# HIGHGATE CEMETERY:
# CHAPELS & ENTRANCE BUILDING, SOUTH LODGE

## RIBA STAGE 3 SCHEDULE OF WORKS APPENDIX 3

## MATERIALS ANALYSIS

WEST SCOTT ARCHITECTS
Issue P2: Draft final: October 2024

## 1. MORTAR ANALYSIS

Carried out by Peter Ellis FSA

**HIGHGATE CEMETERY**

**SCHEDULE OF SAMPLING AND INVESTIGATIONS**
MORTAR AND RENDER ONLY

| **Building** | **Sample No** | **Sample location** | **Sample details** | **Sample date** | **Analysis** | **Results** |
|---|---|---|---|---|---|---|
| **Chapel** | | | | | | |
| | 1/M1 | | Brickwork bedding mortar | Not yet available | | |
| | 1/M2 | | Stone bedding mortar | Not yet available | | |
| | | | | | | |
| **Cuttings catacombs** | | | | | | |
| | 5/M1 | Gap at Vault 8 | Brick pointing mortar | 27/03/2024 | | |
| | 5/M2 | Gap at Vault 8 | Brick bedding mortar | Not yet available | | |
| | 5/M3 | Vault 13 façade | Render, 2 coats, possibly modern | 27/03/2024 | | |
| | 5/M4 | Vault 11 (Baxter) | Render historic | 27/03/2024 | | |
| | | | | | | |
| **Egyptian Avenue** | | | | | | |
| | 6/M1 | Avenue lower façade | Render | Not yet available | | |
| | 6/M2 | RH obelisk | Render (Roman cement?) 3 samples | 27/03/2024 | | |
| | 6/M3 | LH obelisk | Render (Roman cement?) 1 sample | 27/03/2024 | | |
| | | | | | | |
| **Circle of Lebanon** | | | | | | |
| | 7/M1 | Inner circle façade | Brickwork bedding mortar | Not yet available | | |
| | 7/M2 | Inner circle façade | Historic render previously reattached with s-steel pin | 23/03/2024 | | |
| | 7/M3 | Outer circle East steps plinth | Render 1 sample | 27/03/2024 | | |
| | | | | | | |
| **Terrace catacombs** | | | | | | |
| | 8/M1 | East wing façade | Yellow render base coat | 27/03/2024 | | |
| | 8/M2 | East wing façade | Yellow render top coat | 27/03/2024 | | |
| | 8/M3 | East wing façade | Grey render base coat | 27/03/2024 | | |
| | 8/M4 | East wing façade | Grey render top coat | 27/03/2024 | | |
| | 8/M5 | West wing transept | Internal render from door jamb | 27/03/2024 | | |
| | 8/M6 | West wing transept | Internal plaster wall and vaulted ceiling | 27/03/2024 | | |
| | 8/M7 | East wing ramp retaining wall | Render backing coat | 22/04/2024 | | |
| | 8/M8 | East wing ramp retaining wall | Render finish coat | 22/04/2024 | | |
| | | | | | | |
| **Mausolea** | | | | | | |
| **Beer** | | | | | | |
| | 9b/M1 | Lower level entrance court | Brickwork pointing mortar | 27/03/2024 | | |
| | 9b/M2 | Lower level entrance court | Gateway render | 27/03/2024 | | |
| | 9b/G1 | Upper level interior | Pate de verre tile fragments | 27/03/2024 | | |
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| | | | | | | |

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June 17, 2024.

**Highgate Cemetery, London N6.**
**Mortar Analysis. Results Summary - 5809/HC/01-06.**

The results of my analysis of the six samples are as follows.

**Sample 5/M4 (5809/HC/01)**. This render sample from Vault 11 (Baxter) in the Cuttings catacombs comprises a thin pale grey finish coat applied to a yellow-brown backing coat. The finish coat has not been tested but it is almost certainly Portland cement mixed with fine sand probably at circa 1: 3. The backing coat has not fully carbonated and is Portland cement and washed yellow-brown quartz sand at circa 1 : 4 to 5. I understand this vault may date from circa 1850 and whilst it is possible that this render dates from then, I think it more likely to be later. Portland cement was not in common use in London until the 1860s and the lack of full carbonation and the washed sand may suggest a late 19th or early 20th century material.

**Sample 6/M2 (5809/HC/02)**. This render sample from the RH Obelisk in Egyptian Avenue is a Roman cement binder and fine quartz sand at circa 1: 2. Roman cement was patented in 1796 and produced by calcining natural concretions known as septaria. It was a fast-setting material used primarily for external renders and run mouldings. It was gradually superseded by early Portland cements in the 2nd half of the 19th century. This is likely to be the original 1839 material.

**Sample 6/M3 (5809/HC/03)**. This render sample from the LH Obelisk in Egyptian Avenue is also a Roman cement binder and fine quartz sand at circa 1: 2. It is similar to Sample 6/M2 and likely to be the original 1839 material.

**Sample 7/M2 (5809/HC/04)**. This render sample from the inner circle façade of the Circle of Lebanon is also a Roman cement binder and fine quartz sand at circa 1: 2. It is similar to Samples 6/M2 and 6/M3 and likely to be the original 1839 material.

**Sample 8/M7 (5809/HC/05)**. This backing coat render from the east wing ramp retaining wall to the Terrace catacombs is Portland cement mixed with a medium quartz and flint sand at circa 1: 3 to 4. Portland cement was not manufactured until the mid-1840s and not in common use in London until the 1860s and this material cannot date from 1839.

**Sample 8/M8 (5809/HC/06)**. This finish coat render from the east wing ramp retaining wall to the Terrace catacombs is Portland cement mixed with fine quartz sand at circa 1: 3 and as with Sample 8/M7 cannot date from 1839.

Please do come back to me if you would like to discuss my findings.

Peter R. Ellis.

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# Mortar Analysis

# Test Report No. 5809/HC/01.

## Highgate Cemetery, London N6.

## Cuttings Catacombs. Sample 5/M4.

A sample (39.5g) of external backing coat render collected from Vault 11 (Baxter) in the Cuttings catacombs has been analysed chemically and microscopically.

**Sample Assessment and Microscopic Observations.**

Thin (2mm-3mm) hard pale grey finish coat removed prior to analysis. Intact yellow-brown render fragments c.12mm thick. High strength (sample could not be broken by hand nor crumbled in fingers; disrupted using pestle with difficulty). Aggregate is principally yellow quartz with occasional particles of other geological types. Calcareous aggregate not positively determined. Kiln-fuel particles not found. Hair or fibre reinforcement not present.

**Preliminary Tests.**

Damp sample. Partially carbonated (phenolphthalein carbonation test).
Apparent water permeability low (water droplet absorption on dried surface).
Moderate effervescence on addition of dilute hydrochloric acid.

**Chemical Dissolution Analysis (% dry mass) to BS4551:2005+A2:2013 (+ICP-OES).**

| | | |
|---|---|---|
| % | Initial Moisture (oven @ 100$^0$C) | 8.56 |
| % | Total Calcium as CaO (titrimetric method) | 10.83 |
| % | Total Magnesium as MgO (ICP-OES method) | 0.28 |
| % | Acid & alkali soluble Silicon as $SiO_2$ (gravimetric method) | 2.59 |
| % | Soluble Aluminium as $Al_2O_3$ (ICP-OES method) | 1.18 |
| % | Soluble Iron as $Fe_2O_3$ (ICP-OES method) | 0.77 |
| % | Total (acid-soluble) sulphate as $SO_3$ (gravimetric method) | 0.58 |
| % | Total Acid Insolubles | 76.1 |

**BINDER**

The binder in this sample is partially carbonated Portland cement as confirmed by the elevated soluble silica, alumina and iron test results.

**AGGREGATE**

**Insoluble particle size range: 3.35mm to 45µm ( 97.1%) : <45µm ( 2.9%)**

The acid-insoluble residue is a washed sand principally comprising:

Yellow-brown quartz
Occasional particles of other geological and mineral types.
Yellow-brown fines - principally clay and very fine quartz.



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**TEST REPORT 5809/HC/01**

**MORTAR BY VOLUME**

Acid-soluble calcareous aggregate was not positively determined, and an allowance has therefore not been made. The results adjusted for typical bulk density indicate a volumetric mix of approximately:

| | |
|---|---|
| 1 part | (Early?) Portland cement |
| 4 to 5 parts | Aggregate |

**COMPARATIVE HYDRAULICITY**

The hydraulicity determined is more hydraulic than modern NHL5.

