Project: USHG [redacted]

March 12, 2020

[redacted]

EVALUATION OF MORTAR COMPOSITION – ASTM C1324

[redacted]

INTRODUCTION

Two samples, consisting of hardened masonry mortar fragments, were received for analysis on [redacted]. The samples were chemically and petrographically analyzed in order to determine composition. The project identification is: [redacted].

METHODS OF ANALYSIS

ASTM C1324 - The samples were analyzed according to chemical procedures and petrographic examination methods of ASTM C1324, "Standard Test Method for Examination and Analysis of Hardened Masonry Mortars".

The mortar was examined using a stereomicroscope up to a magnification of 100X. Portions of the binder portion of the mortar were prepared on glass slides in several refractive index oils in the range of 1.30 to 1.71 and examined for identification using a polarizing (petrographic) microscope up to a magnification of 600X. The optical and morphological properties of the phases present were used to identify the various constituents present, including primary and secondary calcium carbonate, hydrated lime, gypsum, brucite, free lime, portland cement, and any other substances.

The chemical analysis was conducted, using wet chemical procedures in ASTM C1324 and X-ray fluorescence spectroscopy (XRF), X-ray diffraction (XRD) and thermal analysis.

SAMPLES RECEIVED FOR ANALYSIS

Two samples consisting of hardened mortar fragments were received for analysis. The mortar was reported to be approximately one hundred and seven years old (circa 1923).
The mortar fragments were obtained from two separate locations, as listed in the following table.

The samples, received in well-sealed plastic bags, had the following identifications and properties:

Sample Identification	Mortar Color	Sample Weight	Mortar Fragment Size
#1 Brick Mortar [redacted]	Gray	161 grams	One hardened mortar fragment measuring 4.00" x2.875" x 0.50" Tooled mortar joint is not present.
#2 Limestone Mortar [redacted]	Light Gray	149 grams	One hardened mortar fragment measuring 7.125" x 2.125" x 0.375" Tooled mortar joint is not present.

RESULTS - PETROGRAPHIC EXAMINATION

Two Mortar Samples: [redacted] *(Brick Mortar)*

The sample identified as [redacted] is an unpigmented masonry cement mortar. The paste was comprised of unhydrated and partially hydrated portland cement clinker particles and limestone fines (Photograph 1). The paste hardness was considered firm.

The mortar as represented by the submitted sample is purposely air entrained based on the relative abundance of small spherical voids that are less than 1 mm in diameter. The total hardened air content is estimated to be between 5 and 7% (Photograph 2).

The paste was mostly carbonated with small region of non-carbonated paste near the center of the mortar bed.

The sand was a natural sand comprised of relatively diverse lithology that included, but was not limited to, whole grains of quartz and feldspar, granite limestone, dolomite, graywacke, schist, sandstone, quartzite, siltstone, metavolcanics, chert, shale and some iron oxide. Distribution of the sand was considered uniform. The shape of the sand ranged from rounded to angular. The largest sand grain observed was 2.5 mm in the least dimension.

[redacted] *(Limestone Mortar)*

As received, the mortar was still adhered to a portion of the limestone. The bond between the mortar and the limestone appeared to be moderately tight to tight with small microcracks observed at the bond surface based on thin section examination. Some of these microcracks were autogenously healed.

The mortar as represented by the submitted sample [redacted] is a slaked lime mortar with a small portion of portland cement added (Photographs 3 through 5). The paste contained a relative abundance of fissures, which is consistent with high-lime mortars (Photograph 6).

Numerous microcracks were observed within paste regions near the exposed surface. These microcracks were often autogenously healed (Photographs 7 and 8).

The paste was mostly carbonated with small pockets of uncarbonated paste.

The mortar is not intentionally air entrained with the air content visually estimated to be between 1 and 2%.

The sand was a natural sand comprised of whole quartz and feldspar grains along with grains of a relatively diverse lithology. Rock types included, but were not limited to, granite, limestone, dolomitic limestone, dolomite, siltstone, schist, chert, shale, and iron oxide. Distribution of the sand was considered uniform. The shape of the sand was mostly subangular to angular with lesser quantities of rounded grains. The largest sand grain was 1.54 mm in the least dimension.

