APPENDIX 1-A

Mortar Analysis of Structure 144

JAMES CRENSHAW
PETROGRAPHIC REPORT OF HARDENED MORTAR

CLIENT: Mr. Carl Lounsbury
The Colonial Williamsburg Foundation
P.O. Box 1776
Williamsburg, Virginia 23187-1776

PROJECT: Ludwell Statehouses
Jamestown, Virginia

TEST METHOD: ASTM C 856 - 88
ASTM C 1324 - 96 (partial)

Froehling & Robertson, Inc. (F&R) Richmond is pleased to submit the results of the visual and petrographic examination performed on 33 mortar samples. Mr. Willie Graham of the Colonial Williamsburg Foundation submitted the samples for examination on September 21, 2000. The mortar samples were taken from several structures located in historical Jamestown. The structures were a group of houses named House 1, House 2, House 3, House 4 and the Statehouse. The original construction was during the time period of about 1640 to 1650. The purpose of the examination was to classify each individual sample and compare specific groups of samples for compatibility as it relates to time periods of construction.

The petrographic examination was performed in accordance with ASTM C 1324-96 Examination and Analysis of Hardened Masonry Mortar and ASTM C 856-88 Petrographic Examination of Hardened Concrete, Table 2 (Outline for Examination with Stereomicroscope). The sand to cement / lime ratio was determined using the dilute Hydrochloric acid separation method.

EXAMINATION

Upon receipt of the samples to the laboratory, each was placed into the oven and dried. To analyze the samples for composition, a portion of each of the 33 mortar samples weighing approximately 35 - 45 grams were selected and used for the determination of sand / cement ratio using the dilute hydrochloric acid separation method.
After the acid separation was completed, the non-reactive sand portion of the mortar was saved and used for the particle size analysis, microscopic evaluation to determine the mineral constituents of each sample, physical properties, surface features and particle morphology of the sand grains. Microscopic examination using the stereomicroscope (60x power) before the acid separation showed that carbonate constituents in the form of large shell fragments were included in the mortar. The shell fragments generally measured approximately ½ inch to 0.187 inches (#4 sieve) in size.

The sand portion of the mortar was mainly composed of quartz. The percentage of quartz ranged from 80 to 95 percent in most samples. Particle sizes were generally in the range of 1.19 millimeters to .074 millimeters, sieve sizes #16 to #200, respectively. Other minor constituents such as hornblende, sandstone clusters (particles made of cemented fine sand grains and a clay binder), remnants of organic plant or grass roots, weathered granite and feldspar fragments and other miscellaneous particles were also observed. Particle form was equidimensional and compact. The quartz grains were predominately clear color however particles showing various other colors were noted. The surface texture of the quartz particles was generally smooth with a glassy appearance.

The binder for the mortar samples was lime putty or soft paste. Chunks of putty were visible throughout the mortar samples. Generally, the chunks had diameters of approximately 2 to 3 millimeters. The lime for the putty was made from burning coastal shells (oyster and mollusk) which were abundant in the area to obtain the lime. Microscopic observations show that wood cinders from the fire were included as a minor constituent of the mortar. Also, the ash created from the fire added some hydraulic properties to the mortar. These constituents were mixed in varying proportions with just enough water to produce a soft and workable mortar. Over a period of time, the lime carbonates by reacting with carbon dioxide in the atmosphere to become harder and more durable. After the sand particle size analysis was completed, the -200 sieve material (clay, silt and ash particles) were displayed in glass vials to facilitate color comparisons between samples. Although the colors of some samples matched rather closely in some comparisons, the range of colors were variable and provided only limited support in determining if one sample or group of samples were compatible to one another.

Included in the report are individual descriptions of each mortar sample. The description includes information on the composition, particle form and surface features of the constituents. Information such as the visual appearance of the mortar as received and its relative hardness were noted.

Graphs of the particle size distribution of the mortar sand in each sample have been provided with this report to facilitate comparisons of one sample to another.

