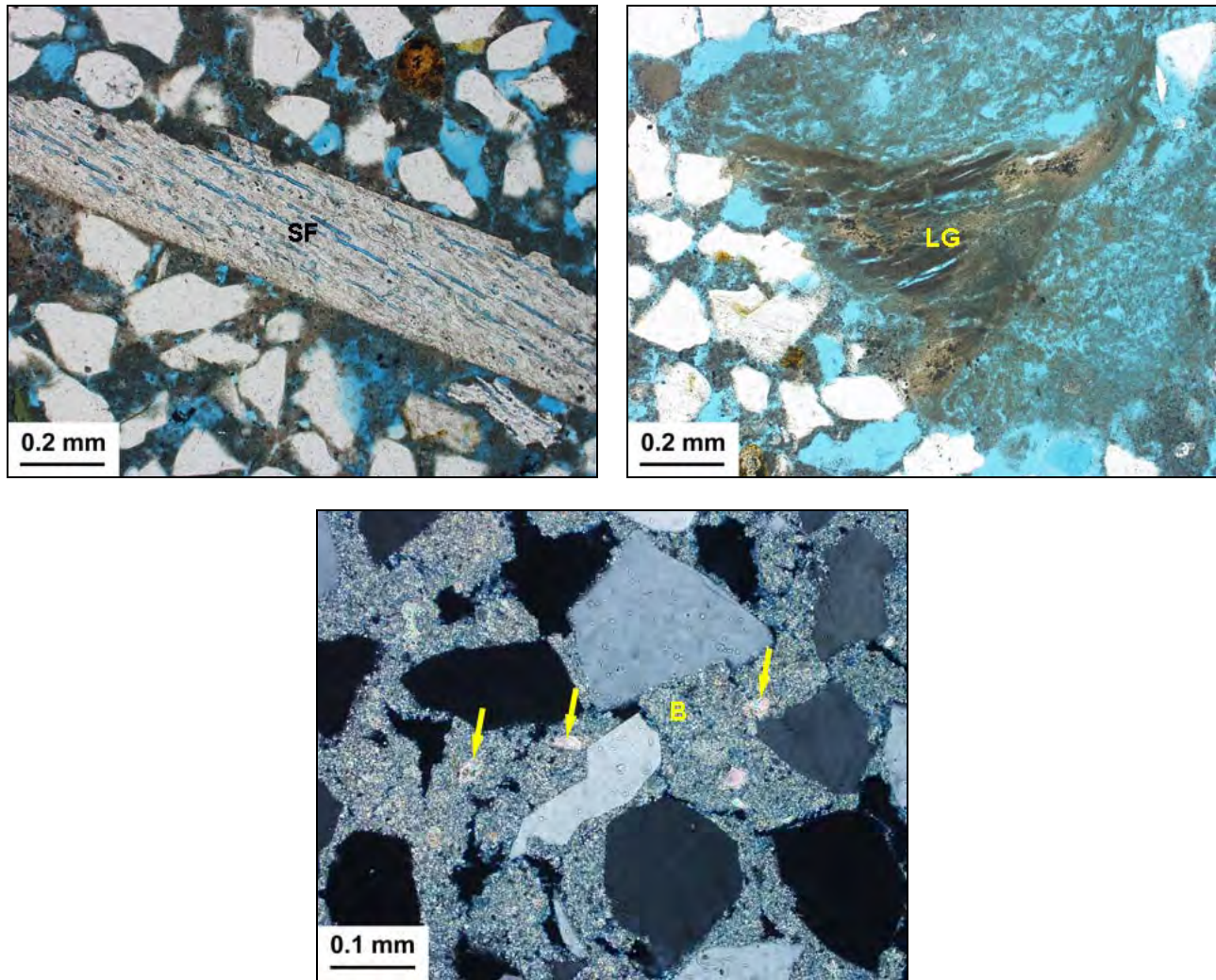


Figure 4: Photomicrographs illustrating the quality of the fired lime. (Upper left PPL image) Unburned shell fragments (SF) are typically plate-like and no more than a few millimeters in length. (Upper right PPL image) Carbonated lime grains (LG) often contain evidence for the shell origin. As is evident in this image, microscopic partings correspond to lamination textures originally present in the shell. (Lower XPL image) The arrows indicate very fine carbonate crystals. These represent single crystals that became disaggregated from the original shell during firing. The adjacent binder (B) is fully carbonated.

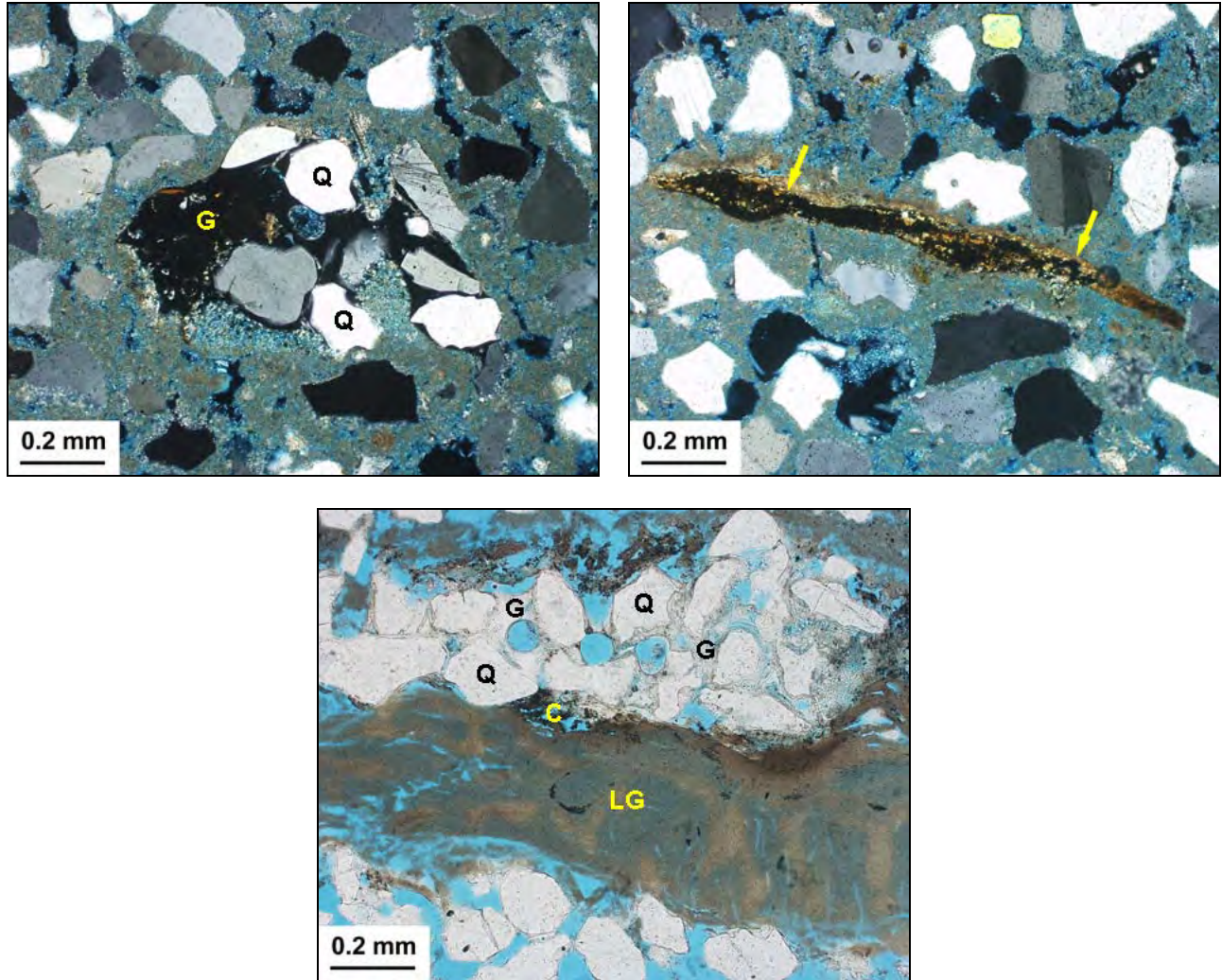


Figure 5: Minor impurities are also associated with the lime. These represent variously fired sand and clay residues originally adhered to the shell surfaces. (Upper left XPL image) A cluster of quartz particles (Q) are fused together with glass (G). (Upper right XPL image) The arrows indicate a thin arcuate flake of calcined clay that maintains the negative impression of the original shell. (Lower PPL image) The relationship between the shells and impurities are evident in this photomicrograph. A lime grain (LG) clearly has the shape of a former shell and is thickly lined with calcined clay (C) and quartz fused with glass (Q and G respectively).

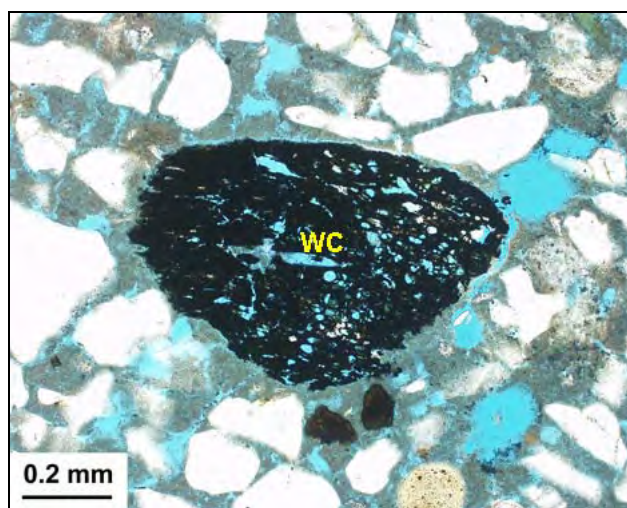


Figure 6: PPL photomicrograph. Traces of wood cinder (WC) represent relicts from the fuel used to calcine the lime.

Appendix III: Sample Log

Table III.1: Summary of Received Samples

The laboratory has shortened the sample identifications for more convenient presentation in the reports. The shortened IDs are describe in the "HMC ID" column.