**SUGGESTED MATCHING MIX**

**This is not a specification for a repair mortar, nor must it be treated as one.**

The 'Portland cement' patented by Joseph Aspdin in 1829 was in fact an artificial hydraulic lime, and it wasn't until the mid-1840s that his son William developed a material that would be recognised today as Portland cement. The binder in this sample must be later than 1845 and partial carbonation may suggest it is late 19th or early 20th century.

If this mortar were to be matched on a 'like-for-like' basis, the following approximate volumetric matching mix recipe might be helpful.

This does not necessarily imply that I recommend a 'like-for-like' repair mortar mix design in this particular situation, as there are many relevant factors in addition to mortar analysis that must be taken into account when deciding on mortar specification.

| | |
|---|---|
| 1 part | Portland cement |
| 4 to 5 parts | Yellow-brown quartz sand <3.35mm |

**SOURCES OF MATERIALS**

Many limes, sands, stonedusts and aggregates are available from Rose of Jericho.

**NOTES:**

1. Sample mixes must always be prepared to ensure suitability and an accurate colour and texture match.

2. Sands and aggregates conforming to the relevant European Standard and with a particle size and grading appropriate for the intended use must be selected.

3. Manufacturers advice should be sought and recommended application mix proportions and 'Best Practice' guides must be complied with.

4. It should be remembered that mortars change over time. When analysing an aged material, one is ascertaining what it now is and looking for evidence for what it originally was. Calcium hydroxide carbonates to form calcium carbonate, and calcium silicate hydrate (C-S-H), the principal reaction product in hydraulic limes and pozzolanic limes itself reacts over time with carbonic acid to produce calcium carbonate and hydrous siliceous, aluminate and silico-aluminate gels.

15.06.2024



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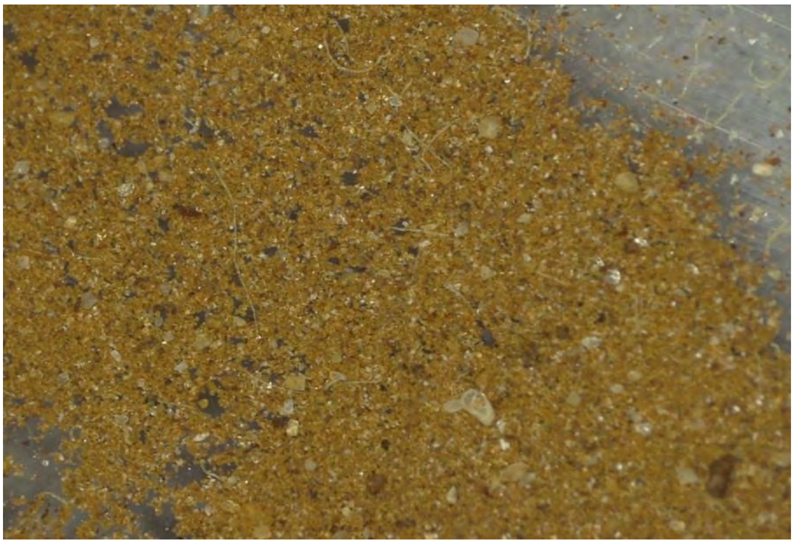
**TEST REPORT 5809/HC/01**

**IMAGES OF SAMPLE & INSOLUBLE RESIDUES**

5809/HC/01
Sample as tested

5809/HC/01
Insolubles >45µm
Stereomicroscope x10



5809/HC/01
Insoluble fines <45µm
Stereomicroscope x20

Peter Ellis FSA
Historic Buildings Consultancy
Materials, Method & Analysis

# Mortar Analysis

# Test Report No. 5809/HC/02.

## Highgate Cemetery, London N6.

## Egyptian Avenue. Sample 6/M2.

A sample (36.3g) of render collected from the RH Obelisk has been analysed chemically and microscopically. This is thought to be the original early/mid-19$^{th}$ century material.

**Sample Assessment and Microscopic Observations.**

Intact brown render fragments c.15mm thick. High/moderate (variable) strength (fragments could not be broken by hand nor crumbled in fingers; disrupted using pestle with some difficulty). Aggregate is principally fine yellow-brown quartz. Calcareous aggregate not positively determined. Kiln-fuel particles not found. Hair or fibre reinforcement not present.

**Preliminary Tests.**

Dry sample. Fully carbonated (phenolphthalein carbonation test).
Apparent water permeability moderate/low (water droplet absorption on dried surface).
Moderate effervescence on addition of dilute hydrochloric acid.

**Chemical Dissolution Analysis (% dry mass) to BS4551:2005+A2:2013 (+ICP-OES).**

| | | |
|---|---|---|
| % | Initial Moisture (oven @ 100$^0$C) | 3.31 |
| % | Total Calcium as CaO (titrimetric method) | 16.74 |
| % | Total Magnesium as MgO (ICP-OES method) | 0.44 |
| % | Acid & alkali soluble Silicon as $SiO_2$ (gravimetric method) | 3.87 |
| % | Soluble Aluminium as $Al_2O_3$ (ICP-OES method) | 1.51 |
| % | Soluble Iron as $Fe_2O_3$ (ICP-OES method) | 0.85 |
| % | Total (acid-soluble) sulphate as $SO_3$ (gravimetric method) | 5.66 |
| % | Total Acid Insolubles | 61.1 |

**BINDER**

The binder in this sample is hydraulic as confirmed by the elevated soluble silica, alumina and iron test results, and is a binder of the 'Roman cement' type. The elevated sulphate is likely to indicate a surface reaction in a polluted sulphurous environment and does not indicate gypsum to be a deliberate mix component.

**AGGREGATE**

**Insoluble particle size range: 1.60mm to 45µm ( 90.8%) : <45µm ( 9.2%)**

The acid-insoluble residue principally comprises:

Yellow-brown quartz
Occasional particles of other geological and mineral types.
Reddish-brown fines - principally clay.



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**TEST REPORT 5809/HC/02**

## MORTAR BY VOLUME

Acid-soluble calcareous aggregate was not positively determined, and an allowance has therefore not been made. The results adjusted for typical bulk density indicate a volumetric mix of approximately:

| | |
|---|---|
| 1 part | Roman cement |
| 2 parts | Aggregate |

## COMPARATIVE HYDRAULICITY

The hydraulicity determined is more hydraulic than modern NHL5.

## SUGGESTED MATCHING MIX

**This is not a specification for a repair mortar, nor must it be treated as one.**

Roman cements were manufactured in the late 18th and 19th century by calcining septaria, a natural calcareous 'concretion' and are no longer produced. Repair mixes are normally based on Vicat Prompt natural cement.

If this mortar were to be matched on a 'like-for-like' basis, the following approximate volumetric matching mix recipe might be helpful.

This does not necessarily imply that I recommend a 'like-for-like' repair mortar mix design in this particular situation, as there are many relevant factors in addition to mortar analysis that must be taken into account when deciding on mortar specification.

| | |
|---|---|
| 1 part | Prompt Natural Cement* |
| 1.5 parts | Yellow-brown quartz sand <1.60mm |
| 0.5 parts | Hornton brown sand <1.18mm |

***Note:** This is a fast-setting binder and a set-retarder may be necessary

## SOURCES OF MATERIALS

Many limes, sands, stonedusts and aggregates are available from Rose of Jericho.

## NOTES:

1. Sample mixes must always be prepared to ensure suitability and an accurate colour and texture match.

2. Sands and aggregates conforming to the relevant European Standard and with a particle size and grading appropriate for the intended use must be selected.

3. Manufacturers advice should be sought and recommended application mix proportions and 'Best Practice' guides must be complied with.

4. It should be remembered that mortars change over time. When analysing an aged material, one is ascertaining what it now is and looking for evidence for what it originally was. Calcium hydroxide carbonates to form calcium carbonate, and calcium silicate hydrate (C-S-H), the principal reaction product in hydraulic limes and pozzolanic limes itself reacts over time with carbonic acid to produce calcium carbonate and hydrous siliceous, aluminate and silico-aluminate gels.

14.06.2024



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**TEST REPORT 5809/HC/02**

**IMAGES OF SAMPLE & INSOLUBLE RESIDUES**

5809/HC/02
Sample as tested

5809/HC/02
Insolubles >45µm
Stereomicroscope x10

5809/HC/02
Insoluble fines <45µm
Stereomicroscope x20

Peter Ellis FSA
Historic Buildings Consultancy
Materials, Method & Analysis

# Mortar Analysis

## Test Report No. 5809/HC/03.

## Highgate Cemetery, London N6.

## Egyptian Avenue. Sample 6/M3.

A sample (44.7g) of render collected from the LH Obelisk has been analysed chemically and microscopically. This is thought to be the original early/mid-19$^{th}$ century material.