In addition, a chart is provided listing the sand to lime ratio of each sample. The sand to lime ratio did not include the coarse shell pieces, which were removed from the samples because they were considered as coarse aggregate and did not contribute to the lime putty paste used as the mortar binder.
Colonial Williamsburg Foundation  
Ludwell Statehouses  
Sand : Lime Ratio:

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Ratio Sand : Lime</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.9 : 1</td>
</tr>
<tr>
<td>2</td>
<td>1.7 : 1</td>
</tr>
<tr>
<td>3</td>
<td>1.3 : 1</td>
</tr>
<tr>
<td>4</td>
<td>1.4 : 1</td>
</tr>
<tr>
<td>5</td>
<td>1.3 : 1</td>
</tr>
<tr>
<td>6</td>
<td>1.2 : 1</td>
</tr>
<tr>
<td>7</td>
<td>1.7 : 1</td>
</tr>
<tr>
<td>8</td>
<td>1.4 : 1</td>
</tr>
<tr>
<td>9</td>
<td>1.6 : 1</td>
</tr>
<tr>
<td>10</td>
<td>2.1 : 1</td>
</tr>
<tr>
<td>11</td>
<td>2.7 : 1</td>
</tr>
<tr>
<td>12</td>
<td>2.0 : 1</td>
</tr>
<tr>
<td>13</td>
<td>1.8 : 1</td>
</tr>
<tr>
<td>14</td>
<td>1.3 : 1</td>
</tr>
<tr>
<td>15</td>
<td>1.5 : 1</td>
</tr>
<tr>
<td>16</td>
<td>1.9 : 1</td>
</tr>
<tr>
<td>17</td>
<td>1.7 : 1</td>
</tr>
<tr>
<td>18</td>
<td>1.5 : 1</td>
</tr>
<tr>
<td>19</td>
<td>Soil Sample</td>
</tr>
<tr>
<td>20</td>
<td>2.3 : 1</td>
</tr>
<tr>
<td>21</td>
<td>1.7 : 1</td>
</tr>
<tr>
<td>22</td>
<td>2.0 : 1</td>
</tr>
<tr>
<td>23</td>
<td>3.1 : 1</td>
</tr>
<tr>
<td>24</td>
<td>1.9 : 1</td>
</tr>
<tr>
<td>25</td>
<td>2.5 : 1</td>
</tr>
<tr>
<td>26</td>
<td>2.1 : 1</td>
</tr>
<tr>
<td>27</td>
<td>1.9 : 1</td>
</tr>
<tr>
<td>28</td>
<td>1.6 : 1</td>
</tr>
<tr>
<td>29</td>
<td>1.9 : 1</td>
</tr>
<tr>
<td>30</td>
<td>1.9 : 1</td>
</tr>
<tr>
<td>31</td>
<td>1.4 : 1</td>
</tr>
<tr>
<td>32</td>
<td>2.8 : 1</td>
</tr>
<tr>
<td>33</td>
<td>2.0 : 1</td>
</tr>
</tbody>
</table>

Calculations to convert from weight to volume were based on bag weights of 80 pounds for the sand and 65 pounds for the lime.
CONCLUSIONS

1. Information concerning mortar hardness on the outside of the structure versus the inside of the buildings was confirmed after comparing sand/lime ratios calculated for the different structures. Data show that there was no difference in the amount of lime used in the mortar, which influences the hardness of the mortar for houses No. 1 and No. 2. However, data show that more lime was used for the outside mortar construction of houses No. 3, No. 4 and the Statehouse.

2. Investigation of data relating to the compatibility of samples concerning construction on the back additions of Houses No. 3 and No. 4 with the front portions of the same houses showed evidence that the construction was compatible. Mortar samples No. 10, 11, and 15 were examined representing the front of the houses and samples No. 12,13,14,16 and 20 were examined from the back of the houses. Mineral constituents and particle size distribution were very similar along with sand/lime ratios, giving credence to the fact that construction was during the same period of time.

3. Mortar samples No. 1 – 8 representing first period construction showed very good compatibility when compared one to another. Mortar samples No. 4, 6 and 7 were examined closely and confirmed the compatibility of the construction period.