Material	Client ID	Chimney No.	HMC ID	Client description	Testing
Tabby brick	Stafford.7	16	07	East side of hearth, "f" marked on face	Compositional analysis, clay identification
	Stafford.8	1	08	West side of hearth	
	Stafford.9	18	09	Interior-facing side of chimney (same location as Stafford.1), original orientation of brick not clear.	Soluble salt identification through XRD
	Stafford.10	10	10	Found in rubble pile next to chimney	Strength, absorption
	Stafford.11	10	11	Found in rubble pile next to chimney	
	Stafford.12	22	12	Found in rubble pile next to chimney	Strength, absorption
	Stafford.13	22	13	Found in rubble pile next to chimney	Strength, absorption
	Stafford.14	22	14	Found in rubble pile next to chimney	Strength, absorption
	Stafford.15	22	15	Found in rubble pile next to chimney	
	Stafford.16	22	16	Found in rubble pile next to chimney	Strength, absorption
	Stafford.18	4	18	Removed from west side of chimney, significant erosion of brick face.	Soluble salt identification through XRD
	Stafford.19	3	19	Removed from back exterior face of chimney, significant erosion of brick face.	Soluble salt identification through XRD
Red clay brick	Stafford.20	16	20	Removed from northwest corner of chimney, face only, "B" marked on back/interior of brick) mild erosion of brick face	
	Stafford.6	4	06	Found on ground next to chimney, presumed to be from west surround of hearth.	Petrographic examination
Tabby brick bedding mortar	Stafford.17	22	17	Removed from back wall of hearth	
	Stafford.1	18	01	Taken from interior side of chimney above lintel.	
	Stafford.2	11	02	Taken from location of roof peak, area of mortar build-up, mortar continues into adjacent joint (i.e., same material as mortar in joints).	Compositional analysis
Parging	Stafford.3	1	03	Small sample from exterior mortar joint.	
	Stafford.4	4	04	Parging does not appear to be original (different color than mortar original, evidence of soiling on face of mortar under parging).	
Clay	Stafford.4	n/a	21	"Clay rock" from shore	Gradation analysis

Notes:

1. The laboratory has shortened the sample identifications for more convenient presentation in the reports. The shortened IDs are describe in the "HMC ID" column.
2. Three additional tabby brick will be selected for limited insoluble residue testing to evaluate the type and content of siliceous aggregate. These samples have not been selected and the testing is not indicated in the table as of this writing.

Appendix D

“Report on Petrography of Red Clay Brick” (Highbridge Materials Consulting, Inc., 12/24/19)

Report on Petrography of Red Clay Brick

Stafford Slave Settlement, Cumberland Island
National Seashore, Chimney Stabilization
Cumberland Island, Camden County, GA



Prepared for
Building Conservation Associates, Inc.

Client ID
BUIL005

Report No.
SL1443-04

Report Date
12/24/19



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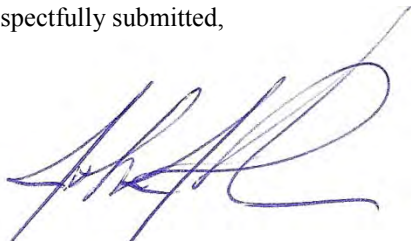
Standard of Care

Highbridge has performed its services in conformance with the care and skill ordinarily exercised by reputable members of the profession practicing under similar conditions at the same time. No other warranty of any kind, expressed or implied, in fact or by law, is made or intended. Interpretations and results are based strictly on samples provided and/or examined.

Cover Image

Photograph of a chimney structure at the Stafford Slave Settlement on Cumberland Island, GA courtesy of Ms. Dorothy Krotzer of Building Conservation Associates, October 2, 2019.

Respectfully submitted,



John J. Walsh
President/ Senior Petrographer
Highbridge Materials Consulting, Inc.

1. Executive Summary

This report presents the results of a petrographic examination on a red clay brick unit sampled from the Stafford Slave Settlement on Cumberland Island, GA. The sample is a hand molded brick with no frogs or manufacturers marks. The brick is uniform in texture with a purplish-red matrix and darker spots distributed evenly throughout the unit. The material is sandy-textured, highly permeable, and well-fired.

Microscopically, the brick is found to have approximately even volumes of sintered clay, fine temper, and micropores. The clay is nonporous and vitrified with partially formed aluminosilicate minerals and well-formed hematite. The temper is a fine quartz sand that was a natural component of the brick clay. The micropores are found at the interstices of the temper grains and form an interconnected void network. The composition and microstructure are typical of many Southern coastal bricks of the nineteenth century.

Only minor hairline cracking is evident in the brick. No significant secondary mineralizations are identified. The material is intact and sound.

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Weathering of the tabby brick may also be the result of the swelling behavior of clay constituents during wetting/drying cycles. X-ray diffraction analysis will be performed on clays extracted from one brick sample to determine whether swelling varieties are present.

3. Compositional analysis of tabby brick

This testing combines petrographic examination and chemical analysis to identify constituents, estimate proportions, and assess overall condition of the tabby brick. An acid digestion to extract an aggregate sample for description and gradation is also included. One sample will be examined comprehensively.

4. Gradation analysis of tabby brick aggregate

It is anticipated that there may be some variation in the tabby brick mix proportions. Rather than examine several samples comprehensively, a less costly acid digestion will be performed on an additional three brick samples. The content and gradation of the acid-insoluble constituents will be compared.

5. Gradation analysis of local silt/clay

The client has provided a sample of local sediments from the shore of the island. It is suspected that this material may have been used in the tabby manufacture. The laboratory will disaggregate this loosely consolidated material and grade it through standard sieves. The color and gradation of the sediment will be compared to the acid-insoluble material recovered from the tabby brick.

6. Physical property testing of tabby brick

The testing includes compressive strength, absorption, and saturation coefficient determination on a sample of five brick specimens. Since the tabby brick potentially contains relatively flat shell fragments and would likely have been compacted in a direction perpendicular to the bed face, it is suspected that there could be significant strength anisotropy. If so, this might have a bearing on the manner in which the brick decays in service. The laboratory will take cores in two directions from each of the five bricks to determine compressive strength. It is also suspected that the tabby brick may be appreciably weaker when wet. One additional core sample will be tested in each orientation under saturated conditions.

7. Compositional analysis of masonry mortar

This testing combines petrographic examination and chemical analysis to identify constituents, estimate proportions, and assess overall condition of the tabby brick bedding mortar. An acid digestion to extract an aggregate sample for description and gradation is also included. One sample will be examined comprehensively.

8. Petrographic examination of red clay brick

One sample of red clay brick will be examined petrographically. The purpose of a petrographic examination is to evaluate the constituents and microstructural features of the brick and to assess any potential causes for deterioration observed by the client on site.

This report presents results of the petrographic examination on the red clay brick. Results for the other tests will be presented under separate cover when complete.

3. Methods of Examination

The petrographic examination was conducted in accordance with the standard practices contained within ASTM C856-18a. The standard is referenced as a more generic document for petrographic examination of inorganic construction materials of all types though the document specifically references concrete. Data collection is performed or supervised by a degreed geologist who by nature of their education is qualified to operate the analytical equipment employed. Analysis and interpretation is performed or directed by a supervising petrographer who satisfies the qualifications as specified in Section 4 of ASTM C856-18a.

The following personnel contributed to the examination:

Technician: M. Pattie
Petrographer: J. Walsh

4. Petrographic Findings

4.1 - Brick Constituents, Casting and Firing

The sample examined petrographically is a solid red clay brick with no frog or manufacturer's mark. The brick is uniform and compact with a purplish-red color overall. The material is sandy and porous though well-vitrified.

The sintered clay consists of a homogeneously developed ultrafine-grained matrix, the constituents of which are barely resolvable at the magnifications available on a typical light microscope. The clay is sparsely distributed and represents approximately 30% of the total brick volume. In general, there are three discernible components. An amorphous vitrified component is reddish brown under plane polarized light. Very little if any submicroscopic microporosity is noted in the vitrified mass. Within the vitrified mass are diffuse, skeletal, and sometimes dendritic crystals up to several tenths of a millimeter in size. These likely consist of mullite, an aluminosilicate mineral common in fired clay products. Finally, discrete hematite crystallites are dispersed throughout the sintered mass. These are generally a few microns in size and are either blocky or rod-like. The hematite crystals are often clustered into small groupings up to 10 μm in diameter and sometimes as thin linings around open micropores. Both the mullite and hematite are coarser-grained and more abundant within darker purplish-red spots distributed evenly throughout the brick. No carbonate or sulfide minerals are identified within the fired clay. There is no evidence for any significant organic matter though certain constituents such as humic acid would likely not be evident after firing.

The brick contains a densely distributed fine quartz temper representing approximately 30% of the total brick volume. As is typical for most Southern coastal brick of the nineteenth century, the temper is a natural component of the brick clay rather than a separate addition. No grog or artificial tempers are detected petrographically. The temper consists almost entirely of quartz mostly as a fine sand. The sand is well sorted with most grains between about 0.125 and 0.20 millimeters. 98% of the grains range in size from 0.075 to 0.30 millimeters. The particles are equant and subangular in shape on average. All of the quartz has reacted to produce thin concentric reaction rims of approximately 2 to 8 microns thickness. These are clear in plane light and dark under crossed polars. The rims likely represent a glass phase though some higher temperature varieties of quartz cannot be excluded. Needle-like mullite crystallites from the adjacent vitrified clay are frequently found within the outer portion of the reaction rims. The quartz grains themselves rarely exhibit internal thermal cracking or localized melting. Trace heavy accessory minerals are also present and these include zircon, kyanite, rutile, and other undifferentiated phases. One trace phase has reacted in the kiln to produce a thick rim of larnite (?). However, this has no impact on the quality of the brick.

The brick matrix is mostly uniform in composition. There are no coarse stone or woody inclusions. Fine clay lumps are relatively infrequent and never more than a few millimeters in diameter. Purplish-red spots are randomly distributed throughout the brick that are locally darker than the surrounding matrix. These are typically several millimeters in size. Petrographically, these are found to contain materials that are essentially the same as those in the surrounding brick. Sometimes they contain a somewhat higher clay proportion, but generally they show different firing characteristics. This suggests that they represent sites of slightly different clay chemistry, possibly areas locally enriched in alkalis. There is often a greater amount of glass in these regions, along with aluminosilicate phases that are more well-crystallized, and coarser blocky hematite crystals.

The brick constituents were well-mixed and there is no streaking of the clay or other similar heterogeneities. The tempered clay was consolidated and adequately compacted into the brick mold. Consolidation voids are present at roughly 10% by volume but these are evenly distributed and not concentrated along molded surfaces to produce significant bugholes. The pores are usually rounded in shape and no more than about 1 centimeter in diameter.