RESULTS - CHEMICAL ANALYSIS

Two Mortar Samples: [redacted]

The results of the chemical analyses and calculations are presented in the table below:

CHEMICAL ANALYSIS – ASTM C1324 [redacted]		
	Sample #1: Brick Mortar [redacted]	**Sample #2: Limestone Mortar** [redacted]
Constituents:	**% by Mass**	**% by Mass**
SiO_2 Soluble Silica	5.72	2.51
CaO Calcium Oxide	15.17	19.07
MgO Magnesium Oxide	3.40	9.43
Insoluble Residue	53.84	40.01
Loss on Ignition:		
@ 23 - 110° C. Free Water	1.74	1.00
@ 110 - 550° C. Hydrate Water	6.86	10.31
@ 550 - 950° C. CO_2	8.81	17.31
Calculated Constituents:		
Portland Cement	27.2	11.95
Slaked Lime (Dolomitic)	NA	11.75
Masonry Cement	35.2	NA

Fine Aggregate	64.7	52.4
Volumetric Proportions (per ASTM C270) – Loose Volume Ratios:		
Portland Cement : Masonry Cement	0.77	NA
Masonry Cement : Sand	1 : 2.4	NA
Portland Cement: Slaked Lime : Sand	NA	1 : 2.3 : 5.2
Mortar Type:	Type M	Type O Under-Sanded

* The limestone fines in masonry cement can be dissolved during the wet chemistry analysis and can affect the ratio of portland cement to limestone fines. The sand in each sample contained carbonate and other constituents that likely interfered with the SiO2 CaO, and MgO determinations. The sand content for USHG #20-013-1 was adjusted for carbonate in the aggregate. The MgO and sand content was adjusted to account for the percentage of dolomite in the aggregate in USHG #20-013-2.

Based on the Chemical Analysis results, Sample 1) Brick Mortar ([redacted]) appears similar to a "Type M" formulation consisting of masonry cement and sand, and Sample 2) Limestone Mortar ([redacted]) appear similar to a "Type O" formulation consisting of a mixture of portland cement, dolomitic slaked hydrated lime, and sand.

Bulk Volumes of Sand in the samples are as follows:

1) Brick Mortar – Loose Volume is 2.4 times the volume of masonry cement, which is slightly low for the ASTM C270 requirement for sand content.
2) Limestone Mortar – Loose Volume is 1.6 times the sum of the separate volumes of cement and hydrated lime, which is very low for the ASTM C270 requirement for sand content.

RECOMMENDED REPLACEMENT MIX

When considering replacement materials, it is important to consider the differences in the materials available during the original construction and modern building materials. The original date of construction of the building was 1923, and the technology for producing portland cement and masonry cement has increased greatly since then. This information is taken into account when recommending replacement materials, as an identical mix ratio using modern portland or masonry cement will produce a mortar that is stronger than the original. For this reason, we recommend that the mortar be replicated with portland cement, hydrated lime and sand, using the following mix proportions:

Sample [redacted] Brick Mortar
1 Part Portland Cement, 1 Part Hydrated Lime and 6 Parts Sand ("Type N" mortar per ASTM C270)

Samples [redacted] Limestone Mortar
1 Part Portland Cement, 2 Parts Hydrated Lime and 8 Parts Sand ("Type O" mortar per ASTM C270)

Note: Masonry work using these formulations must be completed 21 days prior to freeze thaw cycles occurring. Do not perform any masonry work unless air temperatures are between 40 degrees Fahrenheit (10 degrees Celsius) and 90 degrees Fahrenheit (32 degrees Celsius) and will remain so for at least 4 weeks after the completion of the work.

Respectfully submitted,

U.S. Heritage Group, Inc.