4. Second period construction represented by mortar samples No. 9, 10, 12 – 17, 20 – 22, 24 and 26 also showed good compatibility when compared to one another. Of that group, samples 13 and 14 were of different colors but were compatible where constituents and particle size distribution are concerned. Also, of that group, samples No. 21 and 22 were very similar.

5. The compatibility of samples No. 11 and No. 23 was determined to be very good. Both samples have similar compositions, particle size distributions and sand/lime ratios. Each represent second period construction.

6. Samples No. 25, 27 and 28, 29 – 33 were determined to be non-compatible. Particle size distribution, sand/lime ratios and compositions were different. Of that group, samples No. 28 thru No.32 displayed the greatest difference.

7. A general recipe for duplicating the mortar samples would include a lime and sand mixture in the form of a soft workable paste or putty mixed to the proportions determined from the sand/lime ratios provided in this report with some coarse shell fragments. For example, using sample No. 2, the mixture would be 1.7 parts fine sand to 1 part lime paste with approximately .3 parts coarse shell fragments.
Froehling & Robertson, Inc. appreciates this opportunity to be of service. Should you have any questions, please contact this office.

Respectfully Submitted,
FROEHLING & ROBERTSON, INC.

James L. Crenshaw, Jr.                      Ross Deaver, P.E.
Staff Geologist                            Manager
Mortar Descriptions:

Trench #5014

Sample #1:

1. Composition: 80 – 85 % quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 10 percent unburned shell fragments with diameters in the range of 3.0 to 10.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 2.0 percent brick pieces, iron-clay concretions, pink color granitic rock fragments and black color cinders derived from the burning process.

2. Particle form: generally compact and dense
3. Sphericity: intermediate – sub-equant
4. Surface features: The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.

Note: This mortar was hard and adhered well with the brick. The overall mortar color was buff brown. Sand color is brown. Chunks of lime putty were observed in the mortar sample.

Sample #2:

1. Composition: 80 – 85 % quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 10 percent unburned shell fragments with diameters in the range of 3.0 to 7.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 5.0 percent hornblende particles (black color, compact), iron-clay concretions, granitic rock fragments (pink color) and black color cinders derived from the burning process.

2. Particle form: generally compact and dense
3. Sphericity: intermediate – sub-equant
4. Surface features: The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.

Note: This mortar was hard and adhered well with the brick. The overall mortar color was light brown. Chunks of lime putty were observed in the mortar sample.
Sample #3:

1. Composition: 80 – 85 % quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 10 percent unburned shell fragments with diameters in the range of 3.0 to 12.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 5.0 percent hornblende particles (black color, compact), iron-clay concretions, pink color granitic rock fragments and black color cinders derived from the burning process.

2. Particle form: generally compact and dense

3. Sphericity: intermediate – sub-equant

4. Surface features: The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.

Note: This mortar was hard and adhered well with the brick. The overall mortar color was light brown. Chunks of lime putty were observed in the mortar sample.

Trench #5040

Sample #4:

1. Composition: 80 – 85 % quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 10 percent unburned shell fragments with diameters in the range of 3.0 to 12.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 5.0 percent hornblende particles (black color, compact), brick fragments, iron-clay concretions, pink color granitic rock fragments and black color cinders derived from the burning process. Traces of organic roots were observed.

2. Particle form: generally compact and dense

3. Sphericity: intermediate – sub-equant

4. Surface features: The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.

Note: This mortar was hard and adhered well with the brick. The overall mortar color was light brown. Chunks of lime putty were observed in the mortar sample.
Sample #5:

1. Composition: 80 – 85 % quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 10 percent unburned shell fragments with diameters in the range of 3.0 to 12.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 5.0 percent hornblende particles (black color, compact), iron-clay concretions, pink color granitic rock fragments and black color cinders derived from the burning process.

2. Particle form: generally compact and dense

3. Sphericity: intermediate – sub-equant

4. Surface features: The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.

Note: This mortar was hard and adhered well with the brick. The overall mortar color was light brown. Chunks of lime putty were observed in the mortar sample.

