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Our Ref: M/1919/18/C1
Your Ref.: 6040/H712

10th February 2019

CERTIFICATE OF ANALYSIS OF MORTAR SAMPLES FOR DETERMINATION OF MIX COMPOSITION & BINDER TYPE

Project Reference	:	North Yorkshire Moors – This Exploited Land of Iron
Sample Location	:	Warren Moor Mine
Sample Description	:	WM1 – Chimney Brickwork Mortar WM2 – Chimney Stonework Mortar
Date Received	:	8th January 2019
CMC Sample Ref	:	SR 2674 – S1 = WM1 – Brickwork Masonry SR 2674 – S2 = WM2 – Stonework Masonry
Date Analysed	:	17th & 18th September and 10th & 11th October 2018
Method of Test	:	Determination of binder type by X-Ray Diffraction analysis, with mix composition by acid digestion with grading analysis of recovered aggregate, and thin section examination.

Sample

Two mortar samples, identified as mortar from the chimney at Warren Moor Mine, North Yorkshire Moors, was received in CMC's Stirling Laboratory on the 8th January 2019. The samples were submitted by Structural and Civil Consultants Ltd., Northallerton, on behalf of the North York Moors National Parks Authority.

The mortar samples were to be submitted for analysis to determine the composition of the mortar along with identification of the aggregate, and if possible, its particle size distribution. In addition, comment on the type and form of the binder used in the mortar was also requested.

The analysis to be carried out in accordance with CMC's quotation submitted the Maria-Elena Calderon, Land of Iron Cultural Heritage Officer, North York Moors National Parks Authority, by email on the 11th September 2018.

On receipt in the laboratory, the sample details were entered the sample register and the unique sample identification number SR2674 allocated. The sample details are presented below:

CMC Sample Ref.	Client Ref	Location Sampled
SR2674 – S1	WM1	Mortar from the Chimney Brickwork, Warren Moor Mine.
SR2674 – S2	WM2	Mortar from the Chimney Stonework, Warren Moor Mine.

Method of Test

On receipt in the laboratory the samples were logged, with their mass and size recorded prior to being photographed, in the as-received condition. The samples were then submitted to an examination with the aid of a stereo-binocular microscope at a magnification up to x20 in preparation for analysis.

During the microscopic examination the samples were exposed to a series of *ad hoc* droplet tests employing a range of reagents and indicator solutions to aid the identification of the components present and to assess the condition of the mortars as received.

Following the initial examination, and on the basis that the size of the sample from WM2 was insufficient for determination of mix composition by acid digestion, and with the possibility that the aggregates may contain limestone, a petrographic thin section was prepared from each sample. This would permit clarification of the form in which the binders were used along with determination of mix composition by modal analysis.

Identification of the binder type used in the production of the mortars was confirmed by X-ray Diffraction (XRD) analysis. This was achieved by lightly crushing and grinding a representative sub-sample, from each sample, in an agate mortar and pestle. During sample preparation care was exercised to minimise crushing of the aggregate particles, as if in abundance they may mask hydraulic components, that may only be present in trace proportions. The fines were collected by screening the powdered samples over a 63micron sieve, with the fines collected back-packed into proprietary sample holders in preparation for presentation in the X-Ray Diffractometer.

Observations from a Macro/Microscopic examination

On receipt the sample details were logged with the following determined:

Sample Ref.	Client Ref.	Mass of Sample (gram)	Dimensions of Largest piece (mm)	Colour by the Munsell Soil Colour Charts
SR2674-S1	WM1[1]	48.7	29.3 x 24.5 x 19.3	10YR 8/2 “Very Pale Brown”
SR2674-S2	WM2[2]	21.7	35.4 x 25.9 x 16.3	10YR 8/2 “Very Pale Brown”

[1] Sample WM1 was received in two bags, one dated 12th October 2018 and the other 27th December 2018. However, as both were visually very similar and as the samples, on their own, were too small to permit the full suite of tests to be carried out, the two samples were combined, and the sample analysed as one.

[2] Sample WM2 was dated as being collected on the 12th October 2018.

Sample SR2674-S1 (WM1): Mortar from Chimney Brickwork

The sample received was in two separate bags, with each identified as Chimney Brick mortar, with collection dates of the 12th October 2018 and 27th December 2018.

The samples received consisted of 6 fragments (12/10/18) and 9 fragments (27/12/18) of mortar along with a small quantity of fines. The mortar in each sub-sample was visually very similar with respect to colour, texture and composition, and therefore to ensure sufficient material for the full suite of analyses, both samples were combined and treated as a single sample.

The mortar fragments were well compacted and were noted to contain an abundance of lime inclusions. The intact pieces could be broken under moderate finger pressure and once disrupted could be powdered under moderate to firm finger pressure.

Plates No. 1 & 2: The left plate shows the intact pieces of mortar in the sample from 12/10/18,as received, with the right plate showing the intact pieces extracted from the sample dated 27/12/18. The fragments in the latter sample were dustier than the earlier sample and some of the pieces retained brick fragments adhering to their bed faces. The largest piece in the sample dated 12/10/18 displayed localised leaching with one "outer" surface having been affected significantly by weathering.

On examination it was noted that the mortar in both sub-samples displayed the characteristics of a lime mortar, with an abundance of lime inclusions apparent. The inclusions measured up to 2.4mm in size, with these being sub-angular to sub-rounded in shape.

The mortar was well compacted but variable in hardness and most of the pieces could be broken under moderate finger pressure, where the larger fragments broke with an audible "snap", indicating a degree of brittleness. However, a few of the smaller fragments were noticeably softer and finger friable and could be powdered under light to moderate finger pressure.

Plates No. 3 & 4: The left plate shows an outer, weathered surface of one of the mortar pieces in the sample from 12/10/18, with the right plate showing a fractured surface on one of the fragments from sample taken on 27/12/18. Note, the presence of small lime inclusions distributed throughout the fabric in both fragments.

The mortar was indicated from the Phenolphthalein indicator test, to be fully carbonated throughout the thickness of all pieces tested. Water droplets placed onto fractured surfaces were rapidly absorbed and diffused throughout the mortar to depth, indicating a well-connected pore structure within the mortar.