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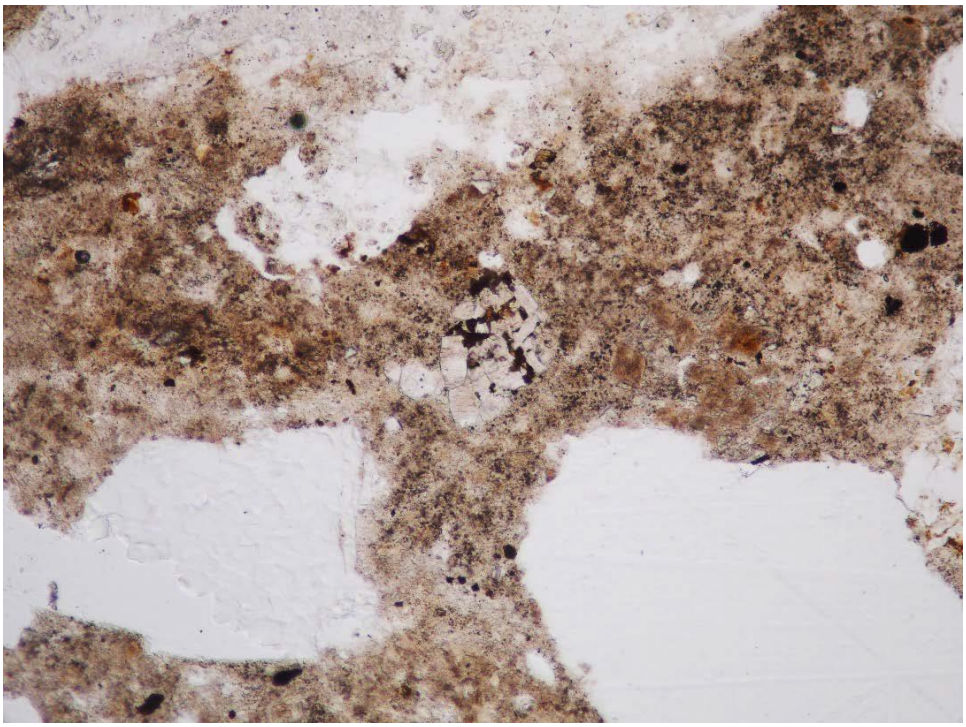
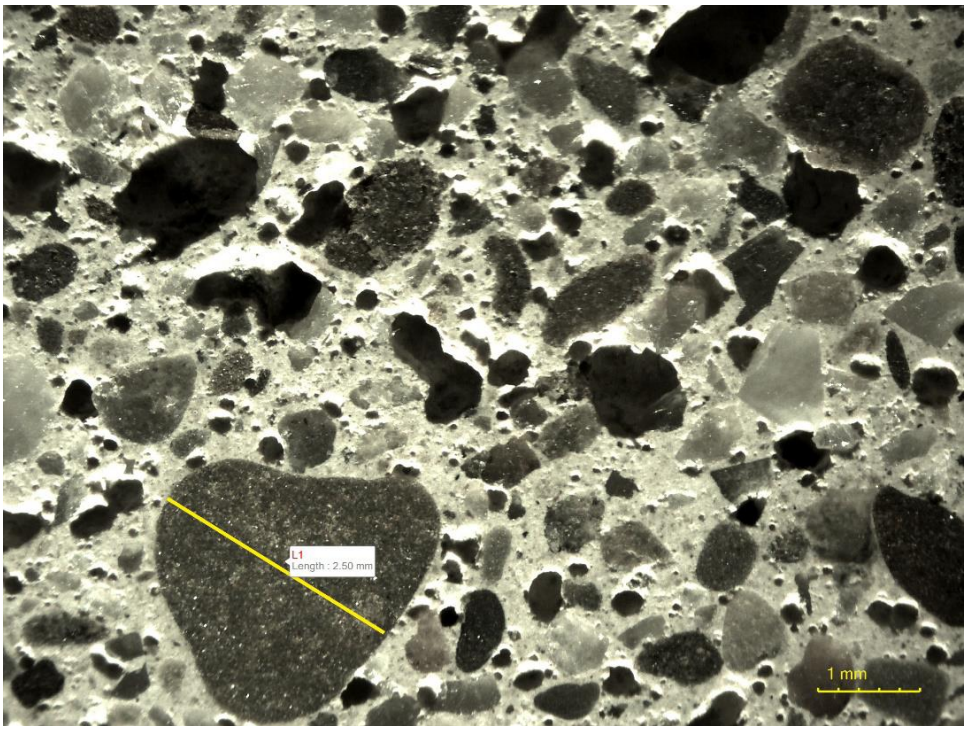
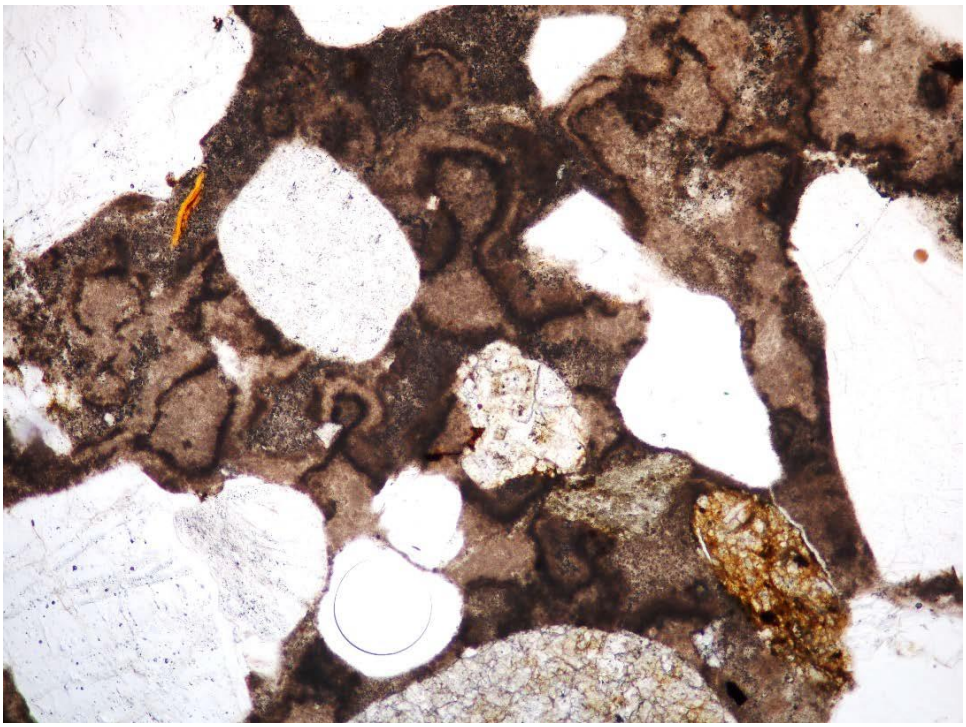