The microscopic porosity of Sample 06 is typical of that observed in other Southern coastal bricks such as Savannah grey bricks. The narrow gradation and high content of temper results in a distinctive microtexture similar to that of a sandstone. Bloating of the clay during firing causes voids to develop and grow within the interstitial space between sand grains. The pore structure is estimated at about 30% by volume. The voids are amoeboid in shape and range in size from tens of microns to about 0.25 millimeters. Due to the high sand content, the voids result in an interconnected pore structure that increases the permeability of the brick. The void structure is uniform and isotropic throughout most of the unit. Toward the edges of the brick, the voids have weakly coalesced to form sheave-like pore structures that are parallel to the brick surfaces. The void structures are not sufficiently continuous for them to behave as cracks.

4.2 - Condition and Service Performance

Though only a half brick was provided for examination, the unit is intact and in relatively sound condition. There is one discrete hairline crack parallel to the head surface. However, this is a relatively minor feature. There is no microscopic cracking identified petrographically. Salt deposits appear to be minimal though some of these may have been washed out during sample preparation for petrography. Some carbonate crystallites are detected within the brick pores but these are not considered deleterious.

Appendix I: Visual Descriptions of Petrographic Sample as Received

Sample ID	06
Dimensions and details	The sample is a half-brick broken along the length with a width of approximately 4" and a height of approximately 3". The brick is slightly deformed in shape. The material is a solid red clay hand-molded brick with no frogs or manufacturer's impressions. Minor mortar residues and green biogrowth are noted on the surfaces.
Brick quality	Minor folds and molding planes are evident. Otherwise, the brick is compact in texture. The brick has a sandy, sintered texture and the fired clay is rapidly absorptive. The matrix has a purplish red color (Munsell code approximately 2.5YR 4/1.75). Darker purplish spots are randomly distributed throughout the matrix. These are usually millimeter-scale features though are sometimes observed at over a centimeter.
Cracks or mineralizations	The broken surface is hackly and is lightly coated with white salt deposits. Another hairline crack is found about halfway between the broken surface and the opposite head face. The crack has a transverse orientation and does not transect the full cross section of the unit.

Appendix II: Photographs and Photomicrographs

Microscopic examination is performed on an Olympus BX-51 polarized/reflected light microscope and a Bausch and Lomb Stereozoom 7 stereoscopic microscope. Both microscopes are fitted with an Olympus DP-11 digital camera. The stereoscopic microscope is used for simple magnification. Sample types examined under this microscope include fractured surfaces, fine constituents extracted through chemical or physical means, or honed or polished cross sections. The polarized light microscope (PLM) magnifies but also employs principals of optical crystallography. The most common sample preparation for the PLM is the petrographic thin section. For this preparation, cross-sectioned samples are mounted to glass slides and are milled to a thickness sufficient to allow light to be transmitted through the material. These are usually prepared without water and with minimal heat to avoid altering minerals that are water or temperature-sensitive. In many cases, the samples are impregnated with a low-viscosity, blue-dyed epoxy. When so treated, blue areas represent some type of void space (e.g., air-voids, capillary pores, cracks, etc.). The polarized light photomicrographs are taken using a variety of optical settings chosen to best demonstrate the feature(s) of interest. These are distinguished as follows:

Plane polarized light (abbreviated as PPL)

This method uses the refractive power of different constituents to produce an artificial sense of surface relief. Otherwise, the method is the closest to a simple magnification of the material. The setting is often used to demonstrate granular relationships or microstructure. Pore spaces and cracks are observable with this setting if the blue-dyed epoxy is used.

Conoscopic polarized light (abbreviated as CPL)

In this setting, the transmitted light is condensed just before passing through the thin section. The method tends to bring colors or finer particulates into higher contrast at the expense of image sharpness. The setting is often used to image grain boundary failures in dimension stone, pigment particulates in binders, or gel phases in the micropores of cement pastes.

Cross polarized light (abbreviated as XPL)

The setting places the thin section between two pieces of polarizing film oriented at 90° to one another. In isotropic materials (e.g., glasses, simple salts), all light is absorbed and the materials appear black. In anisotropic crystals, two light rays traveling at different speeds are produced within the thin section and these offset waves interfere at the upper polarizing film. The interference produces a color that can be used to calculate properties of the crystal structure and aid in identification of mineral species. In essence, the colors are artificial. It should be noted that color is a function of orientation and color differences do not necessarily indicate material differences.

Compensator plates

When in XPL mode, full-wave or quarter-wave compensator plates may be inserted into the light path to add or subtract interference. Technically, these methods are used to calculate properties of the crystal structure. However, they can also be used to alter the image appearance to help improve contrast between different constituents. They can also reveal preferred orientations in some materials (e.g., oriented residual crystallinity in fired ceramics).

Scale bars are included with all photomicrographs. In higher magnification images, the μm symbol represents microns. One micron is equal to 0.001 millimeter.

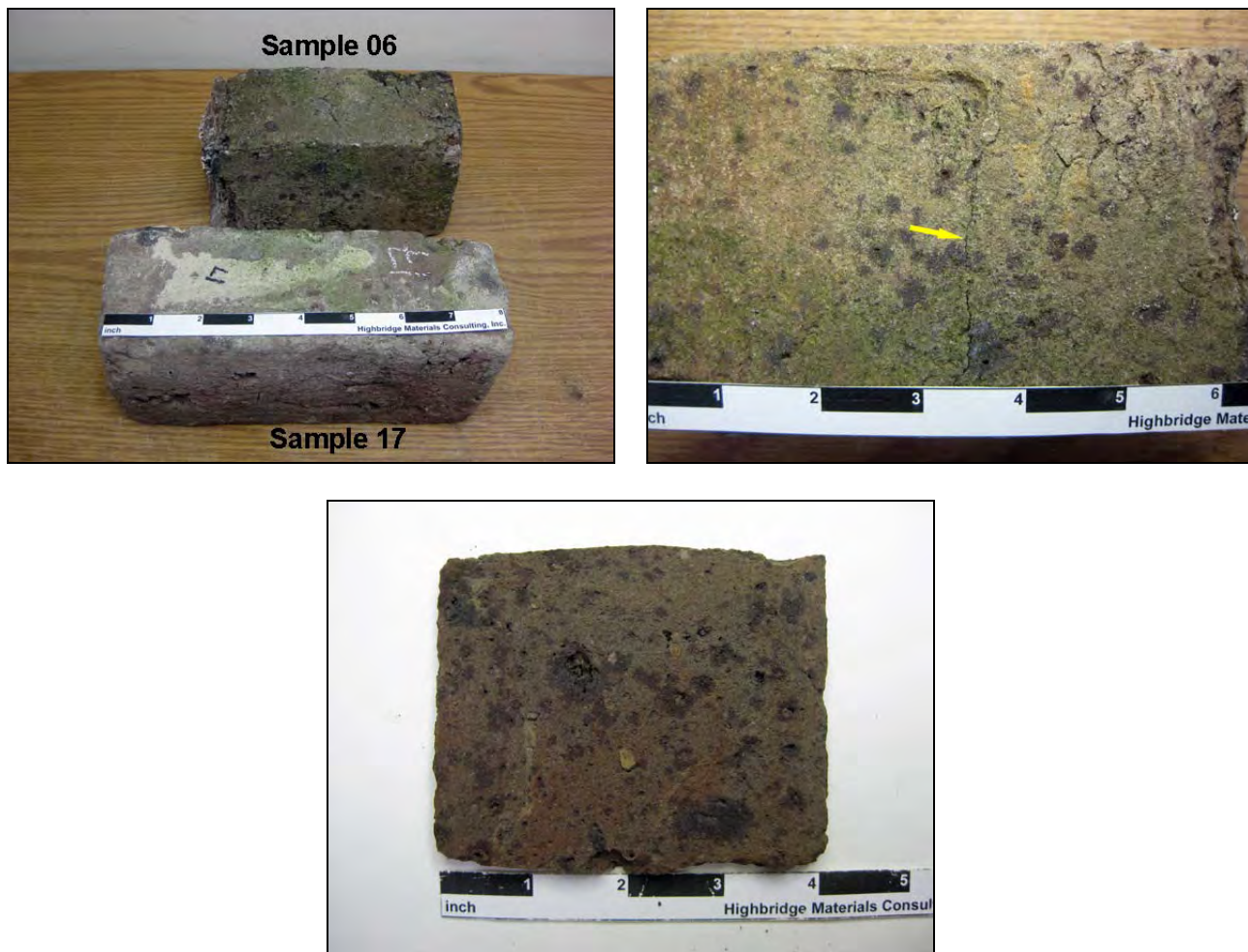


Figure 1: Photographs of the red clay brick provided to Highbridge for analysis. (Upper left) Two red clay bricks were delivered. Highbridge selected Sample 06 for the petrographic examination. (Upper right) A close-up of a bed surface in Sample 06 depicts one minor hairline crack that only partly transects the brick (arrow). The feature is considered minor. (Lower) Photograph of a honed cross section used in the petrographic examination. The brick is uniform in texture with a purplish-red color, and darker spots that are evenly distributed throughout the matrix.

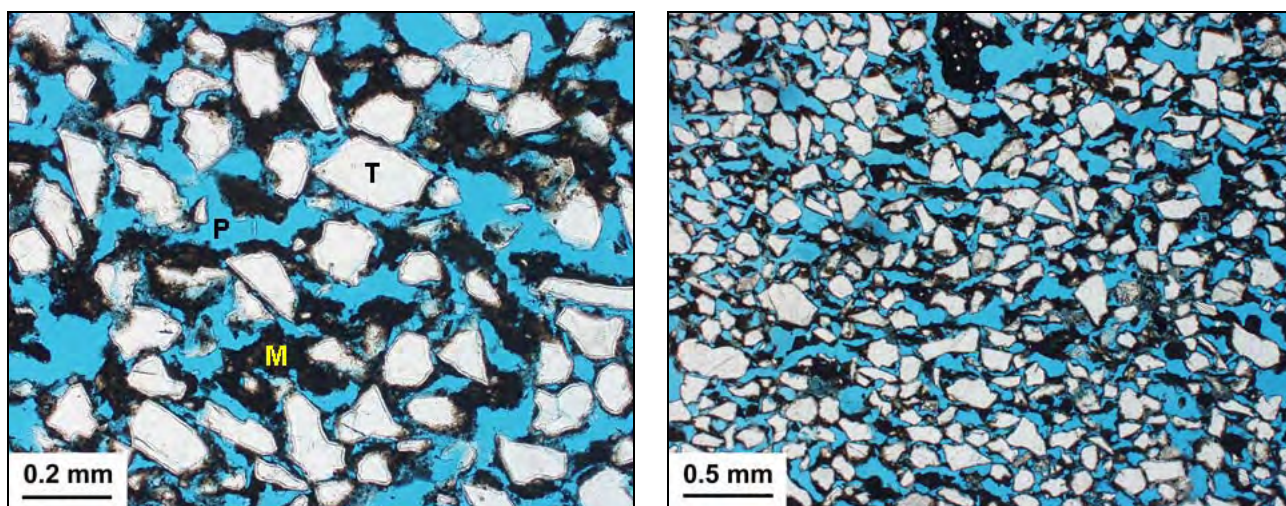


Figure 2: PPL photomicrographs illustrating the overall microtexture of the brick. (Left) Natural quartz temper (T) is abundant and produces a sandy texture. Note the thin reaction rims surrounding each of the temper particles. These formed during firing. A matrix of sintered clay (M) binds the temper. Bloating of the mixture during firing has resulted in abundant micropores (P) located at the interstices between sand grains. These form an interconnected permeability network. (Right) The brick texture is shown near one edge of the sample. Note that the pores (in blue) display a weak parallelism due to coalescence of the voids. This texture is only found near the edges where greater bloating has occurred.