The aggregates are round to sub-round in shape and are dominated by quartz grains with chert fragments, sandstone, siltstone, along with a mixed suite of indeterminate lithic fragments also present. The aggregate particles are mostly finer than 0.8mm in size.

Plate No. 5:

The plate opposite shows a magnified view of a freshly fractured surface through the thickness of a mortar fragment after the application of a Phenolphthalein indicator solution. The absence of a colour change indicating that the mortar was fully carbonated.

There was no evidence of air entrainment in the sample examined although small irregular shaped entrapped air voids were observed, these extending up to 1.4mm in size. All of the voids within the body of the mortar fragments examined appeared to be free of infilling, albeit, locally, fine fringes of secondary crystalline deposits were observed within near surface voids, and these may be redeposited calcite (carbonated leached lime) and/or gypsum.

Sample SR2674-S (WM2): Mortar from Chimney Stonework

This sample consisted of five small fragments of mortar along with a small quantity of fines.

Plates No. 6 & 7: The left plate shows the intact pieces of mortar received. With the right plate showing a close-up of an outer surface where some surface leaching was apparent along with entrapment of soiling within redeposited lime. Small lime inclusions are also apparent on the surface.

The mortar fragments were well compacted, and all were noted to contain small lime inclusions distributed throughout. The inclusions were angular to sub-round and locally irregular in shape, with these measuring up to 1.2mm in size. The intact pieces could be broken under light to moderate finger pressure and once disrupted could be powdered under moderate finger pressure.

Plate No. 8:

The plate opposite shows a freshly fractured surface through the thickness of a mortar fragment after the application of a Phenolphthalein indicator solution to the upper part. The absence of a colour change indicating that the mortar was fully carbonated.

Note the compact condition of the mortar and the small lime inclusions(white) within the fabric.

On testing a freshly fractured surface with a Phenolphthalein indicator solution, the mortar fragments tested were found to be fully carbonated throughout their thickness. As in sample S1, water droplets placed onto fractured surfaces were rapidly absorbed and diffused throughout the mortar to depth, again indicating a well-connected pore structure within the mortar.

There was no evidence of air entrainment in the sample examined but small sub-rounded to elongated entrapped air voids were observed, these are placing artefacts and extended up to 1.7mm in size. A number of the voids, particularly those connected to outer surfaces contained linings of secondary crystalline deposits, which appeared to be mostly of redeposited calcite (carbonated leached lime).

The aggregates are round to sub-round in shape and are dominated by quartz grains with chert fragments, sandstone, siltstone, shale and a mixed suite of indeterminate lithic fragments present. The aggregate particles are mostly finer than 0.8mm in size and appeared visually to be very similar to those in sample SR2674-S1 (WM1).

Results of XRD Analysis for Binder Type

A binder rich powder sub-sample from each sample was analysed in a Philips X-ray Diffractometer to aid in confirming the type of binder used in the preparation of the mortars. The powdered, binder rich, samples were collected from material passing the 63µm sieve with these back-packed into proprietary sample holders for presentation in the diffractometer.

The prepared samples were analysed in a Diffractometer which was fitted with a single crystal monochromator, set to run over the range 3° to 60° 2θ in steps of 0.1° 2θ at a rate of 1° 2θ/minute using CuKα radiation. The digital output from the diffractometer was analysed by a computer program, which matched the peak positions against the JCPDS International Standard Mineral Data-base sub files using a search window of 0.1°.

The results of the analysis, by X-ray Diffraction, are presented in the following attached Figures, in the form of labelled X-ray Diffractograms:

Figure No. **2**: SR2674-S1 (WM1) Binder rich fines from mortar ex Chimney Brickwork Masonry,

Figure No. **2**: SR2674-S2 (WM2) Binder rich fines from mortar ex Chimney Stonework Masonry.

The abbreviations used on the charts, to identify peak positions, are as follows:

cc = Calcite ($CaCO_3$) calcium carbonate, carbonated lime from lime binder and any limestone aggregate present in the mortar,

qz = Quartz (SiO_2) dominant component of the aggregate in the mortar.

fs = Feldspar, with Anorthite of the Plagioclase group being the dominant form detected, along with minor Sanidine, an Alkali Feldspar, also present in sample S2,

mi = Muscovite Mica, common layer lattice mineral, present as an aggregate component,

di = Dickite, Clay mineral of the Kaolinite group, present as an aggregate component, weathering product and soiling. Also, possibly a contaminant from associated masonry brickwork,

gy = Gypsum ($CaSO_4 2H_2O$) Calcium Sulphate Hydrate, Sulphate reaction product, product from a reaction of environmental sulphates (Smoke, soot, acid rain, etc.) with lime in binder,

The data from the XRD Analysis was processed further by Rietveld refinement to enable quantification of the components present, with the following results:

Component	**Proportion (% by Mass)**	
Sample:	**SR2674-S1 (WM1)**	**SR2674-S2 (WM2)**
Calcite	69.7	66.8
Quartz	18.5	23.4
Feldspar (Anorthite)	6.9	1.8
Feldspar (Sanidine)		1.1
Muscovite Mica		4.6
Dickite (Clay)	3.1	1.9
Gypsum	1.8	0.4
Total	**100.0**	**100.0**

Based on the XRD analysis, and data it is indicated that the two samples were both made using a high Calcium air Lime with no hydraulic or pozzolanic components detected in the paste. The Quartz, Feldspar, Mica and Dickite are all present as aggregate components, albeit a proportion of the Dickite may be present as a contaminant, from the brick masonry, as a weathering product, or from accumulated soiling.

The Gypsum is, most likely, present as a reaction product, formed from the action of sulphates on the lime binder used in the mortar. The source of the sulphates may be smoke from the chimney itself, leached from the brick masonry, or the effect of acid rain, or a combination of all. However, given that the proportion of gypsum found in the sample from the stonework masonry was significantly lower than that in sample S1 from the chimney brickwork, and without further knowledge of the structure, or location sampled, it is considered that the brick was probably, at least one, of the sources of the sulphate, and the flue gasses the other.