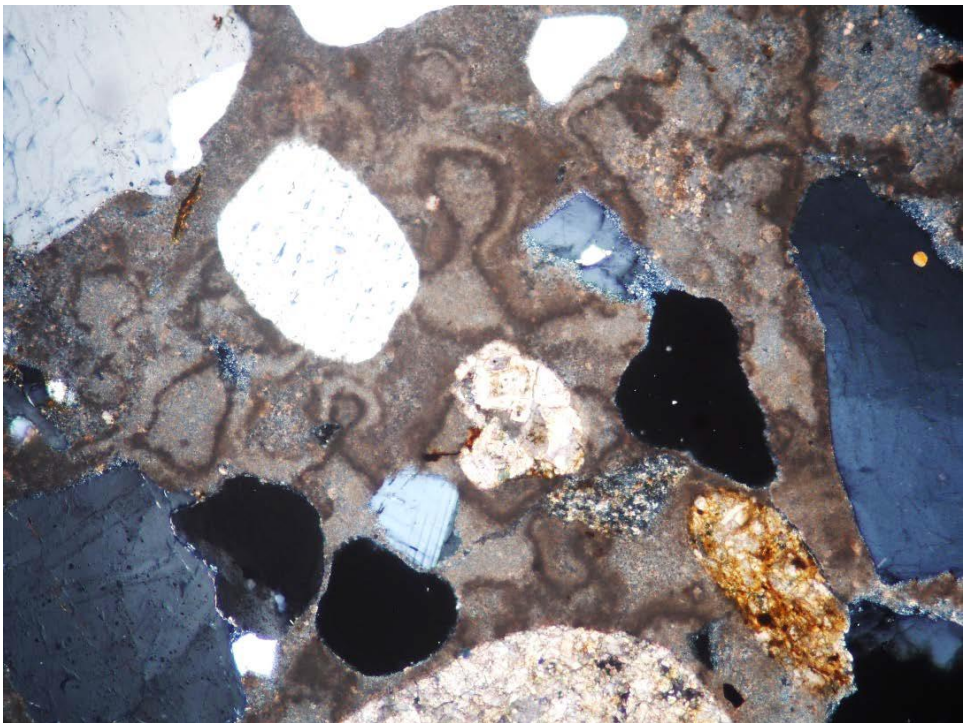
Photograph 1 – Photomicrograph of a paste region in USHG #20-013-1 (Brick Mortar). Note the residual portland cement clinker particle in center of the field of view. Plane polarized light. Field Length = 0.85 mm.



