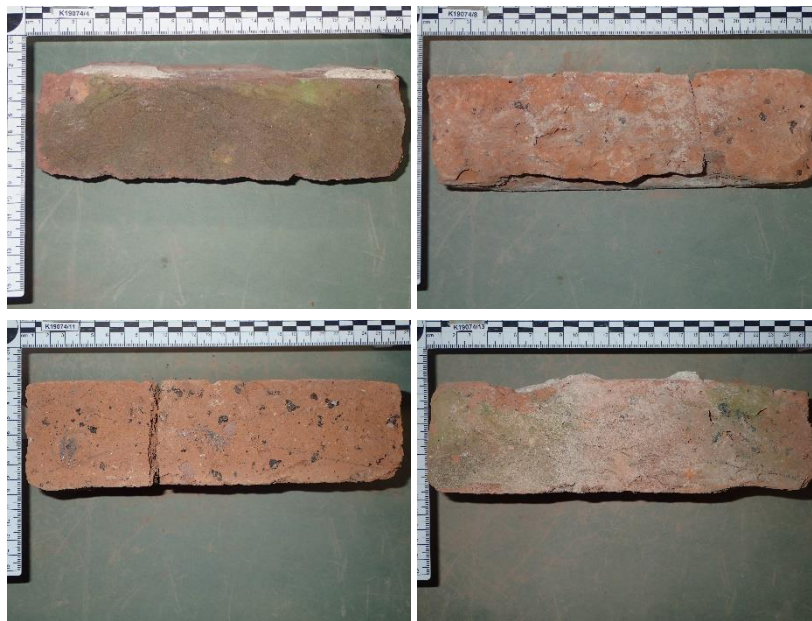




Report - 76948/K

REPORT ON THE PETROGRAPHIC EXAMINATION OF FOUR BRICKS
(Project: (ae1613)71AR 240301 brick testing)



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For the attention of Guy Matheson

26 April 2024

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REPORT ON THE PETROGRAPHIC EXAMINATION OF FOUR BRICKS (Project: (ae1613)71AR 240301 brick testing)

1 INTRODUCTION

Four brick samples were provided as part of a larger batch of samples received on 26 March 2024.

We were advised that the brick samples were sampled from a detached house that had been previously painted and that the paint had subsequently been removed from the brickwork using “aggressive abrasion techniques”. The Client was concerned that the removal of the paint had damaged the surfaces of the brick.

It was requested that four samples be selected from the larger batch of samples for petrographic examination and that one of the selected samples be examined with the scanning electron microscope with particular reference to the surfaces of the bricks and surface deterioration. This report provides the results of petrographic examination and SEM analysis of the samples. The other samples provided were to be tested for water absorption and compressive strength and the results of this testing are given in a separate Sandberg report.

Instructions to proceed with the analysis were provided in an email received from the Client on 19 March 2024.

2 SAMPLES FOR PETROGRAPHIC EXAMINATION AND SEM ANALYSIS

The samples listed in the table below were subjected to petrographic examination. Sample 11 was examined with the SEM.

Laboratory reference	Client / site reference	Approximate sample dimensions
K19074/4	Sample 4, FF+HIS ensuite	215-225/45-60/45-72mm
K19074/8	Sample 8, FF + Guest bedroom 1	230-235/75-98/60-65mm
K19074/11	Sample 11	235-240/103-105/60-65mm
K19074/13	Sample 13, Basement Hallway	230-235/102-105/68-73mm



3 TEST METHODS

The petrographic testing of the brick was carried out using methodology based on BS 1881-211, 2016¹. A summary of the procedures followed and a glossary of terms used in the description of the sample are given in Appendix D. In brief, the following work was carried out.

- (i) The samples were examined as received and photographed.
- (ii) Longitudinal fluorescent resin impregnated thin sections were prepared from each sample to represent cross sections through the originally painted outer surfaces. Each thin section measured about 45x67mm.
- (iii) The thin sections were examined with a Zeiss petrological photomicroscope and the distribution of porosity and microcracking was assessed from an examination of the thin sections in fluorescent light using the petrological microscope.
- (iv) A resin-impregnated polished surface was prepared from Sample 11 using diamond abrasives and polishing pastes to achieve a mirror finish.
- (v) The polished surface was examined using Sandberg's Hitachi SU3500 variable pressure scanning electron microscope and chemical analyses were made of the polished surfaces using an Oxford Instruments energy-dispersive X-ray microanalysis system calibrated with certified mineral standards.

¹ BS 1881-211:2016 Testing concrete. Procedure and terminology for the petrographic examination of hardened concrete

4 PETROGRAPHIC EXAMINATION AND SEM ANALYSIS RESULTS

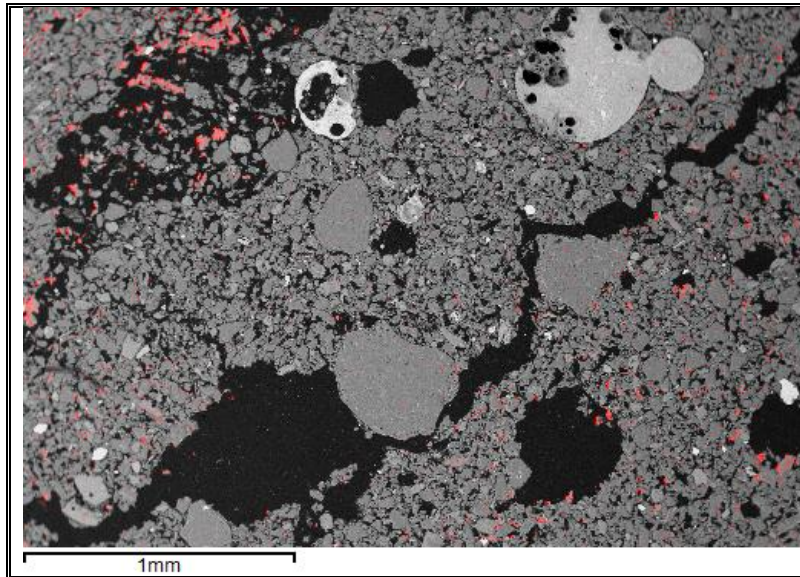
4.1 Petrographic description of the bricks

Petrographic descriptions of the bricks are given in Tables A1 and A2 in Appendix A. The samples as received are illustrated in Appendix B and photomicrographs illustrating the thin sections are given in Appendix C.

4.2 Scanning electron microscopy and X-ray microanalysis (Sample 11)

The results of SEM/EDX analysis of the sample are given in the table below.

	<p>Sample 11:</p> <p><i>Polished surface, backscattered electron image where the scale bar represents 1mm.</i></p> <p>View showing a cross section through the ground surface of the brick along the top of the field of view brick with a furnace bottom ash particle dominating the left side of the field of view. The image has a superimposed X-ray phase map for gypsum shown in red.</p>
	<p>Sample 11:</p> <p><i>Polished surface, backscattered electron image where the scale bar represents 0.2mm.</i></p> <p>View showing an area of the brick close to the outer surface.</p>



Sample 11:

Polished surface, backscattered electron image where the scale bar represents 1mm.

View showing a cross section through a fine crack intersecting the outer surface. The image has a superimposed X-ray phase map for gypsum shown in -red.

5 DISCUSSION

5.1 General characteristics of the bricks

(i) Brick type

All samples are of fired clay bricks with a dark red colour that reflects the presence of iron oxide in the form of hematite. The chemical composition of the brick has a low calcium content that is consistent with the colour of the brick.

(ii) Degree of firing of the brick

There is substantial variation in the degree to which the bricks are fired.

In Sample 4, a high degree of firing is indicated by the glassy nature of the brick matrix and lack of residual sheet silicate structures.

In Samples 8, 11 and 13 a low degree of firing is indicated by the abundance of residual sheet silicates in the matrix and the lack of glass in the matrix.