**Sample Assessment and Microscopic Observations.**

Intact brown render fragments c.15mm thick. Moderate strength (fragments could be broken by hand but not crumbled in fingers; disrupted using pestle with some difficulty). Aggregate is principally yellow-brown quartz and fine flint. Calcareous aggregate not positively determined. Kiln-fuel particles not found. Hair or fibre reinforcement not present.

**Preliminary Tests.**

Moist sample. Fully carbonated (phenolphthalein carbonation test).
Apparent water permeability moderate/low (water droplet absorption on dried surface).
Moderate effervescence on addition of dilute hydrochloric acid.

**Chemical Dissolution Analysis (% dry mass) to BS4551:2005+A2:2013 (+ICP-OES).**

| | | |
|---|---|---|
| % | Initial Moisture (oven @ 100$^0$C) | 10.53 |
| % | Total Calcium as CaO (titrimetric method) | 15.45 |
| % | Total Magnesium as MgO (ICP-OES method) | 0.54 |
| % | Acid & alkali soluble Silicon as $SiO_2$ (gravimetric method) | 3.77 |
| % | Soluble Aluminium as $Al_2O_3$ (ICP-OES method) | 1.59 |
| % | Soluble Iron as $Fe_2O_3$ (ICP-OES method) | 1.12 |
| % | Total (acid-soluble) sulphate as $SO_3$ (gravimetric method) | 2.77 |
| % | Total Acid Insolubles | 65.7 |

**BINDER**

The binder in this sample is hydraulic as confirmed by the elevated soluble silica, alumina and iron test results, and is a binder of the 'Roman cement' type. The elevated sulphate is likely to indicate a surface reaction in a polluted sulphurous environment and does not indicate gypsum to be a deliberate mix component.

**AGGREGATE**

**Insoluble particle size range: 1.60mm to 45µm ( 94.7%) : <45µm ( 5.3%)**

The acid-insoluble residue principally comprises:

Yellow-brown quartz
Occasional particles of fine flint and other geological and mineral types.
Reddish-brown fines - principally clay.



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**TEST REPORT 5809/HC/03**

**MORTAR BY VOLUME**

Acid-soluble calcareous aggregate was not positively determined, and an allowance has therefore not been made. The results adjusted for typical bulk density indicate a volumetric mix of approximately:

| | |
|---|---|
| 1 part | Roman cement |
| 2 parts | Aggregate |

**COMPARATIVE HYDRAULICITY**

The hydraulicity determined is more hydraulic than modern NHL5.

**SUGGESTED MATCHING MIX**

**This is not a specification for a repair mortar, nor must it be treated as one.**

Roman cements were manufactured in the late 18th and 19th century by calcining septaria, a natural calcareous 'concretion' and are no longer produced. Repair mixes are normally based on Vicat Prompt natural cement.

If this mortar were to be matched on a 'like-for-like' basis, the following approximate volumetric matching mix recipe might be helpful.

This does not necessarily imply that I recommend a 'like-for-like' repair mortar mix design in this particular situation, as there are many relevant factors in addition to mortar analysis that must be taken into account when deciding on mortar specification.

| | |
|---|---|
| 1 part | Prompt Natural Cement* |
| 1.5 parts | Yellow-brown quartz sand <1.60mm |
| 0.5 parts | Hornton brown sand <1.18mm |

***Note:** This is a fast-setting binder and a set-retarder may be necessary

**SOURCES OF MATERIALS**

Many limes, sands, stonedusts and aggregates are available from Rose of Jericho.

**NOTES:**

1. Sample mixes <u>must always</u> be prepared to ensure suitability and an accurate colour and texture match.

2. Sands and aggregates conforming to the relevant European Standard and with a particle size and grading appropriate for the intended use must be selected.

3. Manufacturers advice should be sought and recommended application mix proportions and 'Best Practice' guides must be complied with.

4. It should be remembered that mortars change over time. When analysing an aged material, one is ascertaining what it now is and looking for evidence for what it originally was. Calcium hydroxide carbonates to form calcium carbonate, and calcium silicate hydrate (C-S-H), the principal reaction product in hydraulic limes and pozzolanic limes itself reacts over time with carbonic acid to produce calcium carbonate and hydrous siliceous, aluminate and silico-aluminate gels.

14.06.2024



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**TEST REPORT 5809/HC/03**

**IMAGES OF SAMPLE & INSOLUBLE RESIDUES**

5809/HC/03
Sample as tested

5809/HC/03
Insolubles >45µm
Stereomicroscope x10

5809/HC/03
Insoluble fines <45µm
Stereomicroscope x20

Peter Ellis FSA
Historic Buildings Consultancy
Materials, Method & Analysis

# Mortar Analysis

## Test Report No. 5809/HC/04.

## Highgate Cemetery, London N6.

## Circle of Lebanon. Sample 7/M2.

A sample (48.1g) of render collected from the Inner Circle facade has been analysed chemically and microscopically. This is thought to be original early/mid-19th century material.

**Sample Assessment and Microscopic Observations.**

Intact brown render fragments c.30mm thick applied in two coats. High/moderate strength (sample could not be broken by hand nor crumbled in fingers; disrupted using pestle with some difficulty). Aggregate is principally yellow-brown quartz. Calcareous aggregate not positively determined. Kiln-fuel particles not found. Hair or fibre reinforcement not present.

**Preliminary Tests.**

Dry sample. Fully carbonated (phenolphthalein carbonation test).
Apparent water permeability moderate/low (water droplet absorption on dried surface).
Vigorous effervescence on addition of dilute hydrochloric acid.

**Chemical Dissolution Analysis (% dry mass) to BS4551:2005+A2:2013 (+ICP-OES).**

| | | |
|---|---|---|
| % | Initial Moisture (oven @ $100^0$C) | 2.28 |
| % | Total Calcium as CaO (titrimetric method) | 14.91 |
| % | Total Magnesium as MgO (ICP-OES method) | 0.52 |
| % | Acid & alkali soluble Silicon as $SiO_2$ (gravimetric method) | 3.51 |
| % | Soluble Aluminium as $Al_2O_3$ (ICP-OES method) | 1.63 |
| % | Soluble Iron as $Fe_2O_3$ (ICP-OES method) | 1.09 |
| % | Total (acid-soluble) sulphate as $SO_3$ (gravimetric method) | 2.70 |
| % | Total Acid Insolubles | 64.2 |

**BINDER**

The binder in this sample is hydraulic as confirmed by the elevated soluble silica, alumina and iron test results, and is a binder of the ‘Roman cement’ type. The elevated sulphate is likely to indicate a surface reaction in a polluted sulphurous environment and does not indicate gypsum to be a deliberate mix component.

**AGGREGATE**

**Insoluble particle size range: 1.60mm to 45µm ( 92.9%) : <45µm ( 7.1%)**

The acid-insoluble residue principally comprises:

Yellow-brown quartz
Occasional particles of other geological and mineral types.
Reddish-brown fines - principally clay.



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**TEST REPORT 5809/HC/04**

**MORTAR BY VOLUME**

Acid-soluble calcareous aggregate was not positively determined, and an allowance has therefore not been made. The results adjusted for typical bulk density indicate a volumetric mix of approximately:

| | |
|---|---|
| 1 part | Roman cement |
| 2 parts | Aggregate |

**COMPARATIVE HYDRAULICITY**

The hydraulicity determined is more hydraulic than modern NHL5.

**SUGGESTED MATCHING MIX**

**This is not a specification for a repair mortar, nor must it be treated as one.**

Roman cements were manufactured in the late 18th and 19th century by calcining septaria, a natural calcareous 'concretion' and are no longer produced. Repair mixes are normally based on Vicat Prompt natural cement.

If this mortar were to be matched on a 'like-for-like' basis, the following approximate volumetric matching mix recipe might be helpful.

This does not necessarily imply that I recommend a 'like-for-like' repair mortar mix design in this particular situation, as there are many relevant factors in addition to mortar analysis that must be taken into account when deciding on mortar specification.

| | |
|---|---|
| 1 part | Prompt Natural Cement* |
| 1.5 parts | Yellow-brown quartz sand <1.60mm |
| 0.5 parts | Hornton brown sand <1.18mm |

***Note:** This is a fast-setting binder and a set-retarder may be necessary

**SOURCES OF MATERIALS**

Many limes, sands, stonedusts and aggregates are available from Rose of Jericho.