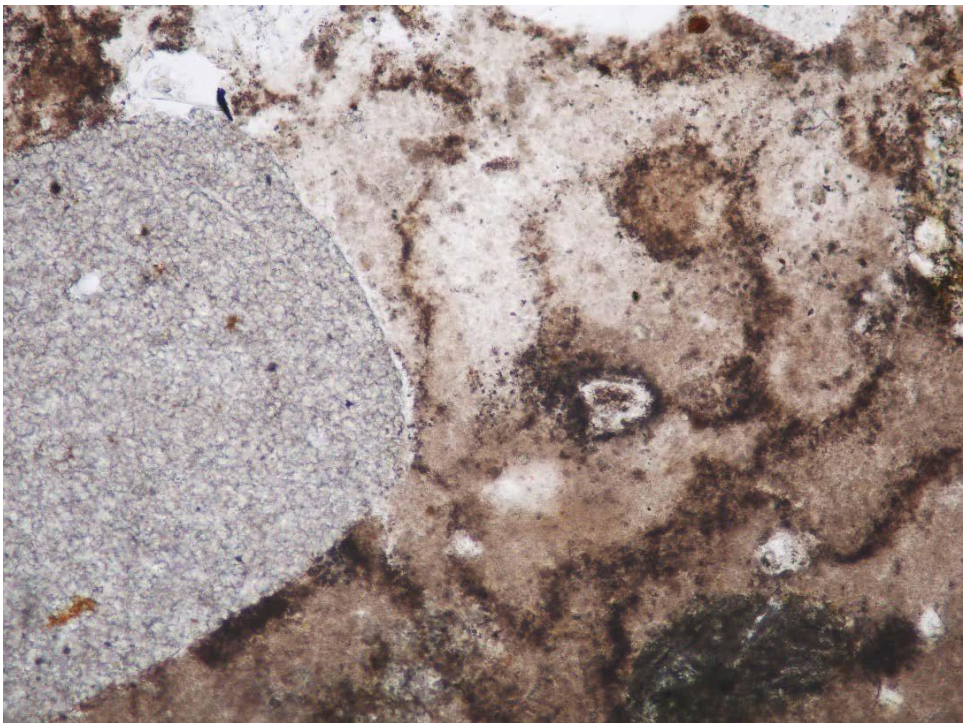
Photograph 2 – Photomicrograph of the polished cross-section of USHG #20-013-1 (Brick Mortar). Note the abundance of small spherical air void less than 1 mm in diameter. Note the largest aggregate particle is 2.5 mm. Scale: each subdivision on the 1 mm scale bar is 0.2 mm.