The variation in the degree of firing of the brick would be expected to result in variation in the compressive strength and water absorption of the brick. The bricks with a higher degree of firing represented by Sample 4 would be expected to have a higher compressive strength and lower water absorption compared to the bricks with lower degree of firing (Samples 8, 11 and 13).

5.2 Surface characteristics of the bricks

(i) Surface appearance

The front face of Sample 4 retains its original surface and the surface of this sample is an uneven moulded surface with fine sand particles exposed on the surface.

The surfaces of Samples 8, 11 and 13 have flat ground surfaces and the original surfaces of these samples have been removed by surface grinding. The removal of the surfaces of the brick has led to an obvious change in the surface appearance of the bricks.

(ii) Surface deterioration

Gypsum crystallization is taking place in the surfaces of Samples 8, 11 and 13. In Sample 11 the gypsum appears to be growing passively within existing void and pore space in the brick without causing damage. In Sample 8 and to a lesser extent in 13 where gypsum crystallization is more extensive gypsum growth in cracks is contributing to superficial surface spalling.

(iii) Effects of the paint removal

The paint removal appears to have been by mechanical means rather than using chemical paint removal compounds. No evidence is seen for chemical residues from paint stripping products in the surfaces of the bricks.

The microscopic analysis of the surfaces of the bricks shows the development of varied degrees of shallow surface microcracking that is of a type that is likely to result from mechanical damage such as might be generated by grinding of the brick surfaces to remove the paint. The surface microcracking would be expected to contribute to a potential for patchy and minor, shallow surface spalling.

Whilst there is currently no evidence for extensive salt crystallization taking place, pre-existing cracks generated by the paint removal would be expected to contribute to the future potential for salt crystallization damage to occur.

The original surfaces of the brick do not appear to have a significant densified surface skin and as such the removal of the original surfaces of the brick is not considered to have had a significant effect on the surface porosity and water absorption characteristics of the bricks.

6 CONCLUSIONS

- 6.1 The original surfaces of the bricks have been removed by surface grinding in order to remove the original painted surfaces of the brick. This process has significantly changed the original surface appearance of the brick.
- 6.2 The surface treatment of the bricks has generated minor and shallow surface-parallel microcracking that would be expected to contribute to a future potential for areas of the brick surfaces to undergo minor surface delamination and to exacerbate the potential for surface damage of the bricks resulting from salt crystallization.
- 6.3 Gypsum crystallization is contributing to shallow surface delamination in Samples 8 and to a lesser extent in Sample 13. A future potential for salt crystallization damage cannot however be ruled out.
- 6.4 Samples 8, 11 and 13 would be expected to be inherently weaker and to have a higher water absorption compared to Sample 4 on account of their low degree of firing.

7 REMARKS

The above concludes the requested programme of testing. Please do not hesitate to contact us if we can be of any further assistance in this matter.

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for GEOMATERIALS RESEARCH SERVICES
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For the attention of Guy Matheson



Reviewed by
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Senior Associate

26 April 2024

Samples can only be retained for a period of two months from the date of issue of the report unless we are instructed otherwise. Samples can be returned or retained for a further charge.
Opinions and interpretations expressed herein are outside the scope of UKAS accreditation.

APPENDIX A – PETROGRAPHIC DESCRIPTION OF THE SAMPLE

PETROGRAPHIC EXAMINATION OF BRICK – BS 1881-211, 2016

TABLE A1 OF 2: PETROGRAPHIC DESCRIPTION OF THE BRICK

Laboratory ref.	K19074/4	K19074/8
Sample ref.	Sample 4	Sample 8
Outer surface	Uneven and slightly rough surface coated with traces of algae	Slightly rough partially broken surface with exposed sand particles
Mortar	Traces of very light yellowish mortar are visible on the sides and horizontal surfaces of the brick that resemble lime mortar or mortar containing lime.	The sample includes separate fragments of mortar that is very light yellow and is probably lime-based.
Visual description of the brick:		
Colour	Medium red	Medium red
Voids	Numerous very fine voids are present, the majority of which <1mm	Numerous very fine voids are present, the majority of which <1mm
Cracking	There is no visible cracking	The surface is partially delaminated and there is a single crack through the full depth of the brick.
Microscopic description of the brick		
Brick type:	Fired clay brick	Fired clay brick
Composition and structure	The brick is fairly homogeneous with no obvious layering or preferred orientation of voids. There are small amounts of furnace bottom ash and burnt shale particles distributed throughout the brick measuring up to about 9mm in nominal maximum size.	The brick is fairly homogeneous with no obvious layering or preferred orientation of voids. There are small amounts of furnace bottom ash and burnt shale particles distributed throughout the brick measuring up to about 14mm in nominal maximum size.
Description of the surfaces of the brick	The surface is intact and unbroken and coated with green algae deposits. No evidence is seen for localised microcracking or alteration at the front face of the brick.	The surface is partially broken around its edges. The intact areas of the surface have exposed quartz particles.
Quartz	Abundant angular silt and fine quartz sand particles are distributed throughout the fired clay matrix and are estimated to account for about 40% by volume of the brick.	Abundant angular silt and fine quartz sand particles are distributed throughout the fired clay matrix and are estimated to account for about 40% by volume of the brick.
Matrix and degree of firing	The brick has a dark red fired clay glassy matrix that contains abundant iron oxides in the form of hematite. No residual sheet silicate structures are visible in the matrix and degree of firing of the brick is high.	The degree of firing is low with sheet silicate structures visible through the matrix including mica and chlorite. The matrix has a low glass content.
Porosity	Very high – occurs as pore space in the matrix and around aggregate surfaces	Very high – occurs as pore space in the matrix and around aggregate surfaces
Microcracking	None seen	Shallow surface-parallel microcracks are seen below about 30% of surface to depths of up to 1.3mm.
Voids and void fillings	The voids are empty. There are few voids but abundant pores measuring <0.005mm.	Traces of calcite and moderate amounts of -gypsum occur in some of the voids close to the surface
Alteration	None seen	Gypsum is developed in surface-parallel cracks close to the outer surface.