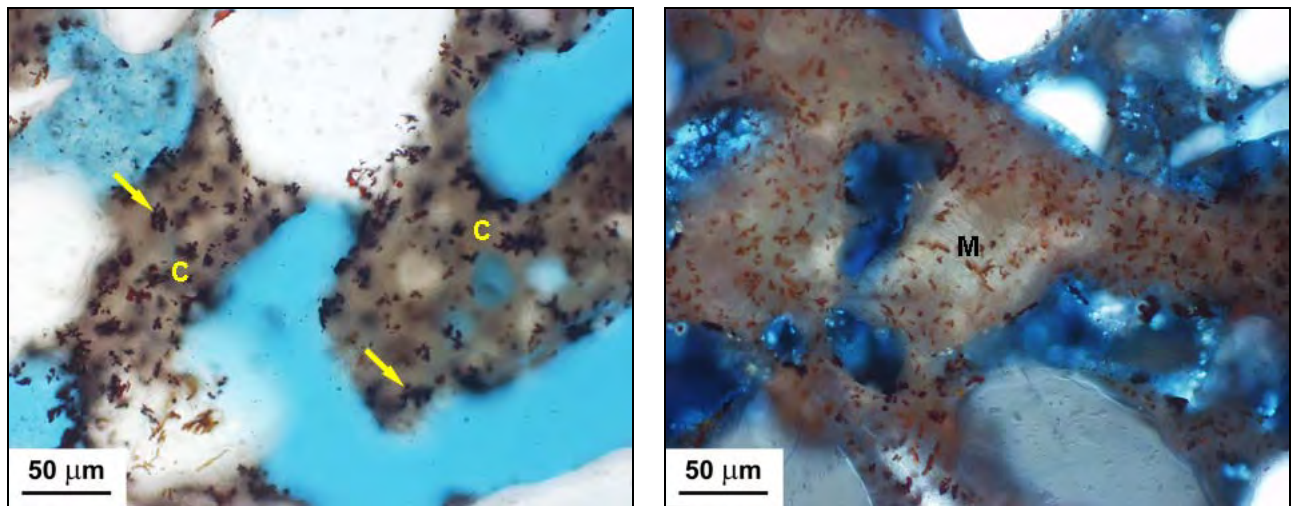


Figure 3: CPL photomicrographs providing high magnification views of the fired clay matrix. The arrows in the left image indicate well-formed hematite crystals dispersed throughout the sintered clay (C). At right, a brighter area in the clay represents a skeletal mullite crystal (M).

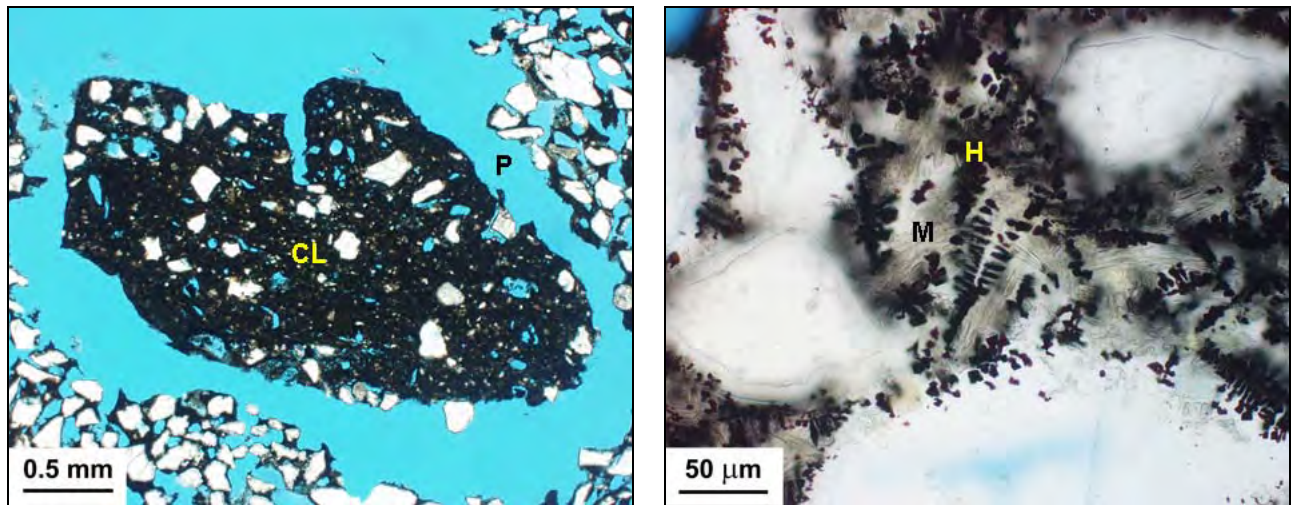


Figure 4: (Left PPL image) Fine clay lumps (CL) are found in minor concentration. Shrinkage of the clay-rich area has resulted in a concentric pore (P). (Right) This CPL photomicrograph was taken within the interior of one of the darker spots. The same constituents are identified. However, the hematite (H) is often coarser-grained with a dendritic texture. Additionally, the mullite (M) is sometimes more thoroughly crystallized.

Appendix III: Sample Log

Table III.1: Summary of Received Samples

The laboratory has shortened the sample identifications for more convenient presentation in the reports. The shortened IDs are describe in the "HMC ID" column.

Material	Client ID	Chimney No.	HMC ID	Client description	Testing
Tabby brick	Stafford.7	16	07	East side of hearth, "f" marked on face	Compositional analysis, clay identification
	Stafford.8	1	08	West side of hearth	
	Stafford.9	18	09	Interior-facing side of chimney (same location as Stafford.1), original orientation of brick not clear.	Soluble salt identification through XRD
	Stafford.10	10	10	Found in rubble pile next to chimney	Strength, absorption
	Stafford.11	10	11	Found in rubble pile next to chimney	
	Stafford.12	22	12	Found in rubble pile next to chimney	Strength, absorption
	Stafford.13	22	13	Found in rubble pile next to chimney	Strength, absorption
	Stafford.14	22	14	Found in rubble pile next to chimney	Strength, absorption
	Stafford.15	22	15	Found in rubble pile next to chimney	
	Stafford.16	22	16	Found in rubble pile next to chimney	Strength, absorption
	Stafford.18	4	18	Removed from west side of chimney, significant erosion of brick face.	Soluble salt identification through XRD
	Stafford.19	3	19	Removed from back exterior face of chimney, significant erosion of brick face.	Soluble salt identification through XRD
	Stafford.20	16	20	Removed from northwest corner of chimney, face only, "B" marked on back/interior of brick) mild erosion of brick face	
Red clay brick	Stafford.6	4	06	Found on ground next to chimney, presumed to be from west surround of hearth.	Petrographic examination
	Stafford.17	22	17	Removed from back wall of hearth	
Tabby brick bedding mortar	Stafford.1	18	01	Taken from interior side of chimney above lintel.	
	Stafford.2	11	02	Taken from location of roof peak, area of mortar build-up, mortar continues into adjacent joint (i.e., same material as mortar in joints).	Compositional analysis
	Stafford.3	1	03	Small sample from exterior mortar joint.	
Parging	Stafford.4	4	04	Parging does not appear to be original (different color than mortar original, evidence of soiling on face of mortar under parging).	
Clay	Stafford.4	n/a	21	"Clay rock" from shore	Gradation analysis

Notes:

1. The laboratory has shortened the sample identifications for more convenient presentation in the reports. The shortened IDs are describe in the "HMC ID" column.
2. Three additional tabby brick will be selected for limited insoluble residue testing to evaluate the type and content of siliceous aggregate. These samples have not been selected and the testing is not indicated in the table as of this writing.

Appendix E

“Report on Salt Analysis of Tabby Brick” (Highbridge Materials Consulting, Inc., 12/31/19)

Report on Salt Analysis of Tabby Brick

Stafford Slave Settlement, Cumberland Island
National Seashore, Chimney Stabilization
Cumberland Island, Camden County, GA



Prepared for
Building Conservation Associates, Inc.

Client ID
BUIL005

Report No.
SL1443-05

Report Date
12/31/19



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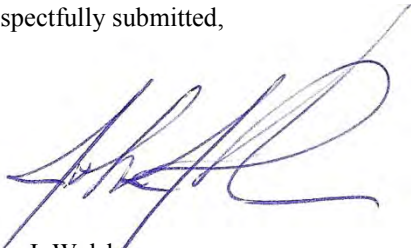
Standard of Care

Highbridge has performed its services in conformance with the care and skill ordinarily exercised by reputable members of the profession practicing under similar conditions at the same time. No other warranty of any kind, expressed or implied, in fact or by law, is made or intended. Interpretations and results are based strictly on samples provided and/or examined.

Cover Image

Photograph of a chimney structure at the Stafford Slave Settlement on Cumberland Island, GA courtesy of Ms. Dorothy Krotzer of Building Conservation Associates, October 2, 2019.

Respectfully submitted,



John J. Walsh
President/ Senior Petrographer
Highbridge Materials Consulting, Inc.



Heather Hartshorn
Chemist/ Staff Scientist
Highbridge Materials Consulting, Inc.