**NOTES:**

1. Sample mixes must always be prepared to ensure suitability and an accurate colour and texture match.

2. Sands and aggregates conforming to the relevant European Standard and with a particle size and grading appropriate for the intended use must be selected.

3. Manufacturers advice should be sought and recommended application mix proportions and 'Best Practice' guides must be complied with.

4. It should be remembered that mortars change over time. When analysing an aged material, one is ascertaining what it now is and looking for evidence for what it originally was. Calcium hydroxide carbonates to form calcium carbonate, and calcium silicate hydrate (C-S-H), the principal reaction product in hydraulic limes and pozzolanic limes itself reacts over time with carbonic acid to produce calcium carbonate and hydrous siliceous, aluminate and silico-aluminate gels.

14.06.2024



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**TEST REPORT 5809/HC/04**

**IMAGES OF SAMPLE & INSOLUBLE RESIDUES**

5809/HC/04
Sample as tested

5809/HC/04
Insolubles >45µm
Stereomicroscope x10

5809/HC/04
Insoluble fines <45µm
Stereomicroscope x20

Peter Ellis FSA
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Materials, Method & Analysis

# Mortar Analysis

## Test Report No. 5809/HC/05.

## Highgate Cemetery, London N6.

## Terrace Catacombs. Sample 8/M7.

A sample (41.2g) of external backing coat render collected from the east wing ramp retaining wall has been analysed chemically and microscopically.

**Sample Assessment and Microscopic Observations.**

Intact yellow-brown render fragments c.15mm thick. High strength (sample could not be broken by hand nor crumbled in fingers; disrupted using pestle with difficulty). Aggregate is principally yellow quartz with particles of flint and other geological types. Calcareous aggregate not positively determined. Kiln-fuel particles not found. Hair or fibre reinforcement not present.

**Preliminary Tests.**

Dry sample. Fully carbonated (phenolphthalein carbonation test).
Apparent water permeability low (water droplet absorption on dried surface).
Vigorous effervescence on addition of dilute hydrochloric acid.

**Chemical Dissolution Analysis (% dry mass) to BS4551:2005+A2:2013 (+ICP-OES).**

| | | |
|---|---|---|
| % | Initial Moisture (oven @ $100^0$C) | 2.60 |
| % | Total Calcium as CaO (titrimetric method) | 15.67 |
| % | Total Magnesium as MgO (ICP-OES method) | 0.46 |
| % | Acid & alkali soluble Silicon as $SiO_2$ (gravimetric method) | 3.99 |
| % | Soluble Aluminium as $Al_2O_3$ (ICP-OES method) | 1.62 |
| % | Soluble Iron as $Fe_2O_3$ (ICP-OES method) | 0.95 |
| % | Total (acid-soluble) sulphate as $SO_3$ (gravimetric method) | 1.81 |
| % | Total Acid Insolubles | 66.4 |

**BINDER**

The binder in this sample is Portland cement as confirmed by the elevated soluble silica, alumina and iron test results. The sulphate is somewhat elevated.

**AGGREGATE**

**Insoluble particle size range: 3.35mm to 45µm ( 93.3%) : <45µm ( 6.7%)**

The acid-insoluble residue principally comprises:

Yellow-brown quartz
Occasional particles of flint and other geological and mineral types.
Yellow-brown fines - principally clay.



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01460 240298. 07976 765734. peterellis200@gmail.com

## MORTAR BY VOLUME

Acid-soluble calcareous aggregate was not positively determined, and an allowance has therefore not been made. The results adjusted for typical bulk density indicate a volumetric mix of approximately:

| | |
|---|---|
| 1 part | (Early?) Portland cement |
| 3 to 4 parts | Aggregate |

## COMPARATIVE HYDRAULICITY

The hydraulicity determined is more hydraulic than modern NHL5.

## SUGGESTED MATCHING MIX

**This is not a specification for a repair mortar, nor must it be treated as one.**

The 'Portland cement' patented by Joseph Aspdin in 1829 was in fact an artificial hydraulic lime, and it wasn't until the mid-1840s that his son William developed a material that would be recognised today as Portland cement. The binder in this sample must be later than 1845 and very likely later than 1850.

If this mortar were to be matched on a ‘like-for-like’ basis, the following approximate volumetric matching mix recipe might be helpful.

This does not necessarily imply that I recommend a ‘like-for-like’ repair mortar mix design in this particular situation, as there are many relevant factors in addition to mortar analysis that must be taken into account when deciding on mortar specification.

| | |
|---|---|
| 1 part | Portland cement (sulphate resisting) |
| 4 parts | Yellow-brown quartz and flint sand <3.35mm |

## SOURCES OF MATERIALS

Many limes, sands, stonedusts and aggregates are available from Rose of Jericho.

## NOTES:

1. Sample mixes must always be prepared to ensure suitability and an accurate colour and texture match.

2. Sands and aggregates conforming to the relevant European Standard and with a particle size and grading appropriate for the intended use must be selected.

3. Manufacturers advice should be sought and recommended application mix proportions and ‘Best Practice’ guides must be complied with.

4. It should be remembered that mortars change over time. When analysing an aged material, one is ascertaining what it now is and looking for evidence for what it originally was. Calcium hydroxide carbonates to form calcium carbonate, and calcium silicate hydrate (C-S-H), the principal reaction product in hydraulic limes and pozzolanic limes itself reacts over time with carbonic acid to produce calcium carbonate and hydrous siliceous, aluminate and silico-aluminate gels.

15.06.2024



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**TEST REPORT 5809/HC/05**
**IMAGES OF SAMPLE & INSOLUBLE RESIDUES**

5809/HC/05
Sample as tested

5809/HC/05
Insolubles >45µm
Stereomicroscope x10

5809/HC/05
Insoluble fines <45µm
Stereomicroscope x20

Peter Ellis FSA
Historic Buildings Consultancy
Materials, Method & Analysis

# Mortar Analysis

## Test Report No. 5809/HC/06.

## Highgate Cemetery, London N6.

## Terrace Catacombs. Sample 8/M8.

A sample (23.9g) of external finish coat render collected from the east wing ramp retaining wall has been analysed chemically and microscopically.

**Sample Assessment and Microscopic Observations.**

Intact pale grey-brown render fragments c.3mm thick. High strength (thin fragments could be snapped by hand with some difficulty but not crumbled in fingers; disrupted using pestle with difficulty). Aggregate is principally fine yellow quartz. Calcareous aggregate not positively determined. Kiln-fuel particles not found. Hair or fibre reinforcement not present.

**Preliminary Tests.**

Dry sample. Fully carbonated (phenolphthalein carbonation test).
Apparent water permeability low (water droplet absorption on dried surface).
Vigorous effervescence on addition of dilute hydrochloric acid.

**Chemical Dissolution Analysis (% dry mass) to BS4551:2005+A2:2013 (+ICP-OES).**

| | | |
|---|---|---|
| % | Initial Moisture (oven @ $100^0$C) | 3.17 |
| % | Total Calcium as CaO (titrimetric method) | 17.83 |
| % | Total Magnesium as MgO (ICP-OES method) | 0.53 |
| % | Acid & alkali soluble Silicon as $SiO_2$ (gravimetric method) | 3.62 |
| % | Soluble Aluminium as $Al_2O_3$ (ICP-OES method) | 1.29 |
| % | Soluble Iron as $Fe_2O_3$ (ICP-OES method) | 0.96 |
| % | Total (acid-soluble) sulphate as $SO_3$ (gravimetric method) | 3.87 |
| % | Total Acid Insolubles | 63.5 |

**BINDER**

The binder in this sample is Portland cement as confirmed by the elevated soluble silica, alumina and iron test results. The sulphate is elevated, likely as a result of a surface reaction in a polluted environment.

**AGGREGATE**

**Insoluble particle size range: 1.18mm to 45µm ( 92.3%) : <45µm ( 7.7%)**

The acid-insoluble residue principally comprises:

Yellow quartz
Occasional particles of other geological and mineral types.
Yellow-brown fines - principally clay.