Mix Composition

The result of the composition analysis, determined by acid digestion, on the combined sample from the two parts of the sub-samples forming SR2674-S1 (WM1), are presented below:

Sample Ref. No.	**SR 2674 – S1 (WM1)**	
Mortar type (from XRD)	Non-Hydraulic Lime	
Binder form:	Quicklime	Putty Lime
Binder/Aggregate Ratio	1.0 : 1.4	
Weight proportions calculated mix ratio by dry mass.		
Lime	1.0	1.0
Aggregate	2.6	1.1
Approximate volume Proportions calculated on the basis of a Non-Hydraulic lime		
Lime	1.0	1.0
Aggregate	0.8	0.9

The results reported should, however, be used with caution, if to act as the basis for the selection of mortars for remedial works, as it was noted that the mortars contained an abundance of lime inclusions, along with a trace proportion of limestone aggregate, all of which may have been, at least in part, digested with the result that the binders reported are perhaps over binder rich.

The aggregates from the acid digestions were recovered and the particle size distribution determined, with the results obtained presented in table No. 1 below, and in the form of an aggregate filled histogram in Figure No. 1.

Sample Reference	SR2674 – S1 (WM1) Brickwork Mortar	
British Standard Sieve Size	**Percentage Retained**	**Percentage Passing**
8.00mm	0	100
4.00mm	0	100
2.00mm	0.9	99.1
1.00mm	6.4	92.7
0.500mm	34.1	58.6
0.250mm	30.8	27.8
0.125mm	10.9	16.9
0.063mm	7.1	9.8
Passing	9.8	

Table No. 1: Results of the grading on recovered aggregate.

The aggregate in the mortar are dominated by quartz grains with minor chert, sandstone, silt and shale, along with other indeterminate lithic fragments, including a minor proportion of limestone. The grains are sub rounded with water worn surfaces, and they are likely to have been won from a local Glaciofluvial deposit. The high fines content, along with the clay minerals detected in the XRD analysis, would suggest that they had been used in the form of "as dug" aggregate, without washing.

Microscopic Examination

To clarify the form in which the binder was used, in both samples, and to permit the mix composition of the mortar to be determined in sample SR2674-S2 (WM2) a petrographic thin section was prepared from each sample. Given the small size of the pieces, each thin section was composed from several intact pieces of the mortar. These were dried to a constant weight at 70°C prior to being impregnated with a blue dyed resin. One side of each piece was then cut and polished prior to being mounted on a glass slide (50mm x 75mm). The fragments were aligned to give the maximum area on the slides. The mounted specimens were then cut and polished to give a thickness in the region of 30µm in preparation for examination in the polarised light microscope. Observations from the examination of both thin sections are presented below:

Sample SR2674-S1 (WM1): Mortar from Chimney Brickwork

Plate No. 9:

Thin section prepared from four pieces of mortar from sample SR2674-S1 (WM1)

Aggregate

The aggregates in the mortar sample are dominated by quartz grains with chert, sandstone, siltstone, shale and a proportion of weathered lithic fragments, mostly of altered igneous rock types, including microgranite, along with coal and ironstone fragments. In addition, there is also a low proportion of limestone, all are calcareous with a range of fabrics observed. The limestone aggregates include fossiliferous forms, containing various shell fragments and bryozoa, and micritic forms i.e. algal/colloidal limestones. No Dolomitic limestone was observed in this sample.

On examination of the limestone fragments, some of the fragments were found to show evidence of having been burnt, although others did not, and, therefore, it is considered that whilst a proportion of the limestone was included in the aggregate, the bulk had been present as unburnt, or overburnt limestone from the Kiln.

The aggregates are sub-angular to sub-round in shape, and all show evidence of water worn surfaces. The shape and texture of the aggregates suggesting a Glaciofluvial source. The aggregates range in size from <0.01mm to 1.7mm (very fine silt/clay to coarse sand) in the section examined. The presence of clay or fine silt materials observed, would infer that aggregate was an as-dug material rather than a washed sand.

Binder

The binder is typical of that in a lime mortar, with a high abundance of lime inclusions observed within the section. None of the inclusions show the presence of any hydraulic components, with some of the incompletely slaked inclusions retaining a faint imprint of a rock fabric, with both a micritic texture and, rarely, the presence of Ooliths and shell fragments.

The paste is fully carbonated and the lime inclusions apparent, include both sub-round and sub-angular inclusions. A low proportion of the inclusions show features consistent with the limestone being either over or under burnt. In addition, a proportion of the inclusions have the appearance of the original quicklime, indicating incomplete slaking at the time of mixing, whilst others have the appearance of fully slaked quicklime, and are typical of putty lime inclusions.

The inclusions range in size from 0.4mm to 2.4mm and it is inferred that the quicklime was added to the sand in the form of a kibbled lime, rather than lump or powdered lime, with the quicklime slaked once mixed with the sand.

A fine fringe of recrystalised calcite along with acicular crystals were observed in a few of the voids, and locally diffused into the paste and within disrupted lime inclusions. These have the appearance of redeposited leached lime, with gypsum crystals locally apparent, the latter as reaction products. The presence of both indicating water percolation through the mortar in the past.

From the examination of this mortar sample it is indicated that the mortar was probably mixed in the form of a Hot Mixed Mortar (HMM), though given the small size of the inclusions and absence of evidence of late slaking in the samples examined, it is possible that it was screened and remixed prior to use, and being placed as a cold mortar.

Voids and microcracks

Voids are present and appear to have formed in response to entrapped air in a stiffening mix. The voids range in size and shape ranging from 0.2mm to 1.8mm, with these typically irregular to elongated in shape, and are most likely placing artefacts.

Cracks are rare and occur as short random shrinkage cracks, with localised features peripheral to, and linking, incompletely slaked quicklime particles. The cracks are fine, ranging in width from <0.03mm to 0.10mm, and are typical of early drying, and plastic shrinkage features.