1. Executive Summary

This report presents a qualitative identification of soluble salts in three tabby brick samples from the Stafford Slave Settlement on Cumberland Island, GA. The client requested testing on two samples described as representative of a distressed condition (Samples 18 and 19), and one representative of a sound condition (Sample 09).

The distressed samples contain approximately 1% soluble salts by weight. These include halite, niter, and darapskite, likely derived from a combination of seawater and the decay products of organic matter in the soil. The salts are certainly capable of producing long-term erosion through wetting and drying cycles. Salt may be the sole contributor to distress given the absence of swelling clays and the relative rarity of freeze-thaw cycles.

Sample 09 contains very little salt. Calcite, halite, syngenite, anhydrite, and an unnamed sulfate are all detected through x-ray diffraction analysis. However, none are considered threatening given the low concentrations.

2. Introduction

On August 27, 2019, Highbridge received a set of masonry samples from Ms. Dorothy Krotzer of Building Conservation Associates reported to have been sampled from chimney structures at the Stafford Slave Settlement on Cumberland Island, GA. A summary of the samples, their identifications, and locations is presented in Appendix III. It is understood from the client that the site represents the ruins of a 19th century slave housing settlement in which only the chimney structures survive. The chimneys are reported to have been constructed of tabby brick with red clay brick used for the hearth and firebox.

At Ms. Krotzer's request, laboratory testing is performed on the samples to provide information that may assist in an ongoing stabilization effort. The testing plan was developed in discussions between Ms. Krotzer and Mr. John Walsh of Highbridge. The plan was finalized in a telephone call on September 20 and includes the following:

1. Qualitative identification of salts in tabby brick

Surface erosions on tabby brick may be the result of salt hydration or crystallization. The client has requested an identification of water-soluble salts present within the brick through x-ray diffraction analysis. Three samples are chosen for the analysis, two the client has identified as distressed and one the client has identified as sound.

2. Qualitative identification of clays in tabby brick

Weathering of the tabby brick may also be the result of the swelling behavior of clay constituents during wetting/drying cycles. X-ray diffraction analysis will be performed on clays extracted from one brick sample to determine whether swelling varieties are present.

3. Compositional analysis of tabby brick

This testing combines petrographic examination and chemical analysis to identify constituents, estimate proportions, and assess overall condition of the tabby brick. An acid digestion to extract an aggregate sample for description and gradation is also included. One sample will be examined comprehensively.

4. Gradation analysis of tabby brick aggregate

It is anticipated that there may be some variation in the tabby brick mix proportions. Rather than examine several samples comprehensively, a less costly acid digestion will be performed on an additional three brick samples. The content and gradation of the acid-insoluble constituents will be compared.

5. Gradation analysis of local silt/clay

The client has provided a sample of local sediments from the shore of the island. It is suspected that this material may have been used in the tabby manufacture. The laboratory will disaggregate this loosely consolidated material and grade it through standard sieves. The color and gradation of the sediment will be compared to the acid-insoluble material recovered from the tabby brick.

6. Physical property testing of tabby brick

The testing includes compressive strength, absorption, and saturation coefficient determination on a sample of five brick specimens. Since the tabby brick potentially contains relatively flat shell fragments and would likely have been compacted in a direction perpendicular to the bed face, it is suspected that there could be significant strength anisotropy. If so, this might have a bearing on the manner in which the brick decays in service. The laboratory will take cores in two directions from each of the five bricks to determine compressive strength. It is also suspected that the tabby brick may be appreciably weaker when wet. One additional core sample will be tested in each orientation under saturated conditions.

7. Compositional analysis of masonry mortar

This testing combines petrographic examination and chemical analysis to identify constituents, estimate proportions, and assess overall condition of the tabby brick bedding mortar. An acid digestion to extract an aggregate sample for description and gradation is also included. One sample will be examined comprehensively.

8. Petrographic examination of red clay brick

One sample of red clay brick will be examined petrographically. The purpose of a petrographic examination is to evaluate the constituents and microstructural features of the brick and to assess any potential causes for deterioration observed by the client on site.

This report presents results of the qualitative salt analyses for the tabby brick. Results for the other tests will be presented under separate cover when complete.

3. Methods of Examination

X-ray diffraction analysis was performed using proprietary methods. Sample preparation was performed at Highbridge's laboratory facility. Instrumentation was performed by H&M Analytical Services in Cream Ridge, NJ. Additional information on methods is presented in Section 4 of this report.

The following personnel contributed to the examination:

Technician:	M. Pattie
Chemists:	H. Hartshorn
	G. Wheeler
Petrographer:	J. Walsh

4. X-Ray Diffraction Analysis

X-ray diffraction analysis (XRD) was used to identify the water-soluble salts present within samples of the tabby brick. The client requested that two samples be selected from a distressed group of brick including Samples 18, 19, and 20. The client also requested one be selected from a group of visually sound brick including Samples 07, 08, and 09. The decision was left to the laboratory's discretion. The author chose Samples 18 and 19 because Sample 20 was too small. The author also chose Sample 09 because there was a desire to reserve Samples 07 and 08 for other testing.

For each sample, an approximately one-third section of brick was dry cut using a diamond-coated saw blade. The subsample was broken up with a hammer and then ground in a porcelain mortar and pestle without excessive force. The subsamples were ground so that most of the material was fine enough to pass a No. 20 sieve. An aliquot of approximately 400 grams was further subsampled from each ground sample. The subsample was digested in approximately 800 mL of distilled water for seven days following a 15-minute boiling water digestion. The solutions were then decanted and filtered through a fine-textured filter paper. The filtrate was slowly evaporated in an oven at 60°C to precipitate out the salts. Approximate weights and visual descriptions of the precipitated salts are presented in Table 4.1.

Table 4.1: Description of Extracted Salts

Sample ID	Extracted salts (wgt. %)	Description
09	0.04	Orange-brown, fine-grained crystals. The recovered material was noticeably sticky when attempting to crush suggesting some deliquescence.
18	0.88	Flaky, pale yellow crystals. Brittle.
19	1.00	Flaky and blocky, pale yellow crystals. Brittle.

Notes:

1. The weight percentages of the extracted salts are only semi-quantitative. The values represent the amount of material that was able to be removed from the bottom the beaker in a dry state. The salt contents are likely underestimated by a modest amount.

Aliquots of the extracted salts were placed in glassine envelopes and delivered to H&M Analytical Services for instrumental analysis. According to Dr. Steven Mercurio, the samples were further ground with a mortar and pestle, loaded into zero background sample holders, and then placed into a Panalytical X'pert MPD diffractometer using Cu radiation at 45KV/40mA. The scans were run over a 2θ range of 6° to 80°, with a step size of 0.0131° and a counting time of 250 seconds per step.

The identified phases are described in Table 4.2. The original spectra from which these phases are interpreted are presented in Appendix I. It should be noted that the sampling for x-ray diffraction involves drying water-soluble extracts. During the drying, ions can be reorganized into new compounds that may not have been present in the specific form identified by XRD.

Table 4.2: XRD - Interpreted Phases

Rietveld refinement is not applied to these spectra and a formal quantification of the phases would not be meaningful. The major, minor, and trace categories given here are rough approximations based on the strength of any given signal relative to the most intense peak.

Sample ID	Major (> 10% by weight)	Minor (2-10% by weight)	Trace (< 2% by weight)
09	Calcite, Halite, DHB ¹ , Syngenite	Anhydrite III	
18	Halite, Niter, Darapskite		
19	Halite, Niter	Darapskite	

Notes:

1. DHB = Dipotassium hexaquamagnesium bisulfate

Table 4.3: Chemical Formulas

Mineral name	Chemical formula
Anhydrite III	CaSO ₄
Calcite	CaCO ₃
Darapskite	Na ₃ (SO ₄)(NO ₃)(H ₂ O)
Dipotassium hexaquamagnesium bisulfate	K ₂ (Mg(H ₂ O) ₆)(SO ₄) ₂
Halite	NaCl
Niter	KNO ₃
Syngenite	K ₂ Ca(SO ₄) ₂ (H ₂ O)

For the most part, the salts extracted from the brick are typical of those expected to be associated with a low-lying marine environment. Specifically, these include chloride and sulfate-based salts that derive from seawater or marine aerosols, and nitrates derived from the decay of organic matter in the soil. The ions contributed by these extrinsic sources may combine in various ways depending on factors such as temperature, humidity, and pore water chemistry. In this way, a salt may precipitate such as darapskite, that possibly contains ions from both seawater and decayed organic matter.

The salts identified through XRD may have migrated upward through capillary action from the underlying soil. However, it is also possible that soluble salts were introduced with the sands used in the tabby brick. A compositional analysis of the tabby brick suggests that some small amount of organic impurities were contributed by the sand (Highbridge Report SL1443-03). Furthermore, the fines that contain these organic residues were detected in lower concentration in Sample 09. It could be argued that this explains the different levels of salt contamination in these samples. However, with Samples 18 and 19 each containing nearly 1% salt contamination by weight, rising damp is a much more likely explanation.

Whatever the source, the variety of salts are capable of resulting in progressive decay of the brick matrix during wetting and drying cycles. The sulfates would tend to be the most destructive, but none of the salts would be considered innocuous. The salts are not necessarily the only cause of erosion in the tabby brick. However, there is no evidence for the presence of swelling clays in the brick matrix (Highbridge Report SL1443-06), and other common environmental factors such as freeze-thaw cycling are clearly minimal. Furthermore, the quantity of recovered salt correlates with the client's description of condition. Specifically, the sample described as sound (Sample 09) contains a negligible amount of soluble salt at only 0.04%, while the two distressed samples (Samples 18 and 19) contain approximately 1% soluble salt.

Finally, the nature of the salts identified for Sample 09 are a function of the low content of soluble phases. For example, calcite is almost certainly a residue from the lime binder that was not completely digested in the sample preparation. Calcite is likely present at the same quantity in the extractions for Samples 18 and 19. However, its signal would be too low to distinguish from the noise in these samples. None of the salts identified in Sample 09 should be considered especially concerning given their low concentrations.