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## TEST REPORT 5809/HC/06

## MORTAR BY VOLUME

Acid-soluble calcareous aggregate was not positively determined, and an allowance has therefore not been made. The results adjusted for typical bulk density indicate a volumetric mix of approximately:

| | |
|---|---|
| 1 part | (Early?) Portland cement |
| 3 parts | Aggregate |

## COMPARATIVE HYDRAULICITY

The hydraulicity determined is more hydraulic than modern NHL5.

## SUGGESTED MATCHING MIX

**This is not a specification for a repair mortar, nor must it be treated as one.**

The 'Portland cement' patented by Joseph Aspdin in 1829 was in fact an artificial hydraulic lime, and it wasn't until 1844 that his son William developed a material that would be recognised today as Portland cement. The binder in this sample must be later than 1845 and very likely later than 1850.

If this mortar were to be matched on a 'like-for-like' basis, the following approximate volumetric matching mix recipe might be helpful.

This does not necessarily imply that I recommend a 'like-for-like' repair mortar mix design in this particular situation, as there are many relevant factors in addition to mortar analysis that must be taken into account when deciding on mortar specification.

| | |
|---|---|
| 1 part | Portland cement (sulphate resisting)* |
| 3 parts | Yellow quartz sand <1.18mm |

## SOURCES OF MATERIALS

Many limes, sands, stonedusts and aggregates are available from Rose of Jericho.

## NOTES:

1. Sample mixes must always be prepared to ensure suitability and an accurate colour and texture match.
2. Sands and aggregates conforming to the relevant European Standard and with a particle size and grading appropriate for the intended use must be selected.
3. Manufacturers advice should be sought and recommended application mix proportions and 'Best Practice' guides must be complied with.
4. It should be remembered that mortars change over time. When analysing an aged material, one is ascertaining what it now is and looking for evidence for what it originally was. Calcium hydroxide carbonates to form calcium carbonate, and calcium silicate hydrate (C-S-H), the principal reaction product in hydraulic limes and pozzolanic limes itself reacts over time with carbonic acid to produce calcium carbonate and hydrous siliceous, aluminate and silico-aluminate gels.

15.06.2024



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**TEST REPORT 5809/HC/06**

**IMAGES OF SAMPLE & INSOLUBLE RESIDUES**

5809/HC/06
Sample as tested

5809/HC/06
Insolubles >45µm
Stereomicroscope x10

5809/HC/06
Insoluble fines <45µm
Stereomicroscope x20

**CHAPEL BUILDING:**

Dissolution tests and analysis not yet available

The bedding mortar for 19th century brickwork and stonework dating from 1838 and 1853 can be identified as a lime mortar from observation.

All repointed in 20th Century using a cement mortar with a struck joint.

The bedding and pointing mortar for works carried out 1982-3 is understood from records and observation to be in a cement mortar, also finished with a struck joint.

## 2. STONE ANALYSIS

Carried out by British Geological Survey

Selected analysis from buildings for which replacement stone is known to be required.

**HIGHGATE CEMETERY**

**SCHEDULE OF SAMPLING AND INVESTIGATIONS**
STONE ONLY

| Building | Sample No | Sample location | Sample details | Sample date | Analysis | Results |
|---|---|---|---|---|---|---|
| | | | | | | |
| **Chapel** | | | | | | |
| | 1/S1 | LH gate pier cap | Stone sample from gate pier cap | 26/02/2024 | BGS | |
| | | Sample representative of consistent stone used throughout the building exterior |  | Purpose: Indent repairs to existing stonework and the replacement of complete missing elements (pinnacles etc) in matching stone | | |
| **Mausolea** | | | | | | |
| **Kelman and Rosa** | | | | | | |
| | 13/S1 | Rear wall Kelman | Stone sample | 27/03/2024 | BGS | |
| | | Sample detached from damaged block on rear wall |   | Purpose: Indent repairs to existing stonework | | |
| **Da Silva** | | | | | | |
| | 16/S1 | LH rear corner cornice | Stone sample | 27/03/2024 | BGS | |
| | | Sample detached from fracture to cornice at LH rear corner |   | | | |
| | | | | | | |

British Geological Survey

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# Highgate Cemetery, London

## Part 1: Gate piers associated with main east entrance to West Cemetery

## Building Stone Assessment:

The BGS Building Stone Assessment service combines geological expertise and building conservation expertise to provide authoritative advice to clients wishing to specify natural stone for repairing or building stone structures. Samples of stone supplied by clients are compared with samples from active quarries held in the BGS Collection of UK Building Stones to identify the closest-matching currently available stone(s). Using the closest-matching stone type in repairs to stone structures maximises the likelihood that the replacement stone will co-exist harmoniously with the 'original' stone and will weather sympathetically.

**GeoReport ID: BGS_339061/1**
**BGS sample number: ENQ20067**
**Client reference: Highgate Cemetery Funerary Buildings (sample 1/S1)**
**Date of report: 11/07/2024**

# Executive Summary

**Site name:** Highgate Cemetery, Camden, London[1].

**Architectural/structural element(s) sampled:** Stone capping to left-hand octagonal pier associated with the gateway adjacent to the southern former mortuary chapel[2]; presumably original C19$^{th}$ (*c.* 1839) stonework.

**Nature of planned repairs:** Indent repairs to stonework of the type represented by the supplied sample and reinstatement of missing elements in matching stone.

[1] See List Entry Number: 1000810 (https://historicengland.org.uk/listing/the-list/list-entry/1000810).

[2] See List Entry Number: 1378877 (https://historicengland.org.uk/listing/the-list/list-entry/1378877).

## The sample(s) of building stone supplied to BGS comprise(s):

*Sample '1/S1' (BGS sample number ENQ20067)*

Two formerly attached pieces of stone[3] comprising a largely cohesive, light buff coloured[4], essentially medium-grained[5], ooidal, peloidal and bioclastic **limestone** with a pervasive intergranular (slightly ferroan) calcite spar and microspar cement. There is little doubt that this limestone is a variety of **'Bath Stone'**, originating from within the Middle Jurassic **Great Oolite Group** succession of the Bath–Bradford-on-Avon–Corsham area. Detailed provenancing of 'Bath Stone' samples is always hampered by the variability (both vertically and laterally) of the source limestone beds, and consequent variation in character through time of the stone originating from particular workings, but comparison with historical BGS-held reference specimens suggests that the source of this 'Bath Stone' was one of the underground quarries in the Corsham area of Wiltshire (where the beds of the **Chalfield Oolite Formation**[6] were, and still are, worked). Stone such as this was marketed historically under a number of different names, typically linked to the specific quarry/mine of origin and also more generally as 'Corsham Down Stone'. The exact origins of this particular 'Corsham Down Stone' are indeterminable petrographically, but we note that its characteristics are reminiscent of current production 'Hartham Park Stone'.

[3] When restored to their true relative positions, these yield a piece of stone with overall maximum dimensions of 125 x 55 x 32 mm, which is bounded by a combination of weathered dressed/sawn and broken surfaces. A thin section was prepared from the sample to enable petrographic analysis of the stone. The section was cut so as to show the 55 x 32 mm plane, but with an unknown orientation with respect to the sedimentary bedding.

[4] Most similar to shades of 'very pale brown' (10YR) on a Munsell® Soil Color Chart.

[5] Denotes a grain size of 0.25–2 mm. Bioclasts > 2 mm in size (i.e. *coarse-grained*) occur sporadically and a subordinate amount of *fine-grained* material (< 0.25 mm in size) is present.

[6] See relevant BGS Lexicon entry at: https://www.bgs.ac.uk/lexicon/lexicon.cfm?pub=CFDO.

## The closest-matching currently available stone is:

Amongst the limited range of 'Bath Stone' varieties in active production, **'Hartham Park Stone'** (ideally in its 'Top Bed' guise) should be pursued in the first instance. Contact details for the relevant producer-supplier are as follows:

**Lovell Stone Group**
Hartham Park Quarry, Park Lane, CORSHAM, Wiltshire
Tel. 01929 439255
Email: sales@lovellstone.com
Website: https://www.lovellstonegroup.com/

We urge you to approach Lovell Stone Group and discuss your requirements, requesting samples of their most recent production for the purposes of conducting an on-site comparison exercise with the existing masonry (to confirm colour and textural suitability). Note that the 'T2 Basebed' variety would not be appropriate in this case.