The results of a point count (modal) analysis are presented in the following table:

Sample Ref:	**SR2674-S1**	
Constituents	**%**	
Aggregate	**Inclusions as binder**	**Inclusions as Aggregate**
Quartz	26.3	26.3
Igneous/metamorphic grains	11.3	11.3
Limestone	0.8	0.7
Sandstone/Siltstone	7.2	7.2
Opaque	3.6	3.6
Lime inclusions	-	11.2
Total Aggregate	**49.2**	**60.4**
Binder (Lime)	39.6	39.6
Clinker	0	0
Lime inclusions	11.2	-
Secondary products/Calcite and gypsum	0	0
Total Binder	**50.8**	**39.6**
Total Constituents	**100.0**	**100.0**
Voids & Cracks	8.6	8.6
Cracks/Voids	**8.6**	**8.6**
	Total	**Effective**
Binder: Aggregate Ratio	**1.0 : 0.97**	**1.0 : 1.5**

Table No. 2: Result of modal analysis (600-point count) on thin section

The effective binder content is calculated on the basis that the inclusions are acting as aggregate rather than as binder and is probably a truer measure of the binder content of the mix, relating to its performance as a mortar. Whereas, the total lime content reflects the mix at the time the mortar was made and placed, including the inclusions (both fully slaked and unslaked) as part of the added lime binder.

Photomicrographs:

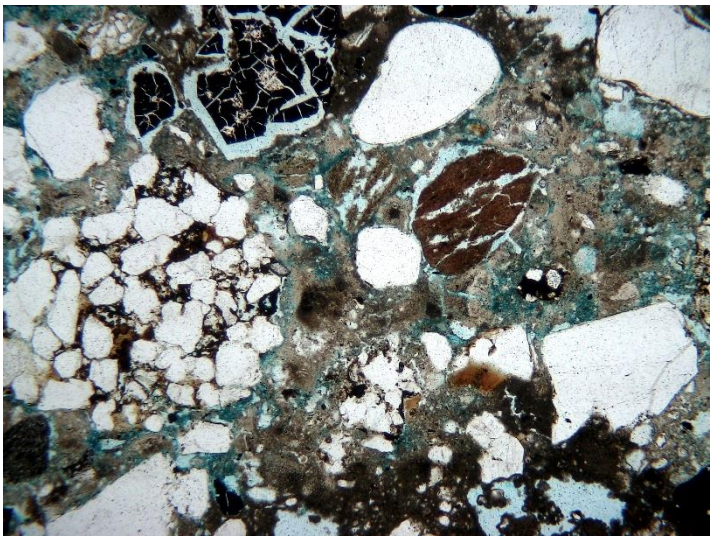

Plate No. 10:

A view in plane polarised light (ppl) showing a typical area of the mortar, with coal fragments displaying shrinkage and cracking apparent, upper left and right of centre.

The paste in view is fully carbonated. The aggregates are dominated by quartz, white in this view, with minor lithic grains and a large sandstone fragments, centre left, with minor igneous grains also apparent

Porosity is highlighted by the blue dyed resin. Field of view 2.4mm.

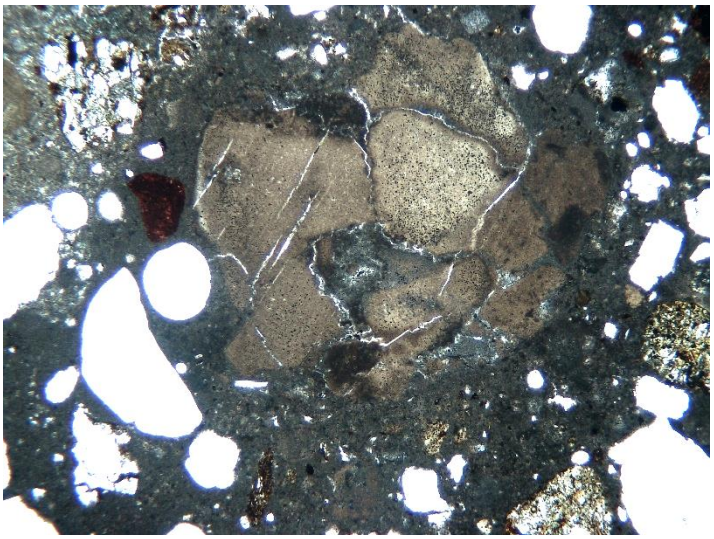

Plate No. 11:

A magnified view of a sub-round lime inclusion in the centre of the plate. This view is again in ppl.

The inclusion is of a partially over burnt limestone fragment, which has been partially slaked, with cracking throughout the fragment, note the patchy diffusion of slaked lime at its outer margin, upper left.

The encapsulating paste is dense and fully carbonated. Aggregates in view are mostly quartz, with minor lithic grains,

Porosity and voids are highlighted by the blue dyed resin. Field of view 1.2mm.

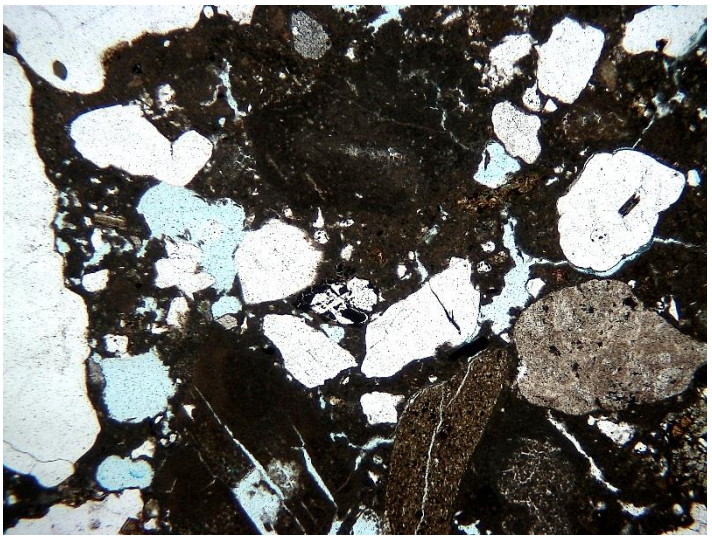

Plate No. 12:

Another view in plane polarised light (ppl), of an area containing an overburnt lime inclusion, upper centre. A limestone aggregate particle, showing a bioclastic fabric, lower right, above a partially burnt and partially slaked lime inclusion. A partially slaked limestone fragment, with linear cracks, can be seen lower left. Aggregates in view consist of quartz, siltstone, shale, igneous fragments, along with ironstone and small coal fragments.