Trench 5008:

Sample #6:

1. Composition: 80 – 85 % quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 10 percent unburned shell fragments with diameters in the range of 3.0 to 12.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 5.0 percent hornblende particles (black color, compact), iron-clay concretions, pink color granitic rock fragments and black color cinders derived from the burning process.

2. Particle form: generally compact and dense

3. Sphericity: intermediate – sub-equant

4. Surface features: The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.

Note: This mortar was hard and adhered well with the brick. The overall mortar color was light brown. Chunks of lime putty were observed in the mortar sample.
Trench 5007:

Sample #7:

1. Composition: 80 – 85 % quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 10 percent unburned shell fragments with diameters in the range of 3.0 to 12.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 5.0 percent hornblende particles (black color, compact), iron-clay concretions, pink color granitic rock and brick fragments and, black color cinders derived from the burning process.

2. Particle form: generally compact and dense
3. Sphericity: intermediate – sub-equant
4. Surface features: The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.

Note: This mortar was hard and adhered well with the brick. The overall mortar color was light brown. Chunks of lime putty were observed in the mortar sample.

Sample #8:

1. Composition: 80 – 85 % quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 10 percent unburned shell fragments with diameters in the range of 3.0 to 12.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 5.0 percent hornblende particles (black color, compact), iron-clay concretions, pink color granitic rock and brick fragments and, black color cinders derived from the burning process.

2. Particle form: generally compact and dense
3. Sphericity: intermediate – sub-equant
4. Surface features: The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.

Note: This mortar was hard and adhered well with the brick. The overall mortar color was light brown. Chunks of lime putty were observed in the mortar sample.
Sample # 9:

1. Composition: 80 – 85 % quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 10 percent unburned shell fragments with diameters in the range of 3.0 to 8.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 5.0 percent hornblende particles (black color, compact), iron-clay concretions, pink color granitic rock fragments and traces of black color cinders derived from the burning process.

2. Particle form: generally compact and dense
3. Sphericity: intermediate – sub-equant
4. Surface features: The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.

Note: This mortar was soft. The overall mortar color was medium brown. Chunks of lime putty were observed in the mortar sample.

Trench #5015:

Sample # 10:

1. Composition: 80 – 85 % quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 10 percent unburned shell fragments with diameters in the range of 3.0 to 10.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 5.0 percent hornblende particles (black color, compact), iron-clay concretions, pink color granitic rock fragments and traces of black color cinders derived from the burning process.

2. Particle form: generally compact and dense
3. Sphericity: intermediate – sub-equant
4. Surface features: The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.

Note: This mortar was soft. The overall mortar color was medium brown. Chunks of lime putty were observed in the mortar sample.
Sample # 11:

1. Composition: 80 – 85 % quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 10 percent unburned shell fragments with diameters in the range of 3.0 to 6.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 5.0 percent hornblende particles (black color, compact), iron-clay concretions, pink color granitic rock fragments and traces of black color cinders derived from the burning process.

2. Particle form: generally compact and dense

3. Sphericity: intermediate – sub-equant

4. Surface features: The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.

Note: This mortar was soft. The overall mortar color was medium brown. Chunks of lime putty were observed in the mortar sample.

Trench #5019:

Sample # 12:

1. Composition: 80 – 85 % quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 10 percent unburned shell fragments with diameters in the range of 3.0 to 12.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 5.0 percent hornblende particles (black color, compact), iron-clay concretions, pink color granitic rock fragments and traces of black color cinders derived from the burning process.

2. Particle form: generally compact and dense

3. Sphericity: intermediate – sub-equant

4. Surface features: The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.

Note: This mortar was soft. The overall mortar color was medium brown. Chunks of lime putty were observed in the mortar sample.
**Sample # 13:**

1. **Composition:** 80 – 85 % quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 10 percent unburned shell fragments with diameters in the range of 3.0 to 10.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 5.0 percent hornblende particles (black color, compact), iron-clay concretions, pink color granitic rock fragments and traces of black color cinders derived from the burning process.