Appendix I: X-Ray Diffraction Spectra

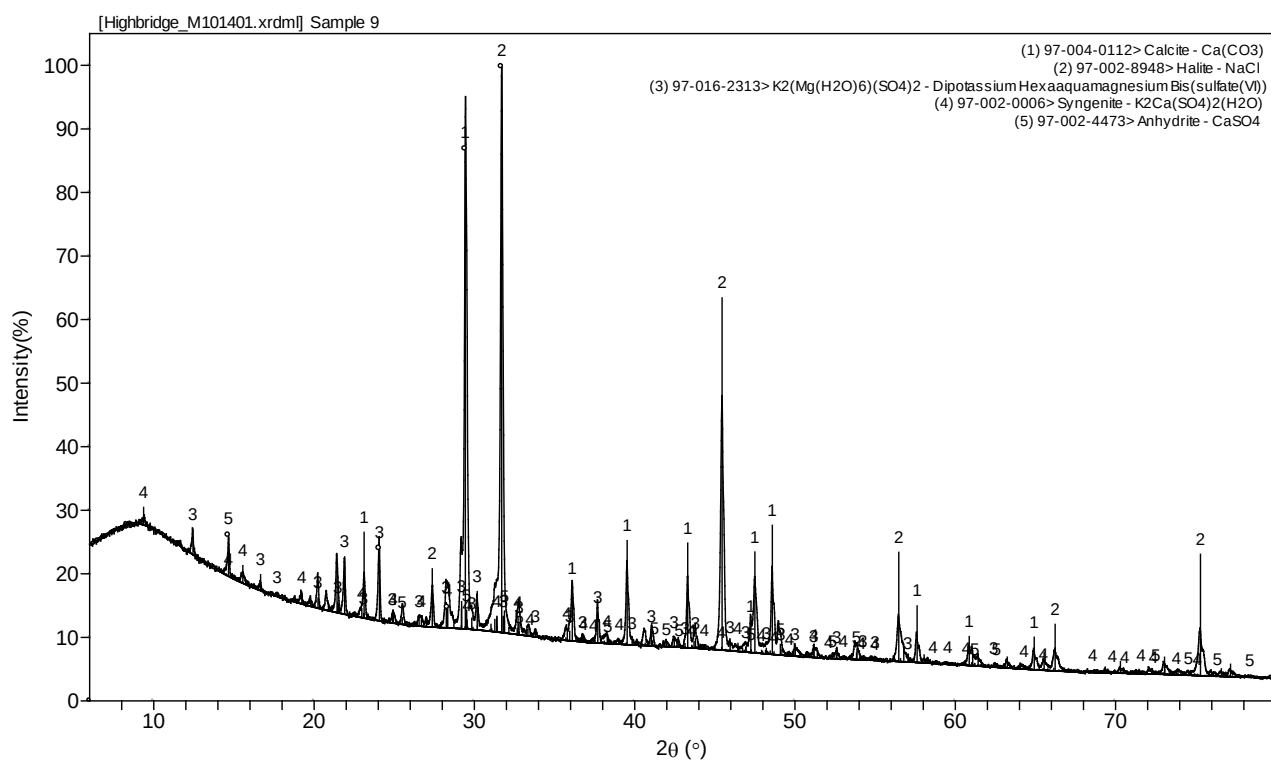


Chart I.1: X-ray diffraction spectrum of Sample 09.

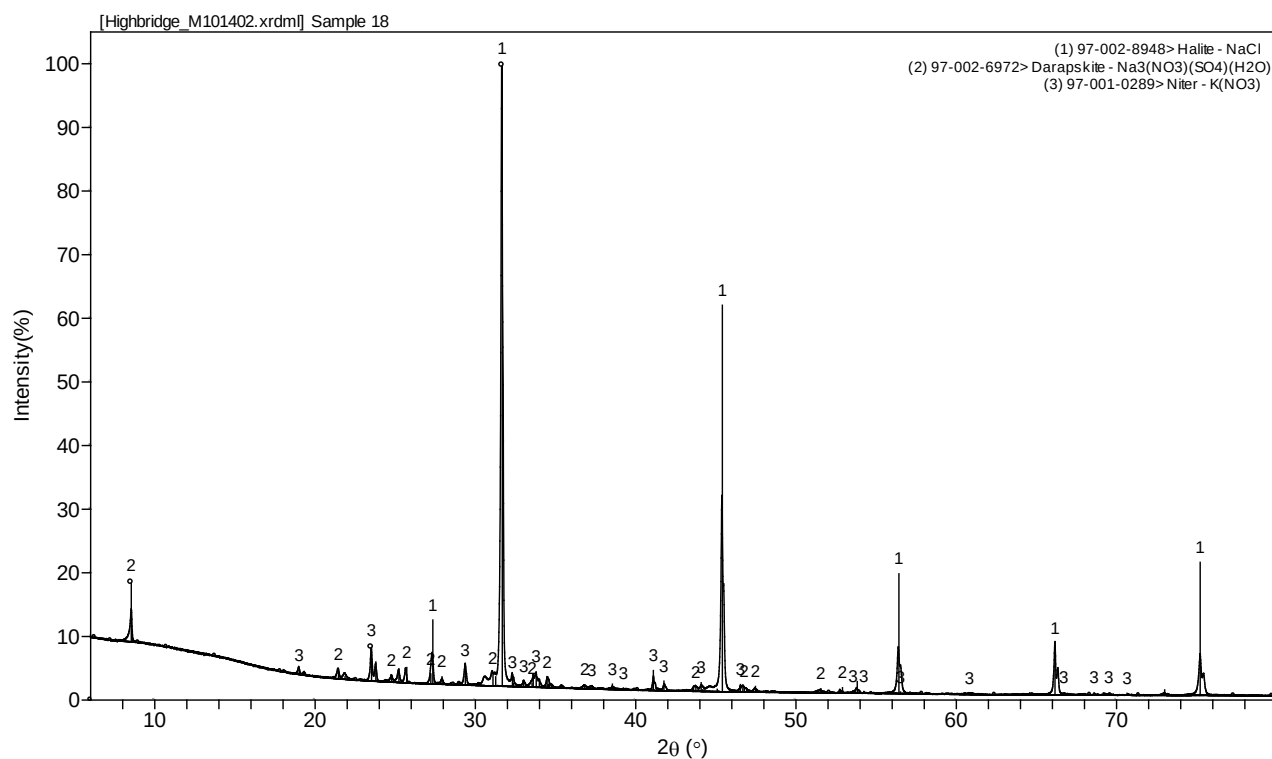


Chart I.2: X-ray diffraction spectrum of Sample 18.

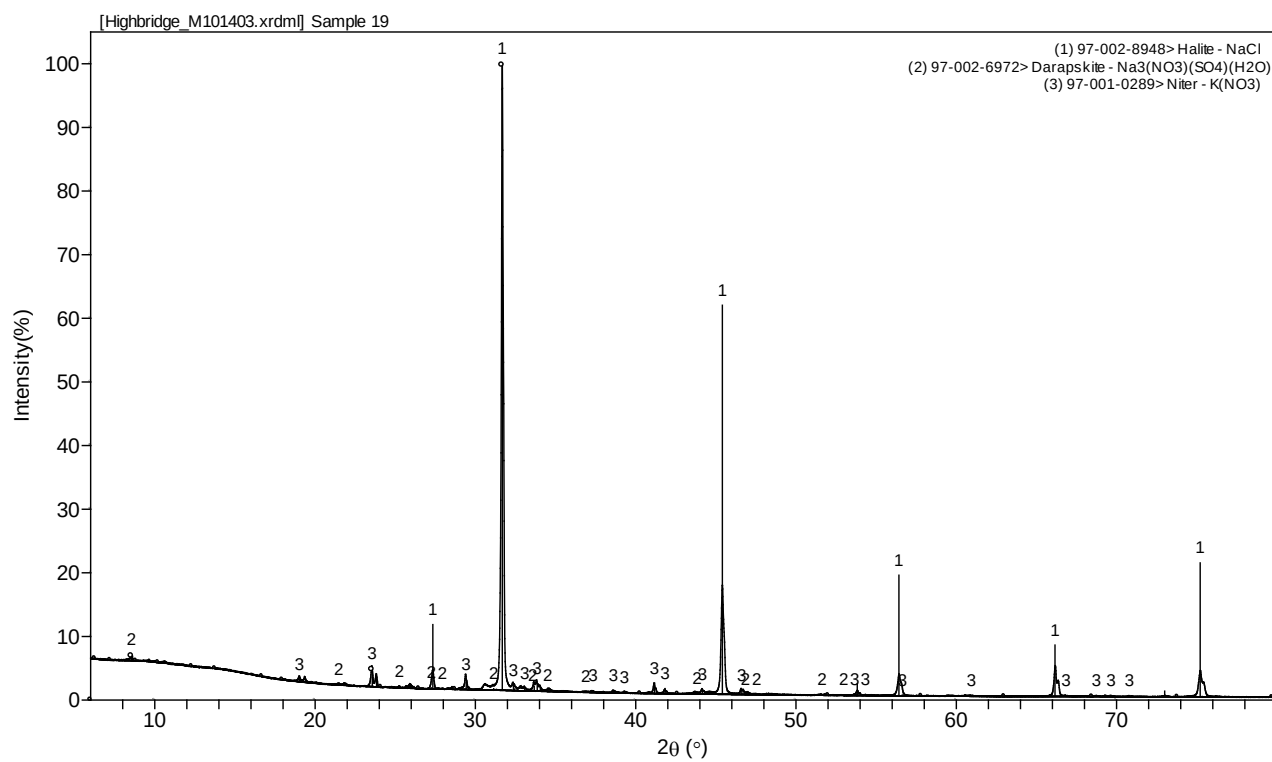


Chart I.3: X-ray diffraction spectrum of Sample 19.

Appendix II: Photographs



Figure 1: Photographs of the three tabby brick samples used for the qualitative salt determination through x-ray diffraction analysis.

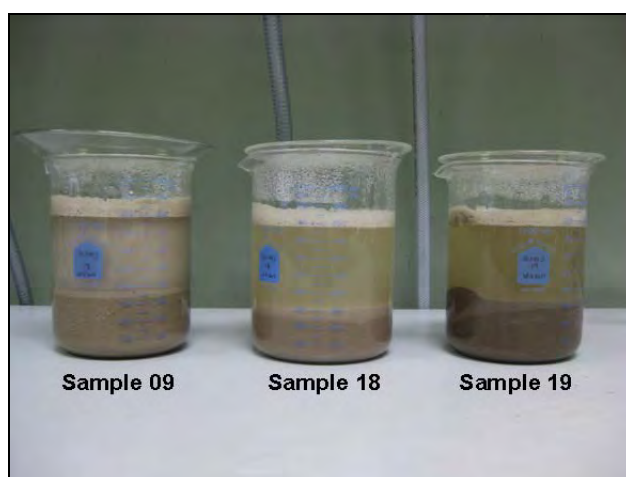


Figure 2: The samples are shown during the water digestion used to extract soluble salts from the crushed brick.