APPENDIX A – PETROGRAPHIC DESCRIPTION OF THE SAMPLE

PETROGRAPHIC EXAMINATION OF BRICK – BS 1881-211, 2016

TABLE A2 OF 2: PETROGRAPHIC DESCRIPTION OF THE BRICK

Laboratory ref.	K19074/11	K19074/13
Sample ref.	Sample 11	Sample 13
Outer surface	Ground surface with abraded furnace bottom ash and burnt shale particles exposed in the surface,	Ground surface with abraded furnace bottom ash and burnt shale particles exposed in the surface,
Mortar	Traces of very light yellowish mortar are visible on the sides, back face and horizontal surfaces of the brick that resemble lime mortar or mortar containing lime.	Traces of very light yellowish mortar are visible on the sides, back face and horizontal surfaces of the brick that resemble lime mortar or mortar containing lime.
Visual description of the brick:		
Colour	Medium red to orangish red	Medium red
Voids	Numerous very fine voids are present, the majority of which <1mm	Numerous very fine voids are present, the majority of which <1mm
Cracking	The brick is fragmented at one end. Cracks connect some of the elongate voids.	The front face is damaged along its edges but there is otherwise no obvious cracking
Microscopic description of the brick		
Brick type:	Fired clay brick	Fired clay brick
Composition and structure	The brick is fairly homogeneous with no obvious layering or preferred orientation of voids. There are small amounts of furnace bottom ash and burnt shale particles distributed throughout the brick measuring up to about 12mm in nominal maximum size.	The brick is fairly homogeneous with no obvious layering or preferred orientation of voids. There are small amounts of furnace bottom ash and burnt shale particles distributed throughout the brick measuring up to about 5mm in nominal maximum size.
Description of the surfaces of the brick	The front surface has been ground with exposed abraded quartz, burnt shale and furnace bottom ash particles that lie flush with the surface. No microcracking is seen below the abraded surface. The back face of the mortar is unground and there is a patchy slightly less porous zone along the back face of the brick that is not seen along the front ground face of the brick.	The front surface has been ground with exposed abraded quartz, burnt shale and furnace bottom ash particles that lie flush with the surface. The pores and voids along the front face contain abundant gypsum and one area of the surface has partially debonded along gypsum-filled elongate surface-parallel voids.
Quartz	Abundant angular silt and fine quartz sand particles are distributed throughout the fired clay matrix and are estimated to account for about 40% by volume of the brick.	Abundant angular silt and fine quartz sand particles are distributed throughout the fired clay matrix and are estimated to account for about 40% by volume of the brick.
Matrix and degree of firing	The degree of firing is low with sheet silicate structures visible through the matrix including mica and chlorite. The matrix has a low glass content.	The degree of firing is low with sheet silicate structures visible through the matrix including mica and chlorite. The matrix has a low glass content.
Porosity	Very high – occurs as pore space in the matrix and around aggregate surfaces.	Very high – occurs as pore space in the matrix and around aggregate surfaces. The microporosity is reduced along the front face due to infillings of gypsum in the pore space and voids.--
Microcracking	Rare cracks connect elongate voids	No microcracks are seen and cracks are very rarely seen in the thin section.
Voids and void fillings	The voids are empty. There are small quantities of irregular, sometimes elongate voids. The matrix has abundant pores measuring <0.005mm.	Locally abundant gypsum occurs in voids along the front face of the brick.
Alteration	None seen	Extensive salt crystallization is seen along the ground front face of the brick. Traces of gypsum occur within a shallow surface-parallel crack.

APPENDIX B – PHOTOGRAPHS ILLUSTRATING THE SAMPLES AS RECEIVED

Figure B1

Sample 4



Sample 4: Front face



Sample 4: Back face

Figure B2

Sample 8



Sample 8: Ground front face



Sample 8: Back face

Figure B3

Sample 11



Sample 11: Ground front face



Sample 11: Back face

Figure B4

Sample 13



Sample 13: Ground front face



Sample 13: Back face

APPENDIX C – PHOTOMICROGRAPHS ILLUSTRATING THE THIN SECTIONS

Figure C1

Sample 4

Thin section, crossed polars: View showing a cross section through the outer surface. The surface runs from A1 to A6 and has patchy lichen growths visible for example in B4. The majority of the field of view is occupied by a fired clay matrix that surrounds quartz particles that are visible for example in E4 and G/H3.

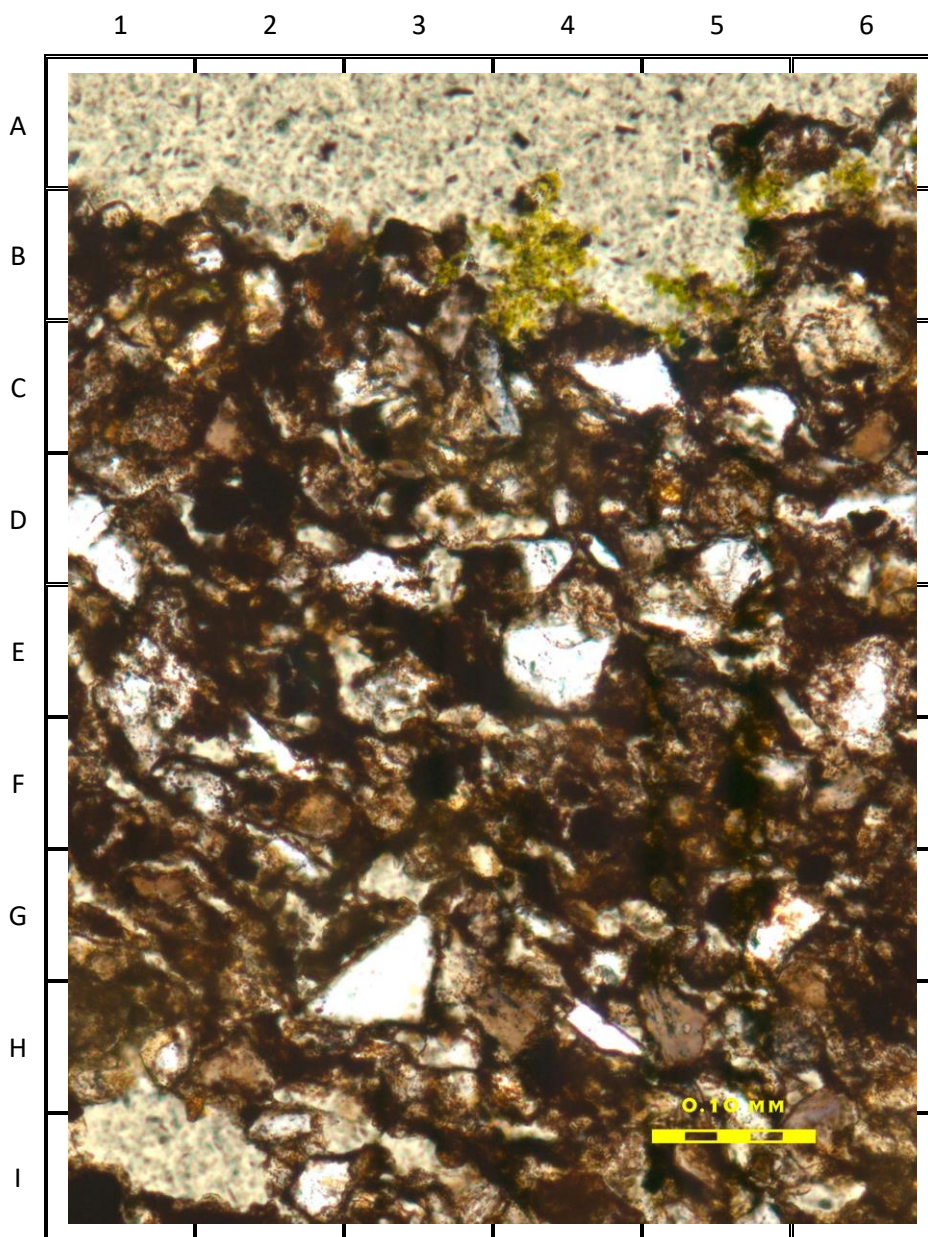


Figure C2

Sample 4

Thin section, oblique polars: Glassy red fired clay matrix dominates the field of view and can be seen for example in A4 and G3. Quartz particles can be seen in C4 and E/F3.