### Other possible replacement stones are:

In the event that an alternative to 'Hartham Park Stone' has to be pursued, then **'Park Lane Bath Stone'** should be regarded as the 'next-best' alternative. The 'Base Bed' and 'Top Bed' varieties will need to be considered, with the final decision being based on which one of the two offers the better gross textural match for the existing 'Bath Stone' of the gate pier (impossible to determine from small *ex situ* samples) and the specific structural locations of the planned repairs. Comparison of the supplied sample with reference specimens of 'Park Lane Bath Stone' held by BGS suggests that the 'Top Bed' will offer the more satisfactory match, but an on-site comparison exercise will still be necessary. It should be borne in mind that the colour of the replacement stone is liable to 'warm' to a degree over time as it weathers. The relevant producer-supplier contact details are as follows:

**Blockstone Ltd.**
Park Lane Mine, Park Lane, The Ridge, CORSHAM, Wiltshire
Tel. 01246 927100 (main Blockstone contact number) or 01277 568050
Email: sales@parklanebathstone.com or sales@blockstone.com
Website: https://blockstone.com/ and https://parklanebathstone.com/

### Other remarks:

Prior to specification, representative samples of each replacement stone under consideration should always be obtained and examined alongside the existing stonework. The blocks of stone ultimately used should ideally be selected at the quarry by the stonemason undertaking the repairs. Do not hesitate to contact us for further advice if required.

Mortar plays an important role with respect to the free movement of moisture and air through stonework. It will be important, therefore, to use a permeable mortar (e.g. lime mortar, which ideally should be at least as permeable as the 'original' stone), as well as a compatible replacement stone, in any repair, to increase the chances of a long-lasting, successful outcome. Portland cement, which is essentially impermeable, should not be used as mortar in stonework.

**Dr. Stephen F. Parry**
**British Geological Survey, Keyworth, Nottingham, UK.**
**23 July 2024**

## Information about this Report

**Introduction:**

This report is designed for use by qualified professionals involved in building repair and/or conservation.

**Limitations of the report:**

- This report is based on an analysis of the sample or samples provided and cannot be assumed to be applicable to all materials in a building or structure unless an on-site assessment has been carried out by BGS or a suitably qualified professional.
- The mention of a specific stone type(s) should not be taken as an endorsement, or otherwise, of the quality of a particular product. Equally, recommendations made with respect to a replacement stone do not constitute a repair specification. All aspects of the building (location, detailing, other materials) must be considered in competent repair work.
- The report is based on petrographic analysis. This does not guarantee that a replacement stone is suitable for a particular purpose (e.g. carved detail), nor does it guarantee specific properties of a stone such as strength.
- The characteristics of stone from a quarry source can vary over time and from place to place within the quarry; there is therefore no guarantee that a sample of quarried stone held by BGS is representative of the stone being supplied by the quarry at any particular point in time. One or more samples of stone should be obtained from a quarry operator prior to stone specification, to confirm the appearance and character of the stone currently being supplied.
- Recommendations made with respect to a replacement stone are based on and limited to an interpretation of the records in the possession of BGS at the time the analysis is carried out.

## BGS Building Stone Assessment

A BGS Building Stone Assessment is usually performed in three stages.

(i) The sample of 'original' stone (usually supplied by the client) is first subjected to a detailed petrographic examination, to establish the range and character of its intrinsic properties.

(ii) The range of properties is then compared with those of stone samples held in the BGS Petrological Collections, to constrain the source of the stone. Historical records and other forms of documentary evidence, if available, and the likelihood that the stone was sourced locally or 'imported', are also taken into account.

(iii) Finally, the closest-matching currently available stone(s) are identified. If the quarry from which the stone was sourced originally has been identified and is still open, it will usually provide the closest-matching stone.

If the quarry from which the stone was sourced originally has not been identified, or is closed, the closest-matching currently available stones are identified by comparing the properties of the 'original' stone with those of samples of currently available stones held in the BGS Collection of UK Building Stones.

Comparing stone properties to identify the source and/or the closest-matching stones is known as stone matching.

## Stone matching

Where possible, the source (quarry and bedrock unit) of the 'original' stone is determined by comparing it with samples held in the BGS Petrological Collections; historical records and other forms of documentary evidence, if available, and the likelihood that the stone was sourced locally or 'imported', are also taken into account, if appropriate. Many thousands of quarries in the UK have supplied building stone in the past, and in many instances it is not possible to relate a stone sample back to one particular quarry or bedrock unit.

Where the source cannot be identified unambiguously, the closest-matching currently available stone(s) are identified by comparing the intrinsic properties of the 'original' stone with those of similar stones that are currently being supplied by quarries in the UK.

The following factors are taken into account when comparing an 'original' stone with a potential replacement stone.

1) *Mineral and textural features* – ideally, these should be as similar as possible in the replacement stone and 'original' stone, to increase the likelihood that the two stones will respond in similar ways and at similar rates to the various physical and chemical processes associated with weathering, and will therefore co-exist harmoniously. Replacement stones are selected to match the 'original' stone in its fresh (rather than weathered/decayed) state, unless otherwise requested.
2) *Permeability* – ideally, the replacement stone and 'original' stone should have similar permeability characteristics, thereby minimising the degree to which fluid (water and air) migration between adjacent blocks of 'original' and replacement stone might be impeded. Accelerated stone decay can occur where fluid migration is impeded.
3) *Appearance* – for aesthetic reasons, the replacement stone and 'original' stone ideally should look similar to the unaided eye in terms of colour and stone fabric at the time the repair is made. However, the closest-matching stones in terms of the properties that govern weathering performance (mineral-textural features and permeability) are not necessarily the closest match in terms of appearance. A repair using stone selected primarily because it is the closest match in terms of appearance may look good initially but could quickly show signs of decay or of being incompatible with the 'original' stone. For that reason, priority is generally given to the properties that govern weathering performance, thereby maximising the likelihood of long-term compatibility of the 'original' stone and replacement stone.

A degree of compromise may in some cases be desirable and acceptable if the closest-matching stones in terms of 'weathering properties' are not a close match in terms of appearance. Immediately following repair, the fresh surfaces of a stone insert or indent will usually contrast in appearance with the soiled or discoloured surfaces of adjacent 'original' masonry, but if the 'weathering properties' of the two stones are a good match the new stone should blend in over time and the contrast should become less obvious.

4) *Functional and performance requirements* – specific functional and performance requirements of a replacement stone are taken into account if requested. For example, if the 'original' stone performed a load-bearing role, the choice of matching stones should include only those that are at least as strong; and if the 'original' stone was carved or shaped in a particular way, the choice of matching stones ideally should include only those that can be carved or shaped in a similar way, with a similar level of detail and quality of finish.

One or more replacement stone types are proposed taking these factors into account.

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# Terms and Conditions

**General Terms & Conditions**

This Report is supplied in accordance with the GeoReports Terms & Conditions available on the BGS website at https://shop.bgs.ac.uk/georeports and also available from the BGS Enquiry Service at the above address.

**Important notes about this Report**

- The data, information and related records supplied in this Report by BGS can only be indicative and should not be taken as a substitute for specialist interpretations, professional advice and/or detailed site investigations. You must seek professional advice before making technical interpretations on the basis of the materials provided.
- Geological observations and interpretations are made according to the prevailing understanding of the subject at the time. The quality of such observations and interpretations may be affected by the availability of new data, by subsequent advances in knowledge, improved methods of interpretation, and better access to sampling locations.
- Raw data may have been transcribed from analogue to digital format, or may have been acquired by means of automated measuring techniques. Although such processes are subjected to quality control to ensure reliability where possible, some raw data may have been processed without human intervention and may in consequence contain undetected errors.
- Detail, which is clearly defined and accurately depicted on large-scale maps, may be lost when small-scale maps are derived from them.
- Although samples and records are maintained with all reasonable care, there may be some deterioration in the long term.
- The most appropriate techniques for copying original records are used, but there may be some loss of detail and dimensional distortion when such records are copied.
- Data may be compiled from the disparate sources of information at BGS's disposal, including material donated to BGS by third parties, and may not originally have been subject to any verification or other quality control process.
- Data, information and related records, which have been donated to BGS, have been produced for a specific purpose, and that may affect the type and completeness of the data recorded and any interpretation. The nature and purpose of data collection, and the age of the resultant material may render it unsuitable for certain applications/uses. You must verify the suitability of the material for your intended usage.
- If a report or other output is produced for you on the basis of data you have provided to BGS, or your own data input into a BGS system, please do not rely on it as a source of information about other areas or geological features, as the report may omit important details.
- The topography shown on any map extracts is based on the latest OS mapping and is not necessarily the same as that used in the original compilation of the BGS geological map, and to which the geological linework available at that time was fitted.
- Note that for some sites, the latest available records may be historical in nature, and while every effort is made to place the analysis in a modern geological context, it is possible in some cases that the detailed geology at a site may differ from that described.