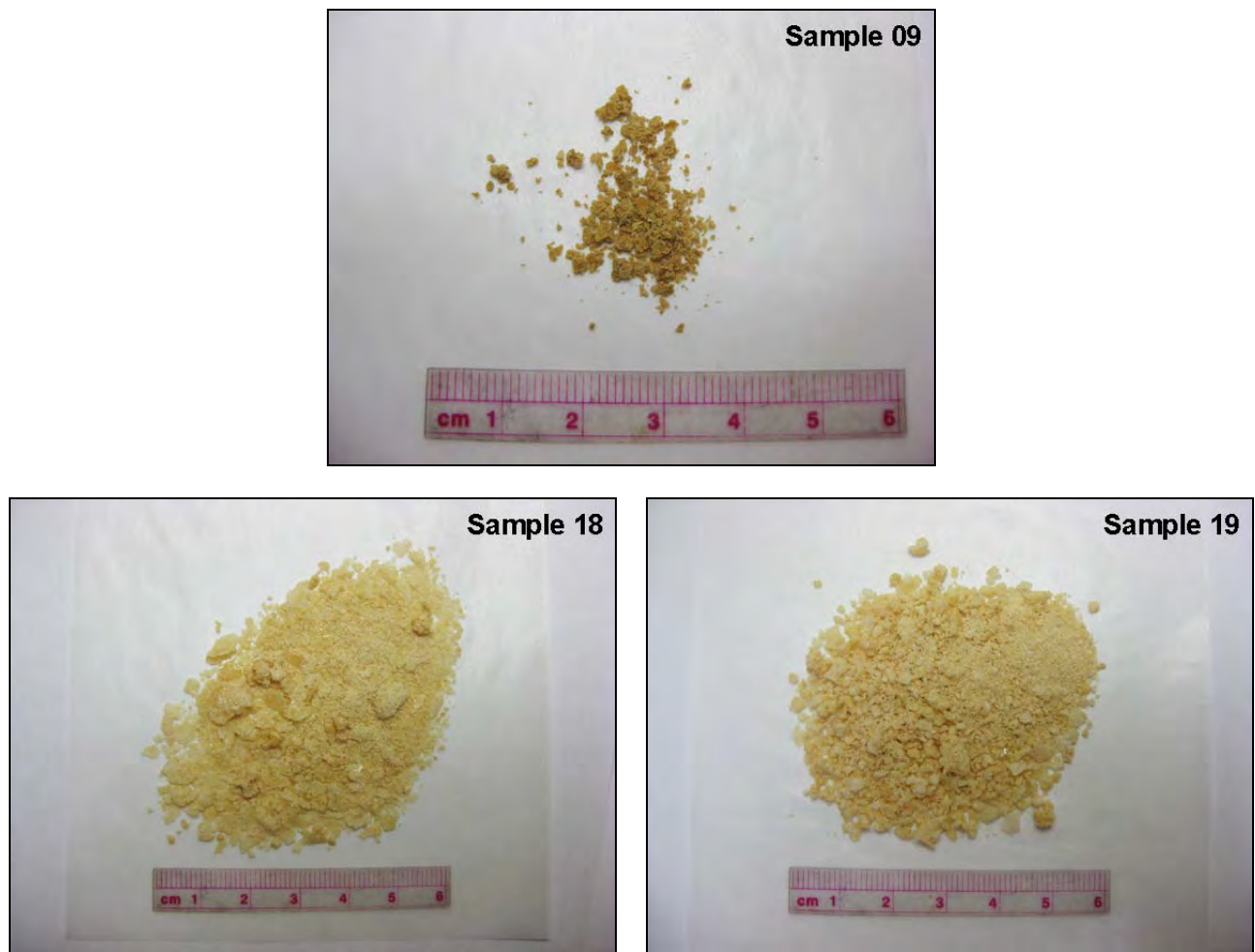


Figure 3: The salts extracted after evaporation are shown in these images. Much less salt was extracted for Sample 09.

Appendix III: Sample Log

Table III.1: Summary of Received Samples

The laboratory has shortened the sample identifications for more convenient presentation in the reports. The shortened IDs are describe in the "HMC ID" column.

Material	Client ID	Chimney No.	HMC ID	Client description	Testing
Tabby brick	Stafford.7	16	07	East side of hearth, "f" marked on face	Compositional analysis, clay identification
	Stafford.8	1	08	West side of hearth	
	Stafford.9	18	09	Interior-facing side of chimney (same location as Stafford.1), original orientation of brick not clear.	Soluble salt identification through XRD
	Stafford.10	10	10	Found in rubble pile next to chimney	Strength, absorption
	Stafford.11	10	11	Found in rubble pile next to chimney	
	Stafford.12	22	12	Found in rubble pile next to chimney	Strength, absorption
	Stafford.13	22	13	Found in rubble pile next to chimney	Strength, absorption
	Stafford.14	22	14	Found in rubble pile next to chimney	Strength, absorption
	Stafford.15	22	15	Found in rubble pile next to chimney	
	Stafford.16	22	16	Found in rubble pile next to chimney	Strength, absorption
	Stafford.18	4	18	Removed from west side of chimney, significant erosion of brick face.	Soluble salt identification through XRD
	Stafford.19	3	19	Removed from back exterior face of chimney, significant erosion of brick face.	Soluble salt identification through XRD
	Stafford.20	16	20	Removed from northwest corner of chimney, face only, "B" marked on back/interior of brick) mild erosion of brick face	
Red clay brick	Stafford.6	4	06	Found on ground next to chimney, presumed to be from west surround of hearth.	Petrographic examination
	Stafford.17	22	17	Removed from back wall of hearth	
Tabby brick bedding mortar	Stafford.1	18	01	Taken from interior side of chimney above lintel.	
	Stafford.2	11	02	Taken from location of roof peak, area of mortar build-up, mortar continues into adjacent joint (i.e., same material as mortar in joints).	Compositional analysis
	Stafford.3	1	03	Small sample from exterior mortar joint.	
Parging	Stafford.4	4	04	Parging does not appear to be original (different color than mortar original, evidence of soiling on face of mortar under parging).	
Clay	Stafford.4	n/a	21	"Clay rock" from shore	Gradation analysis

Notes:

1. The laboratory has shortened the sample identifications for more convenient presentation in the reports. The shortened IDs are describe in the "HMC ID" column.
2. Three additional tabby brick will be selected for limited insoluble residue testing to evaluate the type and content of siliceous aggregate. These samples have not been selected and the testing is not indicated in the table as of this writing.

Appendix F

“Report on Clay Analysis of Tabby Brick” (Highbridge Materials Consulting, Inc., 12/31/19)

Report on Clay Analysis of Tabby Brick

Stafford Slave Settlement, Cumberland Island
National Seashore, Chimney Stabilization
Cumberland Island, Camden County, GA



Prepared for
Building Conservation Associates, Inc.

Client ID
BUIL005

Report No.
SL1443-06

Report Date
12/31/19



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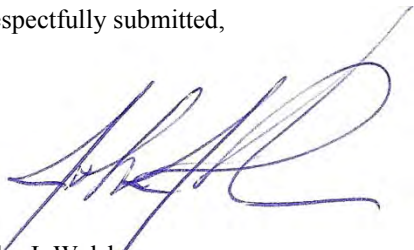
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Highbridge has performed its services in conformance with the care and skill ordinarily exercised by reputable members of the profession practicing under similar conditions at the same time. No other warranty of any kind, expressed or implied, in fact or by law, is made or intended. Interpretations and results are based strictly on samples provided and/or examined.

Cover Image

Photograph of a chimney structure at the Stafford Slave Settlement on Cumberland Island, GA courtesy of Ms. Dorothy Krotzer of Building Conservation Associates, October 2, 2019.

Respectfully submitted,



John J. Walsh
President/ Senior Petrographer
Highbridge Materials Consulting, Inc.



Heather Hartshorn
Chemist/ Staff Scientist
Highbridge Materials Consulting, Inc.

1. Executive Summary

This report presents a qualitative identification of the clay constituents extracted from a tabby brick sample at the Stafford Slave Settlement on Cumberland Island, GA. The purpose of the testing is to determine whether any potentially swelling clays are present in the sample that might have contributed to the long-term erosion of the material.

Swelling clays are clearly not present at any appreciable concentration based on the lack of any shift in the x-ray diffraction spectra after glycolation. Instead, the clay fraction includes mostly a trioctahedral mica such as phlogopite. A small amount of chlorite is also present. Other identified phases are simply the normal constituents of the tabby brick that were not completely removed in the sample preparation.

2. Introduction

On August 27, 2019, Highbridge received a set of masonry samples from Ms. Dorothy Krotzer of Building Conservation Associates reported to have been sampled from chimney structures at the Stafford Slave Settlement on Cumberland Island, GA. A summary of the samples, their identifications, and locations is presented in Appendix II. It is understood from the client that the site represents the ruins of a 19th century slave housing settlement in which only the chimney structures survive. The chimneys are reported to have been constructed of tabby brick with red clay brick used for the hearth and firebox.

At Ms. Krotzer's request, laboratory testing is performed on the samples to provide information that may assist in an ongoing stabilization effort. The testing plan was developed in discussions between Ms. Krotzer and Mr. John Walsh of Highbridge. The plan was finalized in a telephone call on September 20 and includes the following:

1. Qualitative identification of salts in tabby brick

Surface erosions on tabby brick may be the result of salt hydration or crystallization. The client has requested an identification of water-soluble salts present within the brick through x-ray diffraction analysis. Three samples are chosen for the analysis, two the client has identified as distressed and one the client has identified as sound.

2. Qualitative identification of clays in tabby brick

Weathering of the tabby brick may also be the result of the swelling behavior of clay constituents during wetting/drying cycles. X-ray diffraction analysis will be performed on clays extracted from one brick sample to determine whether swelling varieties are present.

3. Compositional analysis of tabby brick

This testing combines petrographic examination and chemical analysis to identify constituents, estimate proportions, and assess overall condition of the tabby brick. An acid digestion to extract an aggregate sample for description and gradation is also included. One sample will be examined comprehensively.

4. Gradation analysis of tabby brick aggregate

It is anticipated that there may be some variation in the tabby brick mix proportions. Rather than examine several samples comprehensively, a less costly acid digestion will be performed on an additional three brick samples. The content and gradation of the acid-insoluble constituents will be compared.