Porosity and voids are highlighted by the blue dyed resin. Field of view 1.2mm.

Sample SR2674-S2 (WM2): Mortar from Chimney Stonework

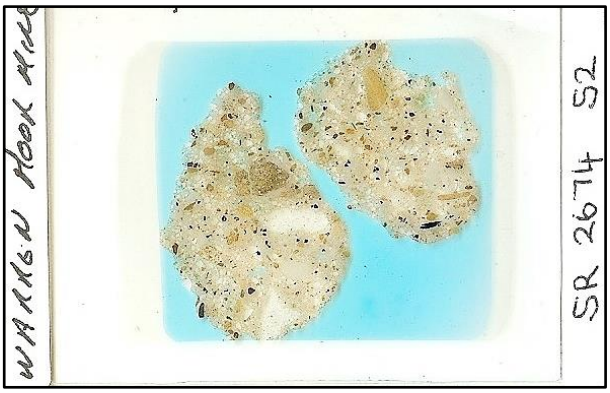

Plate No. 13:

Thin section prepared from the largest two intact pieces of mortar in sample SR2674-S2 (WM2)

Aggregate

The aggregates in this mortar sample are similar to that in sample S1 (WM1), with the aggregates again dominated by quartz grains with chert and lithic fragments, consisting of altered igneous rock types, including microgranite and rocks with a porphyritic texture. Sandstone, siltstone, shale and feldspar, with coal and ironstone also present. However, in this sample there is also a greater proportion of limestone present, again mostly calcareous forms although Dolomitic limestone was also detected (trace proportion only). The opaque particles present, although composed mostly of ironstone and coal were also noted to contain ash components, with possible slags also detected. A low proportion of the coal fragments displayed evidence of having been burnt and, as in sample S1 (WM1) it is considered that most of the coal was included in the aggregate, with a low proportion present with the quicklime as contaminants from the Kiln.

The high opaque content of this mortar may suggest that ash from the kiln was perhaps included in the mortar, along with possibly slag or waste from iron smelting. The addition either intentional or accidental, with ese components included with the aggregates and/or kiln product. However, there was no evidence of any pozzolanic action in the sample examined, with the slag and the ash being encapsulated in carbonated lime paste, with no reaction rims observed.

The aggregates are sub-angular to sub-round in shape, and all show evidence of weathering of the weaker aggregates, with the more resilient particles displaying water worn surfaces. The shape and texture possibly suggesting a Glaciofluvial source.

The aggregates range in size from 0.02mm to 2.8mm (medium silt to very coarse sand) in the section examined. The presence of silt observed is consistent with the aggregate being used as dug, and not processed.

Binder

The binder in this sample is again typical of that in a lime mortar, mixed as an HMM, with a high abundance of lime inclusions observed. Although there was ash and burnt ironstone fragments present in the mortar, there was no evidence of any hydraulic or pozzolanic components in the paste within the section examined.

There is evidence of incompletely slaked inclusions along with fully slaked but incompletely mixed inclusions. Some of the inclusions retain an imprint of a rock fabric, some of which show an Oolitic and bioclastic fabric, whilst others are predominantly micritic.

The paste is fully carbonated, and the lime inclusions include sub-round and sub-angular inclusions, with minor elongated putty lime shaped inclusions, from fully slaked but unmixed lime. A proportion of the inclusions also display over burnt and under burnt features, with the presence of these indicating that the mortar was probably mixed as an HMM. However, in the absence of the features commonly associated with hot placed mortars it is likely that it was slaked and had cooled before placing. The inclusions range in size from 1mm to 8.4 mm and the lime was most likely used in the form of kibbled or lump lime.

Voids and microcracks

Voids were observed, but these are sparse, and are typical of entrapped air voids, as placing artefacts. No small spherical steam generated voids, from slaking lime, were observed in this sample. The voids range in size and shape these ranging from 0.4mm to 0.9mm, with these typically irregular to elongated in shape.

Within some of the voids a fine fringe of acicular crystals was observed. These have the appearance of sulphate minerals, but, in the sample examined, their occurrence is low.

Cracks are rare and occur as localised features that are mostly fine, ranging in width from <0.02mm to 0.05mm, and are typical of plastic and drying shrinkage features.

The results of a point count (modal) analysis are presented in the following table:

Sample Ref:	**SR2674-S2**	
Constituents	**%**	
Aggregate	**Inclusions as binder**	**Inclusions as Aggregate**
Quartz	16.9	16.9
Igneous/metamorphic grains	8.4	8.4
Limestone & Dolomite	4.5	4.5
Sandstone/Siltstone	15.5	15.5
Opaque	2.1	2.1
Lime inclusions	-	9.0
Total Aggregate	**47.4**	**56.4**
Binder (Lime)	43.6	43.6
Clinker	0	0
Lime inclusions	9.0	-
Secondary products/Calcite and gypsum	0	0
Total Binder	**52.6**	**43.6**
Total Constituents	**100.0**	**100.0**
Voids & Cracks	5.0	5.0
Cracks/Voids	**5.0**	**5.0**
	Total	**Effective**
Binder: Aggregate Ratio	**1.0 : 0.9**	**1.0 : 1.3**

Table No. 2: Result of modal analysis (600-point count) on thin section

Photomicrographs:

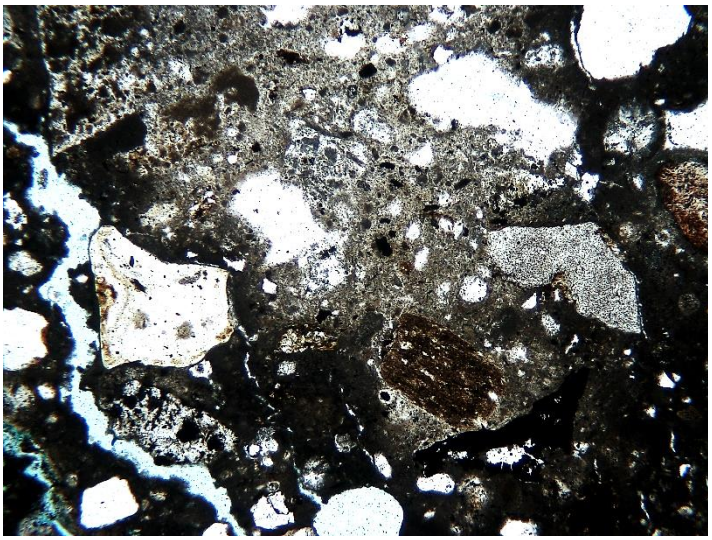

Plate No. 14:

A view in plane polarised light (ppl) showing a typical area of the mortar, with two abutting lime inclusions present. The upper left part is well slaked, and contains small sand grains included within it, whereas the lower right inclusion is poorly calcined and only partially slaked, upper left margin. The aggregates present include quartz, igneous particles, limestone (centre right), coal fragments and a proportion of ash. Note shrinkage crack in left side of plate, crack is free of secondary minerals.