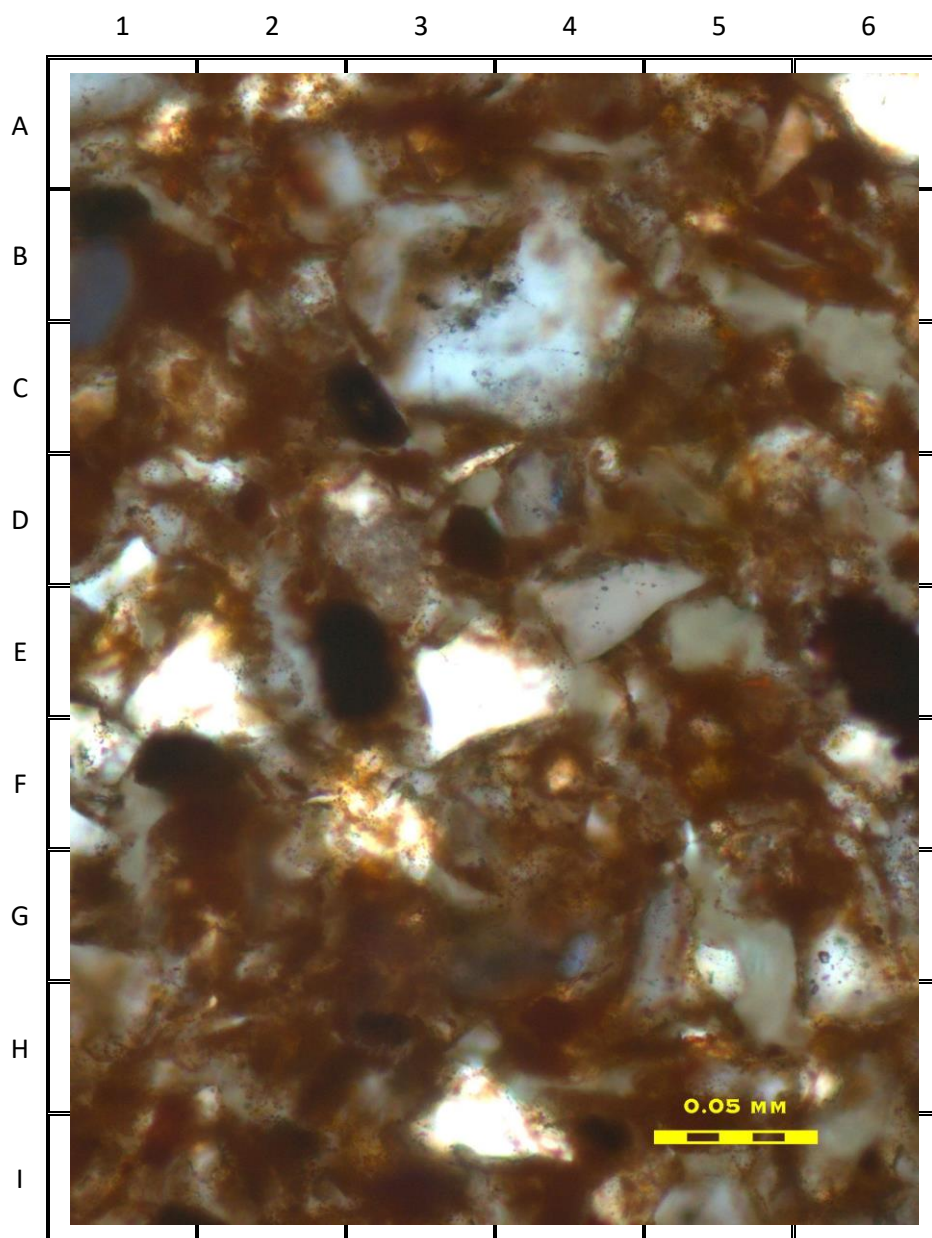


Figure C3

Sample 8

Thin section, oblique polars: View showing an area of the brick close to the ground outer surface. A gypsum-filled is highlighted by yellow arrows. Fired clay matrix with abundant clearly visible mica flakes can be seen for example in C3/4 and G2. Quartz particles are visible for example in H3/4.

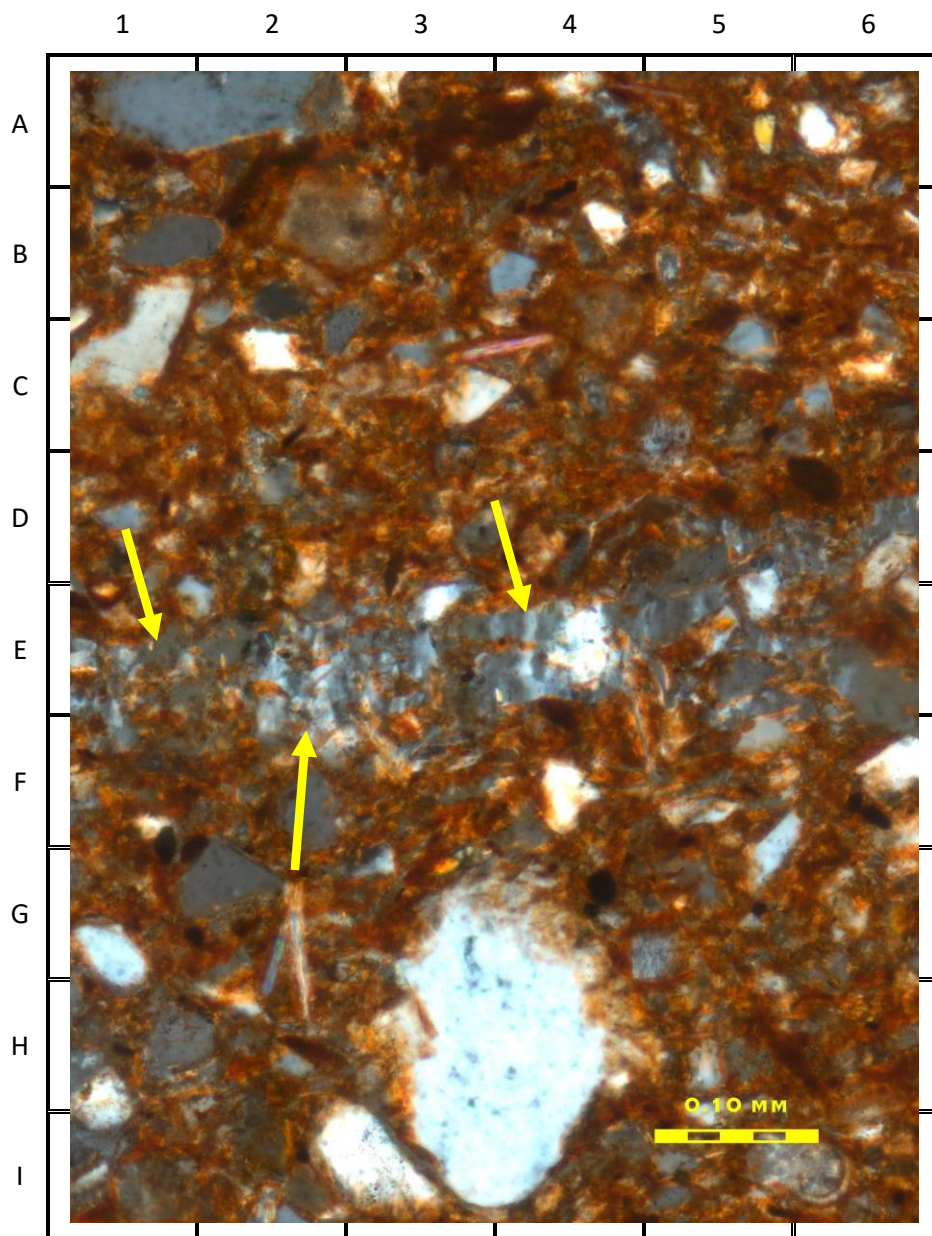


Figure C4

Sample 8

Thin section, oblique polars: View showing the typical appearance of the brick matrix at depth. The matrix contains numerous flaky mica crystals visible for example in F3 and F/G6. Quartz particles can be seen in D2 and G4.