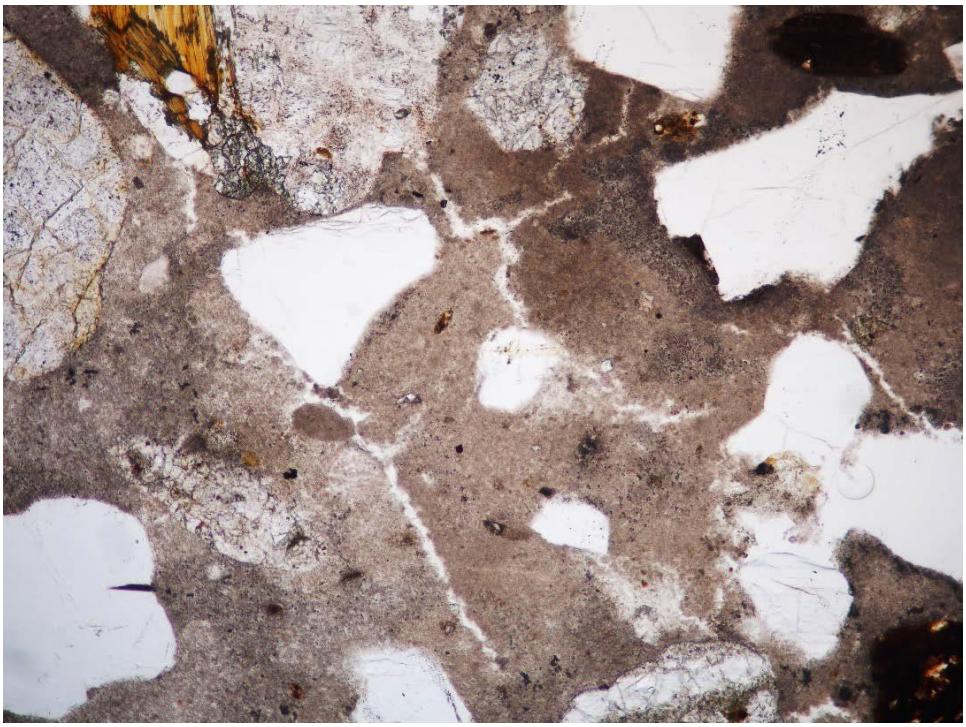
Photograph 3 – Thin section photomicrograph of sample USHG #20-013-2 (Limestone Mortar). Note the texture of the lime in the paste, which is consistent with slaked lime. Plane polarized light. Field Length = 1.67 mm



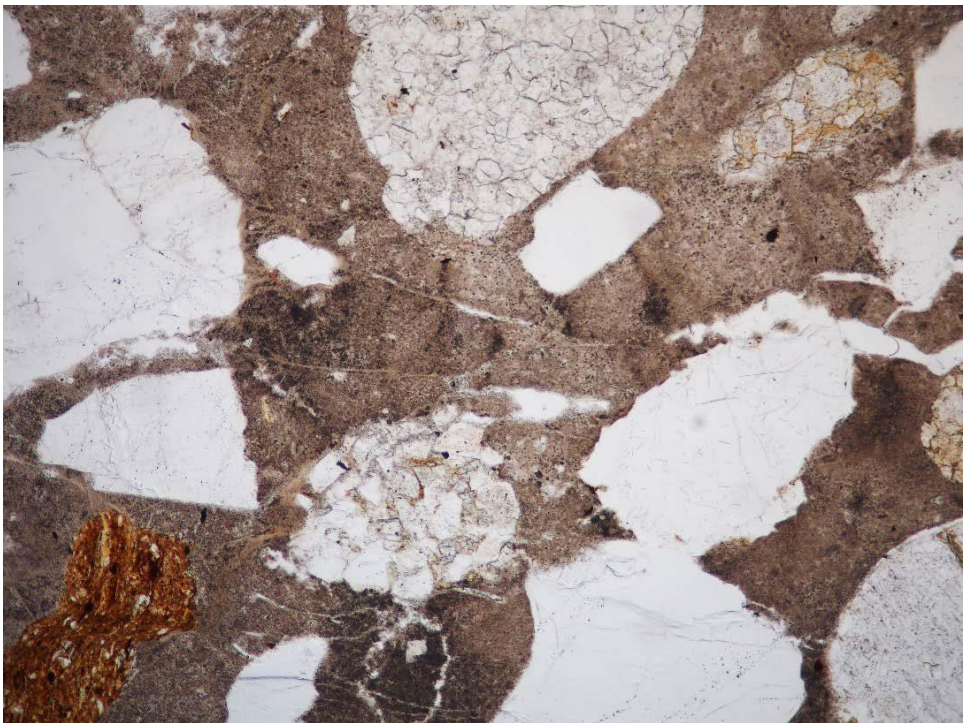
Photomicrograph 4 – Same field of view as Photograph 3 except under cross-polarized light.