**Report issued by**
**BGS Enquiry Service**

GeoReports

British Geological Survey

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# Highgate Cemetery, London

## Part 2: Family mausoleum of James Anderson Kelman

## Building Stone Assessment:

The BGS Building Stone Assessment service combines geological expertise and building conservation expertise to provide authoritative advice to clients wishing to specify natural stone for repairing or building stone structures. Samples of stone supplied by clients are compared with samples from active quarries held in the BGS Collection of UK Building Stones to identify the closest-matching currently available stone(s). Using the closest-matching stone type in repairs to stone structures maximises the likelihood that the replacement stone will co-exist harmoniously with the 'original' stone and will weather sympathetically.

**GeoReport ID: BGS_339061/2**
**BGS sample number: ENQ20068**
**Client reference: Highgate Cemetery Funerary Buildings (sample 13/S1)**
**Date of report: 11/07/2024**

# Executive Summary

**Site name:** Highgate Cemetery, Camden, London [1].

**Architectural/structural element(s) sampled:** Rear wall of the family mausoleum of James Anderson Kelman; presumably original early C20th (*c.* 1907) stonework.

**Nature of planned repairs/usage:** Indent repairs to stonework of the type represented by the supplied sample.

[1] See List Entry Number: 1000810 (https://historicengland.org.uk/listing/the-list/list-entry/1000810).

### The sample(s) of building stone analysed by BGS comprise(s):

*Sample '13/S1' (BGS sample number ENQ20068)*

A single piece [2] of a mostly cohesive, off-white, predominantly fine- to medium-grained [3], ooidal, peloidal and bioclastic **limestone** with a patchily developed intergranular calcite spar cement. Shell fragments of several mm in size (i.e. coarse-grained [3]) occur sporadically, and there is a minor content of siliciclastic material. This limestone is a variety of **'Portland Stone'**, originating from within the Upper Jurassic (Tithonian) **Portland Stone Formation** [4] (more specifically, the **Portland Freestone Member** [5]) succession cropping out on the Isle of Portland, Dorset. The characteristics of this particular sample suggest, on balance, that it represents stone extracted from the horizon known as the ***Basebed***, but we would not discount the possibility that it represents a shell-poor variant of ***Whitbed***. There is nothing sufficiently diagnostic about the stone in terms of its mineral-textural characteristics to enable its actual quarry of origin to be pinpointed.

[2] With maximum dimensions of 45 x 28 x 13 mm. The bounding surface corresponding to the exposed face of the sampled masonry unit is fully covered by a green algal growth. A thin section was prepared from the sample to enable petrographic analysis of the stone. The section was cut so as to show the 45 x 28 mm plane, but with an unknown orientation with respect to the sedimentary bedding.

[3] *Fine-grained* denotes a grain size of 0.064–0.25 mm and *medium-grained* a grain size of 0.25–2 mm. *Coarse-grained* denotes a grain size of > 2 mm.

[4] See relevant BGS Lexicon entry at: https://www.bgs.ac.uk/lexicon/lexicon.cfm?pub=POST.

[5] See relevant BGS Lexicon entry at: https://www.bgs.ac.uk/lexicon/lexicon.cfm?pub=POFR.

### The closest-matching currently available stone is:

**'Portland Stone'** of an appropriate shade of white and relatively low shell content. The ***Basebed*** variety, specifically, should be pursued, although it would be worthwhile considering shell-poor variants of ***Whitbed***, with the final choice being dictated by the degree of shell-related 'flecking' exhibited by the existing stone on a larger scale and the current quarry output. Contact details for the relevant producer-suppliers are provided below. We urge you to approach Albion Stone and Portland Stone Firms and discuss your specific requirements, requesting samples of their most recent relevant production.

**Albion Stone plc** [6]

(continued on following page)

**Albion Stone plc** [6]
Independent Offices, Easton Street, PORTLAND, Dorset
Tel: 01305 860369 (Mine & Factory, Portland) or 01737 771772 (Head Office in Surrey)
Email: enquiries@albionstone.com
Website: https://www.albionstone.com/

[6] Albion Stone currently supply *Basebed* in two guises, marketed as 'Bowers Basebed' and 'Jordans Basebed'. Note, however, that these stones are becoming increasingly similar in character as the source workings become ever closer geographically. Nonetheless, it would be worthwhile examining specimens of both alongside the existing Portland Stone masonry in order to determine which offers the better gross colour and textural match.

**Portland Stone Firms Ltd.** [7]
99 Easton Street, PORTLAND, Dorset
Tel: 01305 820331
Email: sales@stonefirms.com
Website: https://www.stonefirms.com/

[7] The stone marketed as 'Perryfield Basebed' should be pursued in the first instance. It would also be worthwhile considering shell-poor variants of 'Perryfield Whitbed' and 'Broadcroft Whitbed'.

### Other possible replacement stones are:

N/A

### Other remarks:

Representative samples of the *Basebed* and shell-poor *Whitbed* currently being supplied by both Albion Stone and Portland Stone Firms should be obtained and used for the purposes of an on-site comparison exercise with the existing stonework. The variant providing the closest visual match should then be selected accordingly. The specifics of the structural setting/location of use also warrant consideration.

The blocks of stone ultimately used should ideally be selected at the quarry by the stonemason undertaking the repairs.

Mortar plays an important role with respect to the free movement of moisture and air through stonework. It will be important, therefore, to use a permeable mortar (e.g. lime mortar, which ideally should be at least as permeable as the 'original' stone), as well as a compatible replacement stone, in any repair, to increase the chances of a long-lasting, successful outcome. Portland cement, which is essentially impermeable, should not be used as mortar in stonework.

Do not hesitate to contact us for further advice if required.

**Dr. Stephen F. Parry**
**British Geological Survey, Keyworth, Nottingham, UK.**
**23 July 2024**

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- The report is based on petrographic analysis. This does not guarantee that a replacement stone is suitable for a particular purpose (e.g. carved detail), nor does it guarantee specific properties of a stone such as strength.
- The characteristics of stone from a quarry source can vary over time and from place to place within the quarry; there is therefore no guarantee that a sample of quarried stone held by BGS is representative of the stone being supplied by the quarry at any particular point in time. One or more samples of stone should be obtained from a quarry operator prior to stone specification, to confirm the appearance and character of the stone currently being supplied.
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(ii) The range of properties is then compared with those of stone samples held in the BGS Petrological Collections, to constrain the source of the stone. Historical records and other forms of documentary evidence, if available, and the likelihood that the stone was sourced locally or ‘imported’, are also taken into account.

(iii) Finally, the closest-matching currently available stone(s) are identified. If the quarry from which the stone was sourced originally has been identified and is still open, it will usually provide the closest-matching stone. If the quarry from which the stone was sourced originally has not been identified, or is closed, the closest-matching currently available stones are identified by comparing the properties of the ‘original’ stone with those of samples of currently available stones held in the BGS Collection of UK Building Stones.

Comparing stone properties to identify the source and/or the closest-matching stones is known as stone matching.

## Stone matching

Where possible, the source (quarry and bedrock unit) of the ‘original’ stone is determined by comparing it with samples held in the BGS Petrological Collections; historical records and other forms of documentary evidence, if available, and the likelihood that the stone was sourced locally or ‘imported’, are also taken into account, if appropriate. Many thousands of quarries in the UK have supplied building stone in the past, and in many instances it is not possible to relate a stone sample back to one particular quarry or bedrock unit.

Where the source cannot be identified unambiguously, the closest-matching currently available stone(s) are identified by comparing the intrinsic properties of the ‘original’ stone with those of similar stones that are currently being supplied by quarries in the UK.

The following factors are taken into account when comparing an ‘original’ stone with a potential replacement stone.