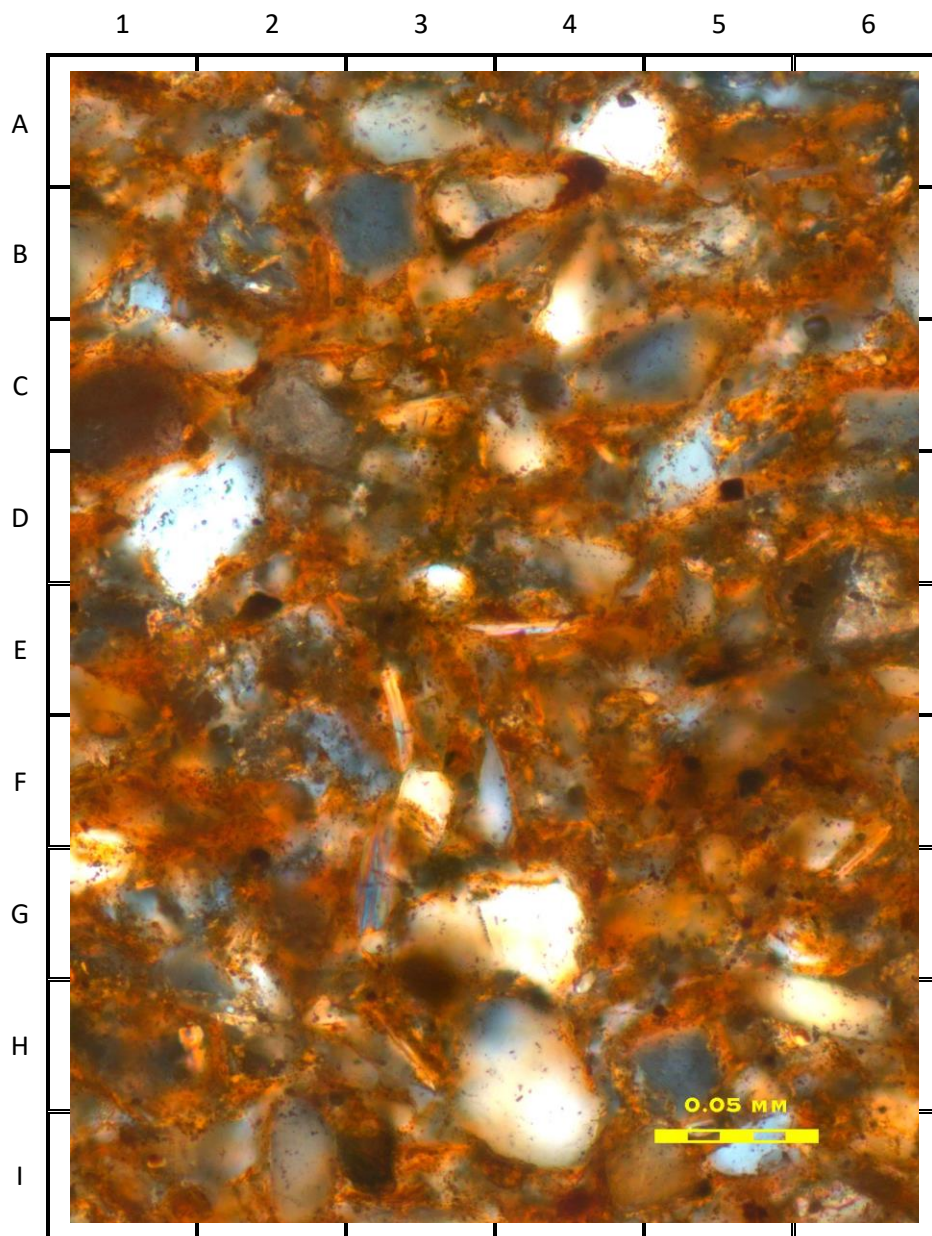


Figure C5

Sample 11

Thin section, oblique polars: The ground -outer surface runs along the top of the field of view from A1 to A6. The field of view is dominated by fired clay matrix and quartz particles appearing various shades from grey to white. Traces of gypsum are present in some of the abundant voids.

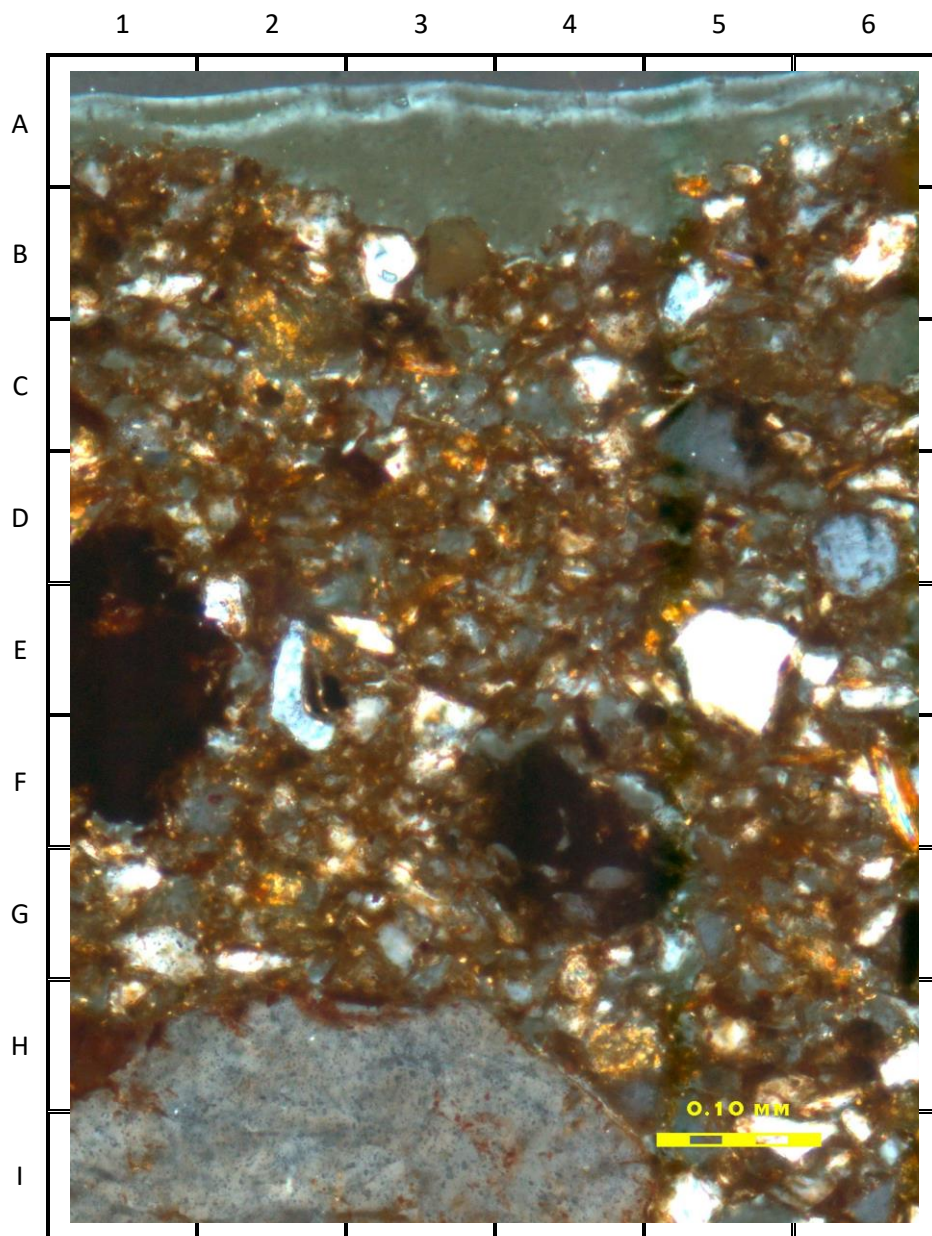


Figure C6

Sample 11

Thin section, oblique polars: View showing the typical appearance of the brick matrix at depth. The matrix contains numerous flaky mica crystals visible for example in C3 and G4/5. Quartz particles can be seen in A1 and G2.