2. **Particle form:** generally compact and dense

3. **Sphericity:** intermediate – sub-equant

4. **Surface features:** The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.

Note: This mortar was soft. The overall mortar color was medium brown. The sand color is brown. Chunks of lime putty were observed in the mortar sample. Traces of fibrous material were observed.

**Sample # 14:**

1. **Composition:** 80 – 85 % quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 10 percent unburned shell fragments with diameters in the range of 3.0 to 6.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 5.0 percent hornblende particles (black color, compact), iron-clay concretions, pink color granitic rock fragments and traces of black color cinders derived from the burning process.

2. **Particle form:** generally compact and dense

3. **Sphericity:** intermediate – sub-equant

4. **Surface features:** The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.

Note: This mortar was hard. The overall mortar color was medium brown. The sand color is brown. Chunks of lime putty were observed in the mortar sample. Traces of fibrous material were observed.
Trench 5016:

Sample # 15:

1. Composition: 85 – 90 % quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 5-8 percent unburned shell fragments with diameters in the range of 3.0 to 20.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 3.0 percent hornblende particles (black color, compact), iron-clay concretions, pink color granitic rock fragments and traces of black color cinders derived from the burning process.

2. Particle form: generally compact and dense
3. Sphericity: intermediate – sub-equant
4. Surface features: The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.

Note: This mortar was soft. The overall mortar color was light brown. The sand color is light brown. Chunks of lime putty were observed in the mortar sample. Traces of fibrous material were observed.

Trench 5010:

Sample # 16:

1. Composition: 85 – 90 % quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 5-8 percent unburned shell fragments with diameters in the range of 3.0 to 12.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 3.0 percent hornblende particles (black color, compact), iron-clay concretions, pink color brick and granitic rock fragments and traces of black color cinders derived from the burning process.

2. Particle form: generally compact and dense
3. Sphericity: intermediate – sub-equant
4. Surface features: The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.
Sample # 17:

1. Composition: 85 – 90 % quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 5-8 percent unburned shell fragments with diameters in the range of 3.0 to 12.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 3.0 percent hornblende particles (black color, compact), iron-clay concretions, pink color brick and granitic rock fragments and traces of black color cinders derived from the burning process.

2. Particle form: generally compact and dense

3. Sphericity: intermediate – sub-equant

4. Surface features: The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.

Note: This mortar was hard. The overall mortar color was brown. The sand color is light brown. Chunks of lime putty were observed in the mortar sample. Traces of fibrous material were observed.

Trench 5018:

Sample # 18:

1. Composition: 80 – 85 % quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 5-8 percent unburned shell fragments with diameters in the range of 3.0 to 12.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 3.0 percent hornblende particles (black color, compact), iron-clay concretions, pink color brick and granitic rock fragments and traces of black color cinders derived from the burning process.

2. Particle form: generally compact and dense

3. Sphericity: intermediate – sub-equant
4. Surface features: The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.

Note: This mortar was hard. The overall mortar color was light brown. The sand color is light brown. Chunks of lime putty were observed in the mortar sample. Traces of fibrous material were observed.

Trench 5006:

Sample # 19: Soil Sample

Sample # 20:

1. Composition: 85 – 90 % quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 5-8 percent unburned shell fragments with diameters in the range of 3.0 to 8.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 2 - 3 percent hornblende particles (black color, compact), iron-clay concretions, pink color granitic rock fragments and traces of black color cinders derived from the burning process.

2. Particle form: generally compact and dense

3. Sphericity: intermediate – sub-equant

4. Surface features: The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.

Note: This mortar was soft. The overall mortar color was light brown. The sand color is light brown. Chunks of lime putty were observed in the mortar sample.
Trench 5012:

**Sample # 21:**

1. Composition: 85 – 90 % quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 5 percent unburned shell fragments with diameters in the range of 3.0 to 8.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 3 - 5 percent hornblende particles (black color, compact), iron-clay concretions, pink color granitic rock fragments and remnants of burned wood fragments. (3-10 mm)

2. Particle form: generally compact and dense

3. Sphericity: intermediate – sub-equant

4. Surface features: The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.

Note: This mortar was soft. The overall mortar color was light brown. The sand color is light brown. Chunks of lime putty were observed in the mortar sample. The percentage of cinders is higher in this sample than the others.