5. Gradation analysis of local silt/clay

The client has provided a sample of local sediments from the shore of the island. It is suspected that this material may have been used in the tabby manufacture. The laboratory will disaggregate this loosely consolidated material and grade it through standard sieves. The color and gradation of the sediment will be compared to the acid-insoluble material recovered from the tabby brick.

6. Physical property testing of tabby brick

The testing includes compressive strength, absorption, and saturation coefficient determination on a sample of five brick specimens. Since the tabby brick potentially contains relatively flat shell fragments and would likely have been compacted in a direction perpendicular to the bed face, it is suspected that there could be significant strength anisotropy. If so, this might have a bearing on the manner in which the brick decays in service. The laboratory will take cores in two directions from each of the five bricks to determine compressive strength. It is also suspected that the tabby brick may be appreciably weaker when wet. One additional core sample will be tested in each orientation under saturated conditions.

7. Compositional analysis of masonry mortar

This testing combines petrographic examination and chemical analysis to identify constituents, estimate proportions, and assess overall condition of the tabby brick bedding mortar. An acid digestion to extract an aggregate sample for description and gradation is also included. One sample will be examined comprehensively.

8. Petrographic examination of red clay brick

One sample of red clay brick will be examined petrographically. The purpose of a petrographic examination is to evaluate the constituents and microstructural features of the brick and to assess any potential causes for deterioration observed by the client on site.

This report presents results of the qualitative clay analyses for the tabby brick. Results for the other tests have been presented under separate cover in Highbridge Reports SL1443-01 through SL1443-05.

3. Methods of Examination

X-ray diffraction analysis was performed using proprietary methods. Sample preparation was performed at Highbridge's laboratory facility. Instrumentation was performed by H&M Analytical Services in Cream Ridge, NJ. Additional information on methods is presented in Section 4 of this report.

The following personnel contributed to the examination:

Technician: M. Pattie
Chemists: H. Hartshorn
Petrographer: J. Walsh

4. X-Ray Diffraction Analysis

4.1 - Laboratory Methods

X-ray diffraction analysis (XRD) was performed on clays extracted from a tabby brick sample to evaluate their susceptibility to swelling behavior during wetting and drying cycles. Sample 07 was chosen for this analysis as it was the same sample used to determine the composition of the material.

A subsample of approximately 10 grams was taken from the powder sample already used for compositional analysis. This was added to 250 mL of buffered acetic acid solution with a pH of approximately 5. The solution was heated for 30 minutes at a temperature just below boiling. The digestion was continued at room temperature for 6 days at which point the pH was confirmed to have remained at the buffer point. The fines were suspended and decanted along with the supernatant. The extract was centrifuged to concentrate the solids. After centrifugation, the supernatant was decanted and replaced with fresh distilled water. The solids were stirred into the water and the centrifugation was repeated. These steps were repeated until the acid was fully rinsed from the sample. The clean fines were transferred to a beaker and heated to dryness in an oven set to 42°C. The final recovery of dry material was approximately 3% of the total sample weight.

The recovered fines were sent to H&M Analytical Services in Cream Ridge, NJ for instrumental analysis. According to Dr. Steven Mercurio, the powder was dispersed in 50 mL of deionized water, then sonicated for 2 minutes. Then, using a pipette, a small amount of the suspension was placed on a standard microscope slide and allowed to dry at room temperature. The slide and resulting sample film was placed in a Panalytical X'pert MPD diffractometer using Cu radiation at 45KV/40ma and high resolution optics. The scan was run over a 2θ range of 3° - 35° with a step size of 0.0167° for 250 seconds per step. Following the initial scan, the sample was placed in a vacuum desiccator and exposed to ethylene glycol vapor for 12 hours at 60°C. After glycolation, a second XRD scan was run. Lastly, the sample was heated to a temperature of 550°C for one hour and, after heating, a third XRD scan was run. The crystalline phases were then identified with the aid of the Powder Diffraction File published by the International Centre for Diffraction Data and "*X-Ray Diffraction and the Identification and Analysis of Clay Minerals*" by Duane Moore and Robert Reynolds.

4.2 - Laboratory Findings

The total x-ray diffraction spectrum is shown in Chart 4.2a below. The most important finding in the context of this study is the absence of any appreciable swelling clay. This is demonstrated by the lack of a horizontal shift in any peak following glycolation. This would normally be prominent at low 2θ values. Instead, within the clay portion of the signal, the most abundant mineral is phlogopite or other mica with a related trioctahedral structure. The exact phase cannot be characterized in this context but it is certain that it is not a potentially deleterious clay. Chlorite is also detected, and it is confirmed based on the removal of secondary reflections after heating. It is possible that some kaolinite is also present. If so, it is in exceedingly trace concentration.

Other minerals are identified and all are interpreted to be normal constituents of the tabby brick that were not completely removed during the sample preparation. These include a large quantity of dolomite with lesser amounts of quartz and calcite. A small amount of feldspar is also detected. The quartz and minor feldspar are clearly constituents of the aggregate. The calcite and dolomite are undissolved portions of the lime binder. The dolomite is so much more prevalent since it is much less soluble than calcite when treated with the buffered acid solution. It is actually a very small component of the high-calcium lime.

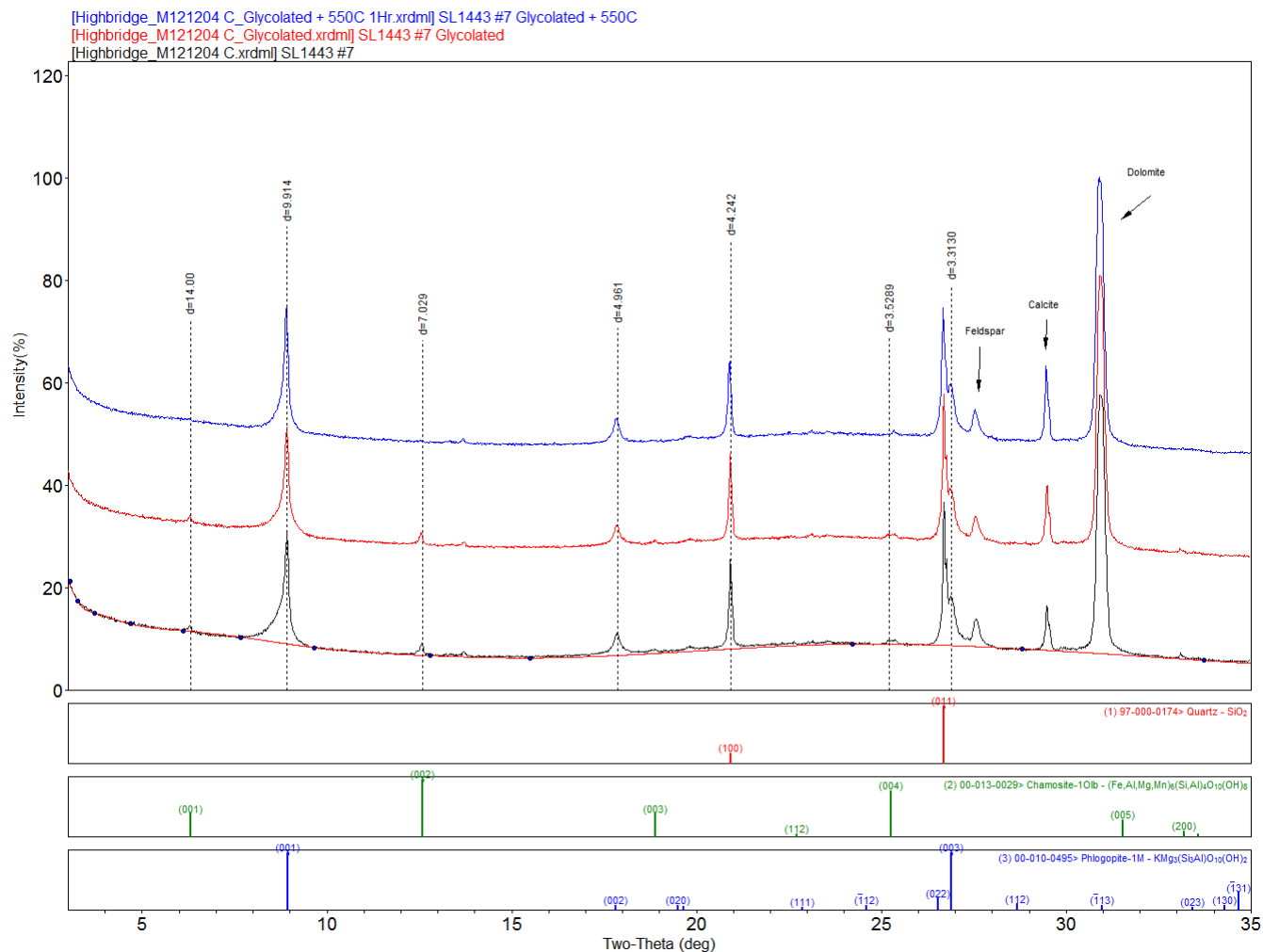


Chart 4.2a: X-ray diffraction spectrum of the acid-insoluble fines extracted from Sample 07, a tabby brick sample. The baseline spectrum for the untreated extract is shown in black. A red-colored curve traces out the background signal. The subsequent runs are vertically offset for clarity. The spectrum after glycolation is shown in red and the spectrum after heating is shown in blue. The strips below the x-ray spectrum contain stick patterns for minerals that are considered matches for those that have produced the signal.

Appendix I: Photographs



Figure 1: (Left) Photograph the tabby brick sample used to extract a clay sample. Sample 07 was used for this purpose. (Right) Photograph of the clays extracted from Sample 07. The extracted material is shown in the centrifuge tube.

Appendix II: Sample Log

Table II.1: Summary of Received Samples

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	Stafford.16	22	16	Found in rubble pile next to chimney	Strength, absorption
	Stafford.18	4	18	Removed from west side of chimney, significant erosion of brick face.	Soluble salt identification through XRD
	Stafford.19	3	19	Removed from back exterior face of chimney, significant erosion of brick face.	Soluble salt identification through XRD
	Stafford.20	16	20	Removed from northwest corner of chimney, face only, "B" marked on back/interior of brick) mild erosion of brick face	
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Tabby brick bedding mortar	Stafford.1	18	01	Taken from interior side of chimney above lintel.	
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