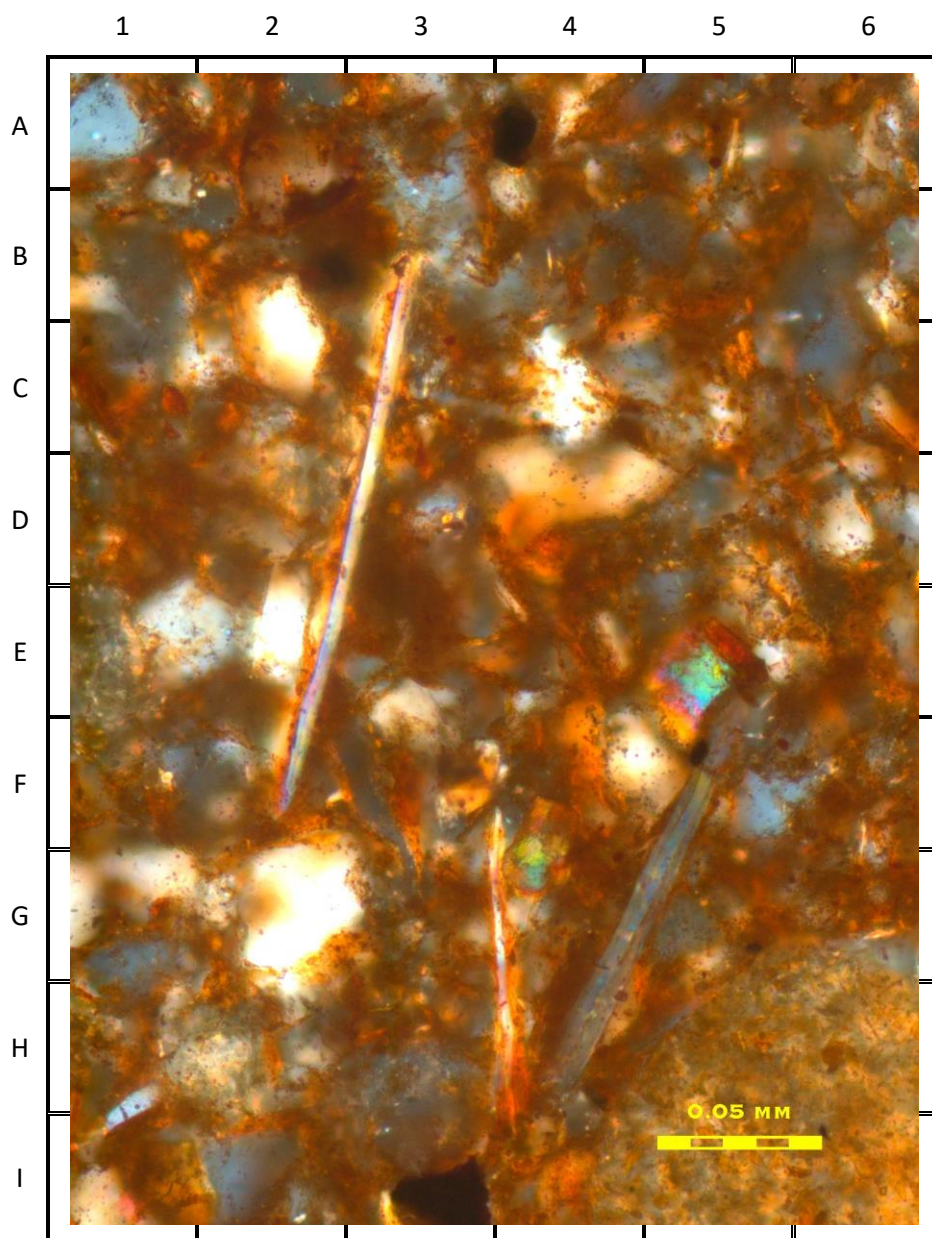


Figure C7

Sample 13

Thin section, oblique polars: View showing an area of the brick close to the outer surface. Minor amounts of gypsum occur in crack that is highlighted by yellow arrows. Quartz particles can be seen for example in D6 and B1/2. Fired clay matrix can be seen in H1 and A1.

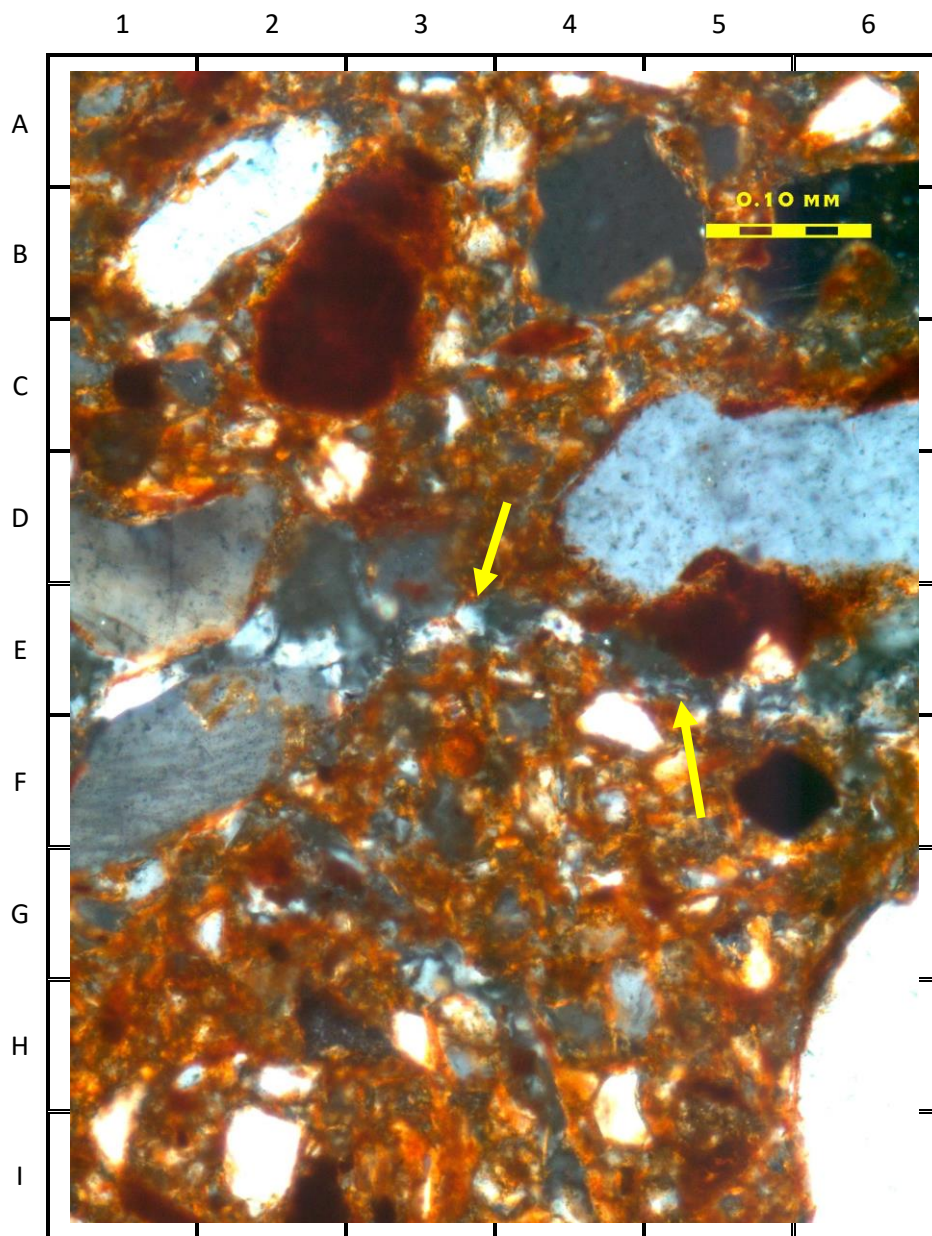
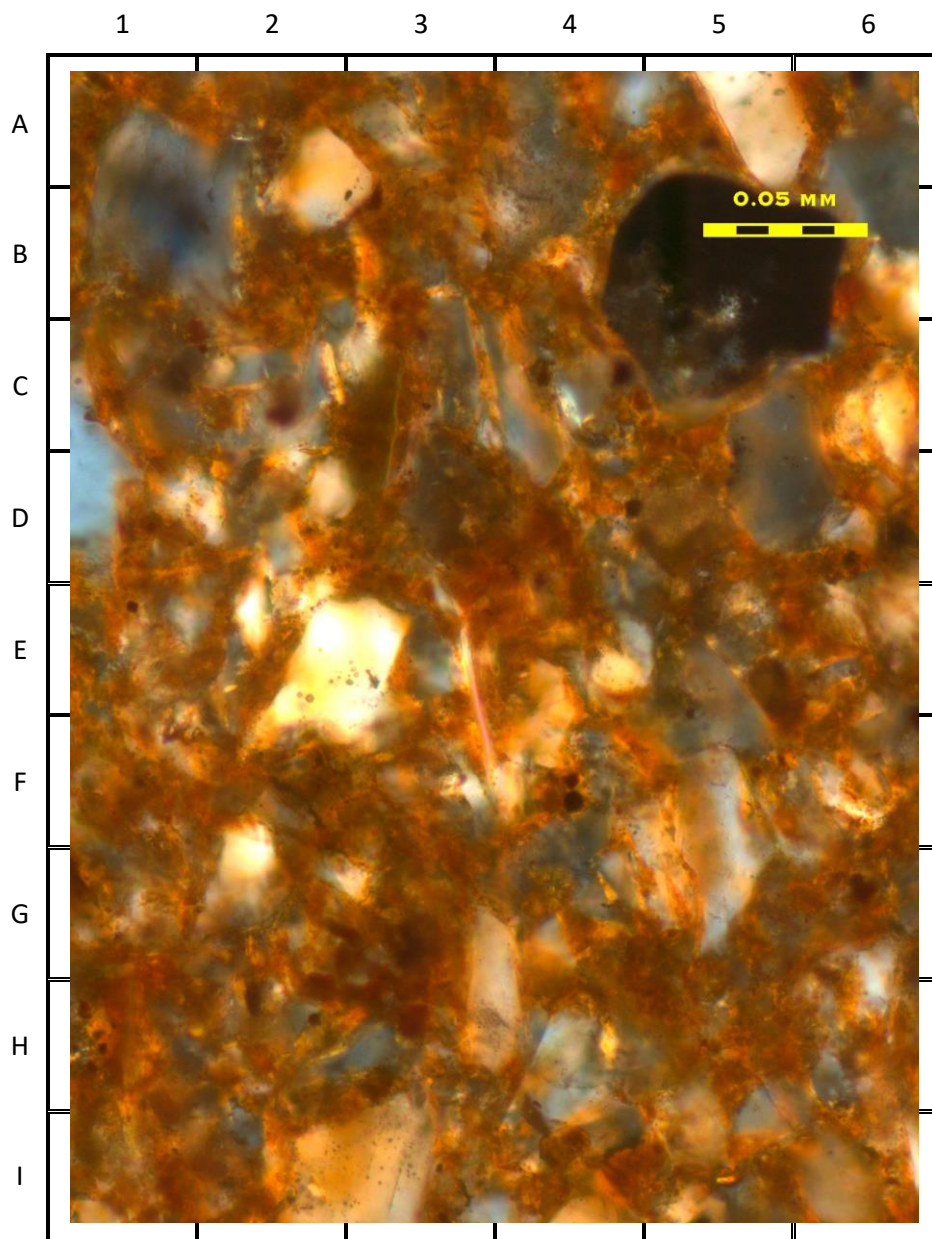