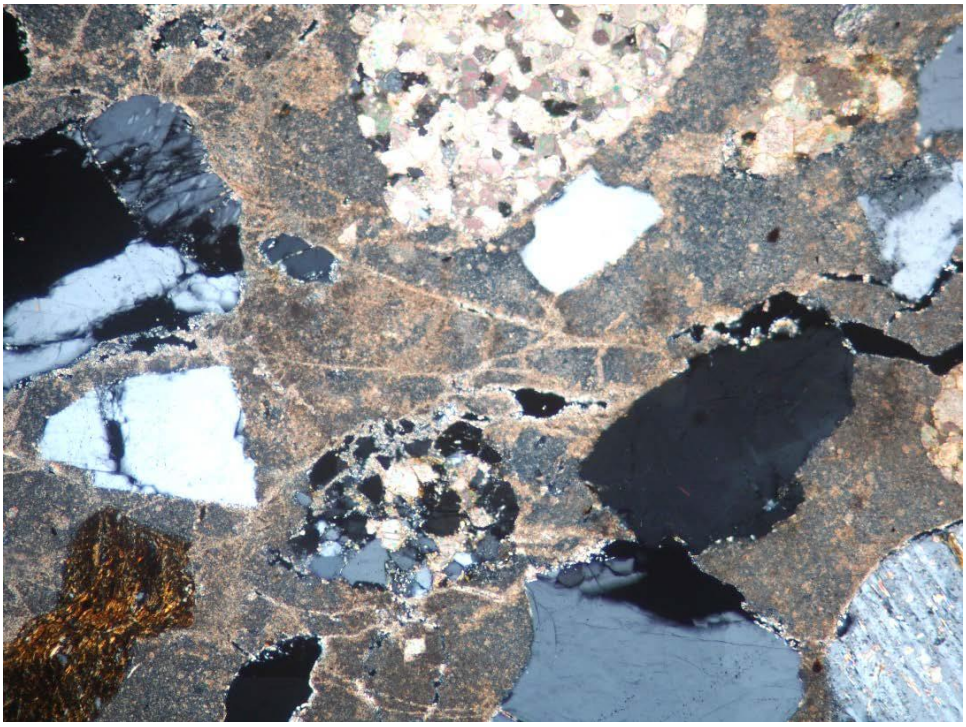
Photograph 5 – Thin section photomicrograph of another area in USHG #20-013-2 (Limestone Mortar). Note the presence of residual portland cement clinker particles (arrows). Plane-polarized light. Field Length = 0.85mm



Photograph 6 – Thin section photomicrograph of fissures within paste regions in USHG #20-013-2 (Limestone Mortar). A relative abundance of fissures is a characteristic of high lime content mortars. Plane-polarized light. Field Length = 1.67 mm.



Photograph 7 – Thin section photomicrograph of microcracking and fissures in USHG #20-013-2 (Limestone Mortar). Plane-polarized light. Field Length = 1.67 mm.



Photomicrograph 8 – Same field of view as Photograph 7 except under cross-polarized light. Note that a majority of the microcracks have autogenously healed.