1) *Mineral and textural features* – ideally, these should be as similar as possible in the replacement stone and ‘original’ stone, to increase the likelihood that the two stones will respond in similar ways and at similar rates to the various physical and chemical processes associated with weathering, and will therefore co-exist harmoniously. Replacement stones are selected to match the ‘original’ stone in its fresh (rather than weathered/decayed) state, unless otherwise requested.
2) *Permeability* – ideally, the replacement stone and ‘original’ stone should have similar permeability characteristics, thereby minimising the degree to which fluid (water and air) migration between adjacent blocks of ‘original’ and replacement stone might be impeded. Accelerated stone decay can occur where fluid migration is impeded.
3) *Appearance* – for aesthetic reasons, the replacement stone and ‘original’ stone ideally should look similar to the unaided eye in terms of colour and stone fabric at the time the repair is made. However, the closest-matching stones in terms of the properties that govern weathering performance (mineral-textural features and permeability) are not necessarily the closest match in terms of appearance. A repair using stone selected primarily because it is the closest match in terms of appearance may look good initially but could quickly show signs of decay or of being incompatible with the ‘original’ stone. For that reason, priority is generally given to the properties that govern weathering performance, thereby maximising the likelihood of long-term compatibility of the ‘original’ stone and replacement stone. A degree of compromise may in some cases be desirable and acceptable if the closest-matching stones in terms of ‘weathering properties’ are not a close match in terms of appearance. Immediately following repair, the fresh surfaces of a stone insert or indent will usually contrast in appearance with the soiled or

discoloured surfaces of adjacent 'original' masonry, but if the 'weathering properties' of the two stones are a good match the new stone should blend in over time and the contrast should become less obvious.

4) *Functional and performance requirements* – specific functional and performance requirements of a replacement stone are taken into account if requested. For example, if the 'original' stone performed a load-bearing role, the choice of matching stones should include only those that are at least as strong; and if the 'original' stone was carved or shaped in a particular way, the choice of matching stones ideally should include only those that can be carved or shaped in a similar way, with a similar level of detail and quality of finish.

One or more replacement stone types are proposed taking these factors into account.

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- Geological observations and interpretations are made according to the prevailing understanding of the subject at the time. The quality of such observations and interpretations may be affected by the availability of new data, by subsequent advances in knowledge, improved methods of interpretation, and better access to sampling locations.
- Raw data may have been transcribed from analogue to digital format, or may have been acquired by means of automated measuring techniques. Although such processes are subjected to quality control to ensure reliability where possible, some raw data may have been processed without human intervention and may in consequence contain undetected errors.
- Detail, which is clearly defined and accurately depicted on large-scale maps, may be lost when small-scale maps are derived from them.
- Although samples and records are maintained with all reasonable care, there may be some deterioration in the long term.
- The most appropriate techniques for copying original records are used, but there may be some loss of detail and dimensional distortion when such records are copied.
- Data may be compiled from the disparate sources of information at BGS's disposal, including material donated to BGS by third parties, and may not originally have been subject to any verification or other quality control process.
- Data, information and related records, which have been donated to BGS, have been produced for a specific purpose, and that may affect the type and completeness of the data recorded and any interpretation. The nature and purpose of data collection, and the age of the resultant material may render it unsuitable for certain applications/uses. You must verify the suitability of the material for your intended usage.
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# GeoReports

British Geological Survey

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# Highgate Cemetery, London

## Part 3: Mausoleum of Eliza Morris da Silva

## Building Stone Assessment:

The BGS Building Stone Assessment service combines geological expertise and building conservation expertise to provide authoritative advice to clients wishing to specify natural stone for repairing or building stone structures. Samples of stone supplied by clients are compared with samples from active quarries held in the BGS Collection of UK Building Stones to identify the closest-matching currently available stone(s). Using the closest-matching stone type in repairs to stone structures maximises the likelihood that the replacement stone will co-exist harmoniously with the 'original' stone and will weather sympathetically.

**GeoReport ID: BGS_339061/3**
**BGS sample number: ENQ20069**
**Client reference: Highgate Cemetery Funerary Buildings (sample 16/S1)**
**Date of report: 11/07/2024**

# Executive Summary

**Site name:** Highgate Cemetery, Camden, London[1].

**Architectural/structural element(s) sampled:** Cornice of the mausoleum of Eliza Morris da Silva; presumably original stonework dating to the second half of the C19th.

**Nature of planned repairs/usage:** No details have been provided, but it is assumed that the planned works will involve full-block and/or indent repairs to stonework of the type represented by the supplied sample.

[1] See List Entry Number: 1000810 (https://historicengland.org.uk/listing/the-list/list-entry/1000810).

### The sample(s) of building stone analysed by BGS comprise(s):

*Sample '16/S1' (BGS sample number ENQ20069)*

A single piece[2] of weathered moulded stonework comprising a mostly cohesive, off-white, predominantly fine- to medium-grained[3], ooidal, peloidal and bioclastic limestone with a widespread (though by no means complete) micritic matrix. Shell fragments of several mm in size (i.e. coarse-grained[3]) occur sporadically, which stand proud of weathered surfaces. There is a minor content of siliciclastic material. This limestone is a variety of **'Portland Stone'**, originating from within the Upper Jurassic (Tithonian) **Portland Stone Formation**[4] (more specifically, the **Portland Freestone Member**[5]) succession cropping out on the Isle of Portland, Dorset. We note that this particular 'Portland Stone' is a lower porosity variant (cf. sample '13/S1' from the family mausoleum of James Anderson Kelman, for example), extracted from either the ***Basebed*** or (perhaps more likely) the ***Whitbed*** horizons. There is nothing sufficiently diagnostic about the stone in terms of its mineral-textural characteristics to enable its actual quarry of origin to be pinpointed.

[2] With maximum dimensions of 71 x 69 x 42 mm, and bounded by a combination of weathered dressed/sawn and freshly broken surfaces; there is a green algal growth on the surfaces corresponding to the exposed part of the sampled masonry unit. A thin section was prepared from the sample enable petrographic analysis of the stone. The section was cut so as to show the moulding in profile, but with an unknown orientation with respect to the sedimentary bedding.

[3] *Fine-grained* denotes a grain size of 0.064–0.25 mm and *medium-grained* a grain size of 0.25–2 mm. *Coarse-grained* denotes a grain size of > 2 mm.

[4] See relevant BGS Lexicon entry at: https://www.bgs.ac.uk/lexicon/lexicon.cfm?pub=POST.

[5] See relevant BGS Lexicon entry at: https://www.bgs.ac.uk/lexicon/lexicon.cfm?pub=POFR.

### The closest-matching currently available stone is:

**'Portland Stone'** – specifically, lower porosity variants of **'Portland Whitbed'** and **'Portland Basebed'**, with the final choice being dictated by the degree of shell-related flecking exhibited by the existing stone on a larger scale and the current quarry output. Contact details for the relevant producer-suppliers are provided on the following page. We urge you to approach Albion Stone and Portland Stone Firms and discuss your specific requirements (in particular, your interest in relatively low porosity *Whitbed* and *Basebed*), requesting samples of their most recent relevant production.

**Albion Stone plc** [6]
Independent Offices, Easton Street, PORTLAND, Dorset
Tel: 01305 860369 (Mine & Factory, Portland) or 01737 771772 (Head Office in Surrey)
Email: enquiries@albionstone.com
Website: https://www.albionstone.com/

[6] Amongst the current production range, 'Jordans Whitbed' and 'Bowers Whitbed' should be considered in the first instance. Nonetheless, it would be worthwhile examining specimens of Albion Stone's *Basebed* alongside the existing 'Portland Stone' masonry in order to determine which variant offers the best gross colour and textural match.

**Portland Stone Firms Ltd.** [7]
99 Easton Street, PORTLAND, Dorset
Tel: 01305 820331
Email: sales@stonefirms.com
Website: https://www.stonefirms.com/

[7] The stone marketed as 'Broadcroft Whitbed' and 'Perryfield Mid-tier Whitbed' should be pursued in the first instance. Nonetheless, it would be worthwhile examining specimens of other *Whitbed*, and indeed *Basebed*, variants alongside the existing 'Portland Stone' masonry in order to determine which offers the best gross colour and textural match.

### Other possible replacement stones are:

N/A

### Other remarks:

Representative samples of the relevant 'Portland Stone' variants currently being supplied by both Albion Stone and Portland Stone Firms should be obtained and used for the purposes of an on-site comparison exercise with the existing stonework. The variant providing the closest visual match should then be selected accordingly. The specifics of the structural setting/location of use also warrant consideration.

The blocks of stone ultimately used should ideally be selected at the quarry by the stonemason undertaking the repairs.

Mortar plays an important role with respect to the free movement of moisture and air through stonework. It will be important, therefore, to use a permeable mortar (e.g. lime mortar, which ideally should be at least as permeable as the 'original' stone), as well as a compatible replacement stone, in any repair, to increase the chances of a long-lasting, successful outcome. Portland cement, which is essentially impermeable, should not be used as mortar in stonework.

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