**Sample # 22:**

1. Composition: 85 – 90 % quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 5-8 percent unburned shell fragments with diameters in the range of 3.0 to 8.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 2 - 3 percent hornblende particles (black color, compact), iron-clay concretions, pink color granitic rock fragments and traces of black color cinders derived from the burning process.

2. Particle form: generally compact and dense

3. Sphericity: intermediate – sub-equant

4. Surface features: The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.

Note: This mortar was soft. The overall mortar color was brown. The sand color is light brown. Chunks of lime putty were observed in the mortar sample.
Sample # 23:

1. Composition: 85 – 90 % quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 5-8 percent unburned shell fragments with diameters in the range of 3.0 to 12.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 2 - 3 percent hornblende particles (black color, compact), iron-clay concretions, pink color granitic rock fragments and traces of black color cinders derived from the burning process.

2. Particle form: generally compact and dense
3. Sphericity: intermediate – sub-equant
4. Surface features: The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.

Note: This mortar was soft. The overall mortar color was brown. The sand color is light brown. Chunks of lime putty were observed in the mortar sample.

Trench 5001:

Sample # 24:

1. Composition: 85 – 90 % quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 5-8 percent unburned shell fragments with diameters in the range of 3.0 to 8.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 2 - 3 percent hornblende particles (black color, compact), iron-clay concretions, pink color granitic rock fragments and traces of black color cinders derived from the burning process.

2. Particle form: generally compact and dense
3. Sphericity: intermediate – sub-equant
4. Surface features: The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.

Note: This mortar was soft. The overall mortar color was brown. The sand color is light brown. Chunks of lime putty were observed in the mortar sample.
**Trench 5013:**

**Sample # 25:**

1. **Composition:** 85 – 90% quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 5-8 percent unburned shell fragments with diameters in the range of 3.0 to 10.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 2 - 3 percent hornblende particles (black color, compact), iron-clay concretions, pink color granitic rock fragments and traces of black color cinders derived from the burning process.

2. **Particle form:** generally compact and dense

3. **Sphericity:** intermediate – sub-equant

4. **Surface features:** The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.

Note: This mortar was soft. The overall mortar color was brown. The sand color is brown. Chunks of lime putty were observed in the mortar sample.

**Sample # 26:**

1. **Composition:** 85 – 90% quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 5-8 percent unburned shell fragments with diameters in the range of 3.0 to 10.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 2 - 3 percent hornblende particles (black color, compact), iron-clay concretions, pink color granitic rock fragments and traces of black color cinders derived from the burning process.

2. **Particle form:** generally compact and dense

3. **Sphericity:** intermediate – sub-equant

4. **Surface features:** The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.

Note: This mortar was soft. The overall mortar color was brown. The sand color is brown. Chunks of lime putty were observed in the mortar sample.
Trench 5005:

**Sample # 27:**

1. Composition: 85 – 90 % quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 5-8 percent unburned shell fragments with diameters in the range of 3.0 to 10.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 2 - 3 percent hornblende particles (black color, compact), iron-clay concretions, pink color granitic rock fragments and traces of black color cinders derived from the burning process.

2. Particle form: generally compact and dense
3. Sphericity: intermediate – sub-equant
4. Surface features: The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.

Note: This mortar was soft. The overall mortar color was light brown. The sand color is light brown. Chunks of lime putty were observed in the mortar sample.

**Sample # 28:**

1. Composition: 85 – 90 % quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 5-8 percent unburned shell fragments with diameters in the range of 3.0 to 10.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 2 - 3 percent hornblende particles (black color, compact), iron-clay concretions, pink color granitic rock fragments and traces of black color cinders derived from the burning process.

2. Particle form: generally compact and dense
3. Sphericity: intermediate – sub-equant
4. Surface features: The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.