Porosity is highlighted by the blue dyed resin. Field of view 2.4mm.

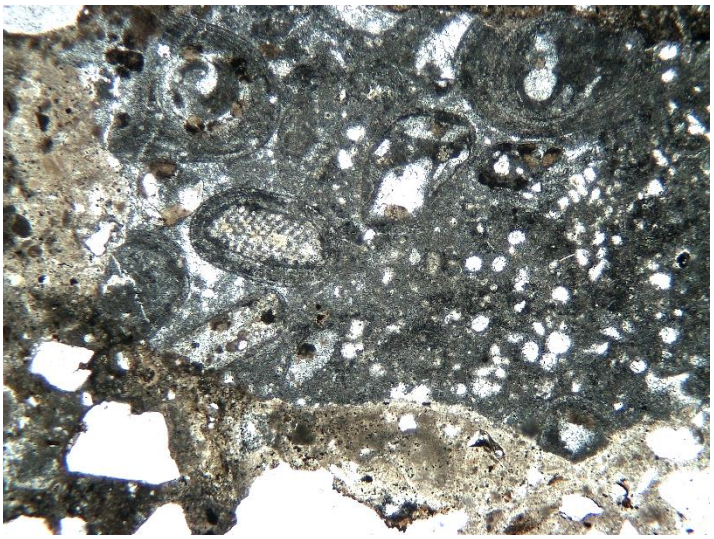

Plate No. 15:

A magnified view of a sub-angular limestone fragment in the centre of the plate. This view is again in ppl.

This is of a limestone fragment, with no evidence of having been calcined. The limestone retains all of its original fabric, i.e. that of a bioclastic limestone, note Oolith in upper right. The particle displays a sharp outer margin. The encapsulating paste is fully carbonated with fine quartz grains and locally, in lower left, some ash grains.

Porosity and voids are highlighted by the blue dyed resin. Field of view 1.2mm.

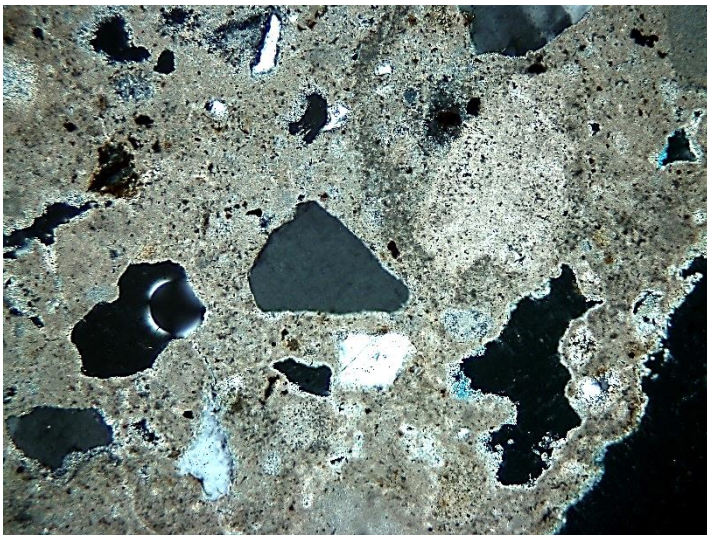

Plate No. 16:

A view in Cross Polarised Light (xpl), of an area containing a fully slaked small angular lime inclusion, upper right of centre. This is well encapsulated within the lime paste but did not diffuse into it. The paste is fully carbonated and the outer surface and void (black in image) are coated with a fine fringe of redeposited calcite and, locally, with sulphate minerals lower left. Aggregates in view are mostly of quartz.

Porosity, the blue impregnating resin and opaque minerals all appear black in xpl. Field of view 1.2mm.

Summary

From the examination and analysis of the mortar sample from Warren Moor Mine Chimney, it is indicated that the mortar was made from a non-hydraulic lime and a natural, as-dug, sand. The sand used in both may be from the same, or a similar, source, with the main difference between the two samples was the presence of ash and a proportion of slag in sample WM2 from the Stone masonry, not present in the mortar sample WM1, from the brickwork masonry. This may suggest a different period of construction, or at least a variation in the materials and or working practices employed in both areas sampled.

The lime is a high calcium lime produced by calcining a local limestone, with both a bioclastic and a micritic limestone varieties used. The fuel in the firing of the kiln appears to have been coal, with a low proportion of the unburnt fuel carried over into the mortars, possibly as a contaminant with the quicklime.

From the examination of the section made from sample WM2, it would also appear that there was a proportion of coal ash and slag incorporated in the mix, however, its low abundance, its poor distribution, present in only one fragment, suggesting a contaminant of the aggregate rather than having been added pozzolan.

Both mortars show characteristics that would infer that the mortars had been mixed as Hot Mixed Mortars, but not necessarily placed as such. With that used in the brickwork placed as a cold mix, perhaps after screening, a common practice of brick masons of the time.

Details of the mix used is summarized below:

Sample Ref.		**SR2674-S1**	**SR2674-S2**
Client Ref.		**WM1 Brickwork**	**WM2 Stonework**
Binder Type		Non -hydraulic, Air lime – Used as Quicklime	
Volume Proportions by Acid Digestion			
Binder: Aggregate Ratio		1.0 : 0.8	
Volume Proportion by modal analysis			
Binder: Aggregate Ratio	(Total)	1.0 : 1.1	1.0 : 1.1
	(Effective)	1.0 : 1.5	1.0 : 1.3

Quality Statement

We confirm that in the preparation of this report we have exercised reasonable skill and care.