Figure C8

Sample 13

Thin section, oblique polars: View showing the typical appearance of the brick matrix at depth. The matrix contains numerous flaky mica crystals visible for example in C3/4 and F3. Quartz particles can be seen in E2/3 and B1.



APPENDIX D – PETROGRAPHIC PROCEDURES AND GLOSSARY**1. Preliminary examination:**

The samples are examined with the binocular microscope as received and their dimensions and main features are recorded. The features observed include the following.

- (a) The presence and position of reinforcement.
- (b) The extent to which reinforcement is corroded.
- (c) The nature of the external surfaces of the concrete.
- (d) The features and distribution of macro and fine cracks.
- (e) The distribution and size range and type of the aggregate.
- (f) The type and condition of the cement paste.
- (g) Any superficial evidence of deleterious processes affecting the concrete.

2. Polished surfaces:

A plate is cut, where possible, from each sample. This is typically about 20 mm thick and usually provides as large a section of the sample as is possible and typically has a polished surface area of >100cm². The plate is polished to give a high quality surface that can be examined with a high quality binocular microscope or even with the petrological microscope if necessary. The polished plate is used to assess the following.

- (a) The size, shape and distribution of coarse and fine aggregate.
- (b) The coherence, colour, and porosity of the cement paste.
- (c) The distribution, size, shape, and content of voids.
- (d) The composition of the concrete in terms of the volume proportions of coarse aggregate, fine aggregate, paste and void.
- (e) The distribution of fine cracks and microcracks. Often the surface is stained with a penetrative dye, so that these cracks can be seen. Microcrack frequency is measured along lines of traverse across the surface.
- (f) The relative abundance of rock types in the coarse aggregate is assessed.

3. Thin sections:

A thin section is prepared for each sample as appropriate. The section is usually made from a plate cut at right angles to the external surface of the concrete, so that the outer 70 mm or so of the concrete are included in the section. Sometimes it is more appropriate to make the section from inner parts of the concrete. This might be appropriate where specific problems are being investigated for example. The section normally measures about 50 x 70 mm.

In manufacturing the thin section a plate some 10 mm thick is cut from the sample. This is impregnated with a penetrative resin containing a yellow fluorescent dye. The resin penetrates into cracks, microcracks, and capillary pores in the sample. One side of the impregnated plate is then polished and the plate is mounted on to a glass slide. The surplus sample is then removed and the plate is ground and polished to give a final thickness of between 20 and 30 micrometres. At all stages the cutting and grinding is carried out using an oil based coolant in order to prevent further hydration of the cement and excessive heating of the section. The thin section is covered and then examined with a high quality Zeiss petrological photomicroscope.

The thin section supplies the following types of information:

- (a) Details of the rock types present in the coarse and fine aggregate and in particular structures seen within those rocks.
- (b) Details of the aggregate properties are measured such as the degree of strain in quartz.
- (c) The size, distribution and abundance of phases in the cement paste are assessed including, for example, the occurrence of calcium hydroxide and the amount of residual unhydrated clinker.
- (d) The presence of cement replacement phases such as slag or PFA can usually be recognised (though the amount of these phases cannot be judged accurately). The presence of high alumina cement can be detected and the type of cement clinker can often be assessed.
- (e) Any products of processes of deterioration of either the cement paste or the aggregate can be recognised.

4. Broken surfaces:

After the specially prepared surfaces and sections are completed, the remainder of the core is examined with the binocular microscope. In particular, the pieces are broken to produce fresh surfaces. These surfaces allow the contents of voids to be studied and the nature of aggregate surfaces or crack surfaces to be investigated.

5. Composition:

Where the size of the sample is appropriate the composition of the sample can be measured using either the polished slice or the thin section, depending on the size of the sample and on details of the aggregate type and paste. The thin section is preferable, for example where large quantities of dust are present. The volume proportions are found by the method of point counting using a mechanical stage. The amount of coarse aggregate can also be assessed by this method if a distinction can be made between coarse and fine aggregate. The results obtained usually represent the sample reasonably, but may not represent the concrete.

6. Water/cement ratio:

The hydration processes of cement paste vary significantly with the original water/cement ratio. Concretes with a low water/cement ratio tend to leave substantial quantities of unhydrated cement clinker and to develop only limited amounts of coarsely crystalline calcium hydroxide. In particular, the extent to which calcium hydroxide is separated into layers on aggregate surfaces and occurs in voids and on void surfaces varies with the original water/cement ratio. The number and proportion of unhydrated cement clinker particles varies inversely with the original water/cement ratio. Comparison with standard concretes made with known water/cement ratios visually, and by measurement allows the water/cement ratio of the cement paste to be assessed directly. The standard error attached to the estimation of water/cement ratio by this means is considered to be approximately +/- 0.1 for unaltered concrete of similar type that in the Sandberg Reference Concrete Collection. It should be noted that aggregate dust, the presence of admixtures and additives all contribute to uncertainty in the petrographic measurement of the water/cement ratio of the concrete.