Note: This mortar was soft. The overall mortar color was light brown. The sand color is light brown. Chunks of lime putty were observed in the mortar sample.
Sample # 29:

1. Composition: 85 – 90 % quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 5-8 percent unburned shell fragments with diameters in the range of 3.0 to 10.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 2 - 3 percent hornblende particles (black color, compact), iron-clay concretions, pink color granitic rock fragments and traces of black color cinders derived from the burning process.

2. Particle form: generally compact and dense
3. Sphericity: intermediate – sub-equant
4. Surface features: The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.

Note: This mortar was soft. The overall mortar color was light brown. The sand color is light brown. Chunks of lime putty were observed in the mortar sample.

Trench 5003:

Sample # 30:

1. Composition: 85 – 90 % quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 5-8 percent unburned shell fragments with diameters in the range of 3.0 to 10.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 1 - 2 percent hornblende particles (black color, compact), iron-clay concretions, pink color granitic rock fragments and traces of black color cinders derived from the burning process.

2. Particle form: generally compact and dense
3. Sphericity: intermediate – sub-equant
4. Surface features: The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.

Note: This mortar was soft. The overall mortar color was brown. The sand color is brown. Chunks of lime putty were observed in the mortar sample.
Trench 5000:

Sample # 31:

1. Composition: 85 – 90 % quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 5-8 percent unburned shell fragments with diameters in the range of 3.0 to 10.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 1 - 2 percent hornblende particles (black color, compact), iron-clay concretions, pink color granitic rock fragments and traces of black color cinders derived from the burning process.

2. Particle form: generally compact and dense

3. Sphericity: intermediate – sub-equant

4. Surface features: The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.

Note: This mortar was soft. The overall mortar color was light brown. The sand color is light brown. Chunks of lime putty were observed in the mortar sample.

Trench 5020:

Sample # 32:

1. Composition: 85 – 90 % quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 5-8 percent unburned shell fragments with diameters in the range of 3.0 to 10.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 1 - 2 percent hornblende particles (black color, compact), iron-clay concretions, pink color granitic rock fragments and traces of black color cinders derived from the burning process.

2. Particle form: generally compact and dense

3. Sphericity: intermediate – sub-equant

4. Surface features: The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.

Note: This mortar was soft. The overall mortar color was brown. The sand color is brown. Chunks of lime putty were observed in the mortar sample.
Sample #33:

1. Composition: 85 – 90 % quartz, particle shape is sub-rounded to angular; particle colors are clear, milky white and rose. Other constituents include approximately 5-8 percent unburned shell fragments with diameters in the range of 3.0 to 15.0 millimeters. The shell fragments are angular shape and display various shades of gray color. Also included are approximately 1 - 2 percent hornblende particles (black color, compact), iron-clay concretions, pink color granitic rock fragments and traces of black color cinders derived from the burning process.

2. Particle form: generally compact and dense

3. Sphericity: intermediate – sub-equant

4. Surface features: The quartz displays a slightly frosted surface texture. The remaining particles have a rough and hackly surface texture, which enhances the bond with the lime putty.

Note: This mortar was soft. The overall mortar color was brown. The sand color is brown. Chunks of lime putty were observed in the mortar sample.
Ludwell Statehouse  Sample #1

Percent Passing (%) vs. Sieve Size (mm)

- 14.1
- 25.9
- 45.8
- 91.5
- 99.3
- 100
Sample 20

Percent Passing (%) vs. Sieve Size (mm)

Ludwell Statehouse Sample 20

- 100% passing through 99.8 mm
- 93.8% passing through 93.8 mm
- 52.4% passing through 52.4 mm
- 30.5% passing through 30.5 mm
- 18.4% passing through 18.4 mm

Sieve Size (mm) vs. Percent Passing (%)
Ludwell Statehouse  Sample 24

Percent Passing (%) vs. Sieve Size (mm)

Key Points:
- 12.1 mm: 0%
- 19.9 mm: 19.9%
- 42 mm: 95.5%
- 95.5 mm: 99.9%
- 100 mm: 100%

Graph shows the percentage of material passing through different sieve sizes.