The results presented, and comments offered relate only to the samples of mortar received in CMC's laboratory on the 8th January 2019 from Structural & Civil Consultants Ltd., which were identified as mortars from the Chimney at the Warren Moor Mine, North Yorkshire .

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For CMC Ltd.

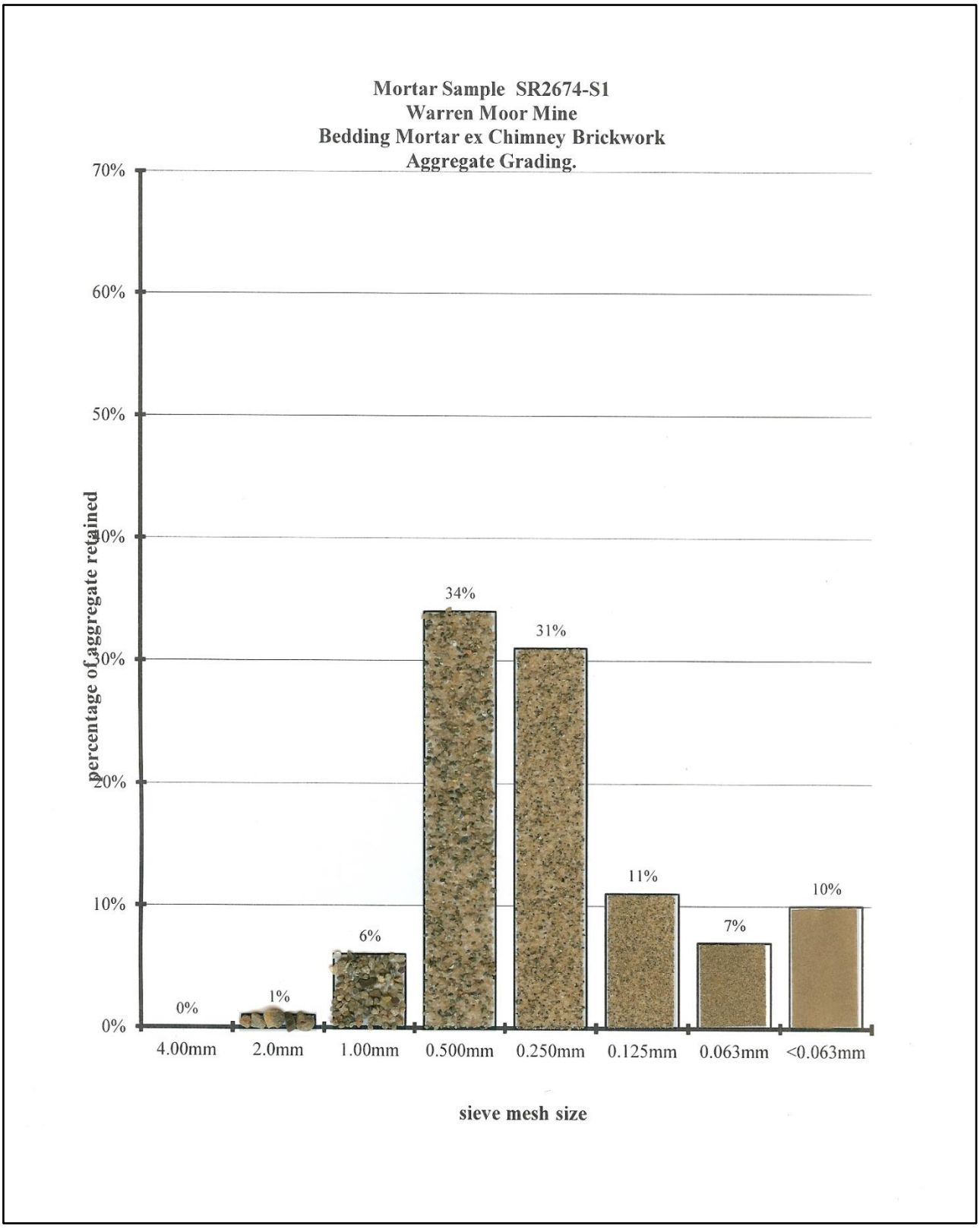

Figure No. 1: Aggregate Grading on Aggregate recovered from sample WM1.