8. Glossary:

The following is a short list of technical terms in common use in the petrographic examination of concrete².

Alkali-aggregate reaction (AAR): This is a broad term encompassing both alkali carbonate reaction (ACR) and alkali silicate reaction and alkali-silica reaction (ASR). It refers to reactions between alkalis in usually derived from the cement in the cement paste and aggregate particles. Some forms of alkali-aggregate reaction such as ASR result in the formation of an alkali-silicate gel that is readily detectable in thin sections. Other forms of alkali-carbonate reaction such as ACR may not result gel formation.

Alkali carbonate reaction (ACR): This form of reaction is very rare in the UK and there is some debate over the precise mechanism of this reaction. Most documented cases of ACR involve argillaceous, dolomitic limestone. The reaction which is expansive is rarely associated with the formation of obvious gel deposits.

Alkali-silicate/silica reaction (ASR): This is by far the most common form of AAR and generally results from reactions between either microcrystalline, cryptocrystalline, or substantially strained quartz and associated microcrystalline quartz at grain margins and alkalis in cement paste. On rare occasions, ASR may result from the presence of highly reactive opaline silica in aggregate. Petrographic examination is the definitive method for the detection of this form of concrete deterioration. The reaction commonly results in the development of cracking that originates within reactive aggregate particles and continues into the surrounding paste and gel deposits are commonly associated with the occurrence of ASR.

Calcium aluminate cement (CAC): This is a general term that encompasses high alumina cement (HAC) as well as some of the more modern aluminate cements used in rapid setting concrete repair materials or some types of sprayed concretes and grouts.

Carbonation: Carbonation most commonly results from the exposure of concrete to atmospheric carbon dioxide and results in the conversion of portlandite to calcium carbonate and also affects some of the cement hydrate phases forming complex calcium silicate hydrate carbonate compounds. In damp conditions or in concrete exposed to moisture containing dissolved carbon dioxide, coarse-textured carbonation may develop and coarse crystals of calcium carbonate may develop within the cement paste. "Popcorn" calcite deposition (PCD) is one form of this type of carbonation.

Cracking: Cracks are classified using the following terms:

- **Macroscopic cracks:** These cracks are visible in the hand specimen or with the aid of a stereo binocular microscope and are typically >0.01mm wide.
- **Macrocrack:** These are cracks that are readily visible to the naked eye without the aid of a stereo binocular microscope and are typically >0.1mm wide.
- **Fine crack:** These are cracks that are only readily visible with a stereo binocular microscope or in thin section. Cracks of this type are typically between 0.01 and 0.10mm wide.
- **Microcracking:** These cracks cannot be detected with a stereo binocular microscope. They are typically <0.01mm wide and are most easily seen in petrographic thin sections containing fluorescent dye and by using fluorescent illumination.

Delayed ettringite formation (DEF): This term describes deleterious ettringite formation in concrete that has been cured at elevated temperatures, typically >65°C. Ettringite formation resulting from this process can be readily detected using thin sections and the ettringite tends to form in peripheral cracks around aggregate surfaces and sometimes within microcracks in the paste.

² Applied Petrography Group. A code of practice for the petrographic examination of concrete (Author M A Eden), SR2, The Geological Society of London, London, 2010 (Available for download from <http://www.appliedpetrographygroup.com>).

Drying shrinkage cracking: Drying shrinkage microcracks tend to develop radially around the surfaces of fine aggregate particles in concrete. Fine cracks and macrocracks caused by drying shrinkage tend to be parallel-sided cracks and orientated perpendicular to concrete surfaces.

Ettringite: This is a very common calcium-alumino-sulphate mineral. It occurs in most concretes where moisture ingress has occurred. Ettringite formation may be deleterious in the case of DEF or sulphate attack where it can give rise to a deleterious expansion and distinctive forms of cracking but in most cases secondary ettringite formation is non-deleterious.

Fly ash (also known as PFA / pulverised fly ash): This material is a by-product of coal burning power stations and can be readily recognised in thin sections, where it is visible as spherical glass particles, some of which may be hollow. Hollow PFA particles may be referred to as cenospheres. PFA is also commonly associated with small quantities of graphite particles that appear black in thin section.

Fine crack: See section on cracking.

GGBS: Ground, granulated blast furnace slag. This material is commonly employed as a cement replacement material in concrete and can be easily recognised in thin section. The GGBS particles are typically angular and are composed almost entirely of glass.

High alumina cement (HAC): This is a form of cement manufactured from the fusion of limestone and bauxite. It is readily distinguishable in thin section from most other types of cement. Petrographic examination is the definitive method for the detection of carbonation in concrete containing HAC.

Macrocrack: See section on cracking.

Macroscopic: This is a general term referring to features that are visible to the naked eye or with the aid of a stereo microscope.

Microcrack: See section on cracking.

Microsilica: Well dispersed microsilica cannot be directly observed in thin sections. However, distinctive clots of undispersed microsilica are commonly present in concrete containing microsilica – even where most of the microsilica is well dispersed. Microsilica clots are isotropic, and tend to be spherical and are sometimes concentrically layered. They are typically <100µm in diameter.

PFA: See section on fly ash

Plastic shrinkage cracking: This form of cracking occurs in concrete prior to its hardening. It can be distinguished from many other forms of cracking in that it results in cracks that are generally restricted to the cement paste and are non-parallel sided. Cracks of this type typically appear on the concrete surface and commonly diminish in width rapidly with depth and the paste surrounding cracks of this type is commonly of locally high porosity reflecting the migration of moisture towards the cracks during the drying out of the concrete surfaces.

Porosity: This term is distinct from void content. It refers to microscopic pores within cement hydrates. Porosity is directly related to water/cement ratio, but is also strongly influenced by curing and many forms of concrete deterioration. Porosity is sometimes used as an indicator of water/cement ratio in hardened concrete.

Portland cement: Portland cement is the most common form of binder used in concrete and is manufactured from the burning of limestone and an alumino-silicate rock (clay or shale) at temperatures of up to 1500°C. There are many forms of Portland cement and it is commonly possible to distinguish sulphate-resisting and white Portland cement and ordinary Portland cement using petrographic thin sections.



Portlandite: Portlandite is calcium hydroxide and is one of the products formed during cement hydration. Portlandite is readily recognisable in thin sections and has a distinctively high birefringence that contrasts with the much lower birefringence of the hydrated cement phases.

Sulphate attack: This is a general term encompassing both conventional sulphate attack resulting in gypsum and ettringite formation, but also includes sulphate attack associated with thaumasite formation. Sulphate attack can be readily recognised in thin sections and commonly results in the development of surface-parallel cracks infilled with ettringite or thaumasite.

Thaumasite: This is a carbonate-sulphate calcium hydrate mineral with a complex composition. It is a common reaction product in concrete exposed to moisture containing both carbonate and sulphate ions. Thaumasite is most commonly encountered in concrete exposed to temperatures of $<4^{\circ}\text{C}$. Some forms of thaumasite can be readily distinguished from ettringite and have a high birefringence. However, some forms of thaumasite have a much lower birefringence and can be difficult to distinguish from ettringite without recourse to SEM micro-analysis.

Void: This describes empty spaces present in concrete that are typically greater than about 5 micrometres in diameter. It encompasses both entrained air voids (spherical voids typically $<1\text{mm}$ in diameter) as well as much larger entrapped air voids. It should be noted that it is possible for concrete to have a low porosity, but a high void content.



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