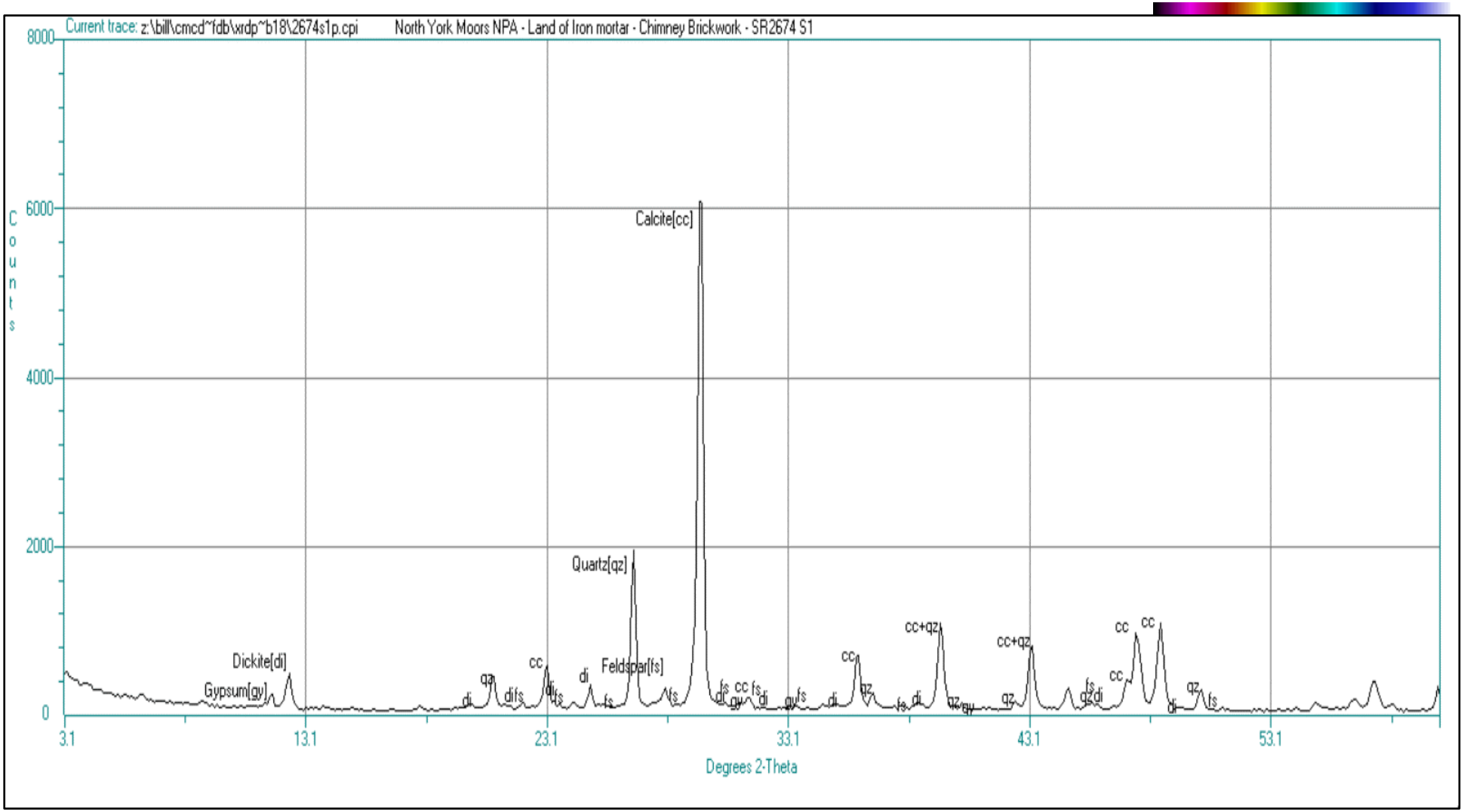

Figure No. 2: SR2674-S1 (WM1) Binder rich fines from mortar ex Chimney Brickwork Masonry.

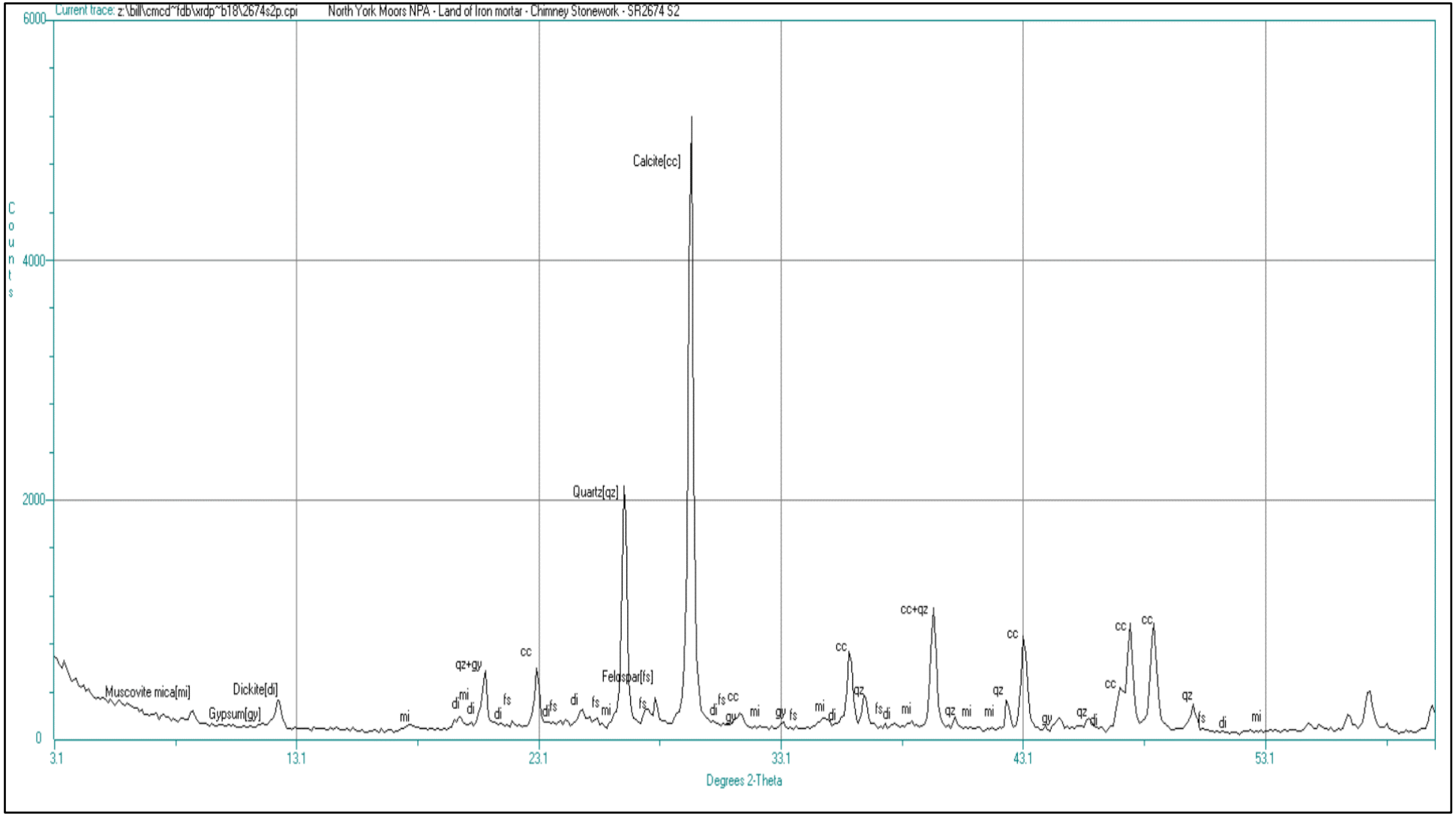

Figure No. 3: SR2674-S2 (WM2) Binder rich fines from mortar ex Chimney Stonework Masonry.