British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

GeoReports

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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.

Report Id: GR_220607
Site Address: 140 West George Street, Glasgow, G2 2HG.
Date sample received: 07/05/2019
Sample Number: ED11966
Date of Report: 13/06/2019

Building Stone Assessment

140 West George Street, Glasgow

1 Introduction

BGS has been asked by Gavin Reilly, acting on behalf of EBS Construction Ltd., to perform a Building Stone Assessment on a sample of sandstone from the building forming 140 West George Street in Glasgow, which is to undergo repair. The purpose of a Building Stone Assessment is to identify which stones from the range currently being supplied by quarries in the UK most closely match the stone requiring repair or replacement. Background information relating to a BGS Building Stone Assessment of sandstone is presented in Appendix 1.

The client has provided a sample of the existing masonry for analysis, which is assumed to be representative of the 'original' stone requiring replacement. The sample, taken from the front elevation of the building, consists of a single *c.* 50 mm length of 30 mm diameter sandstone drill core; this was assigned the BGS sample number ED11966. A thin section was prepared from the sample to enable petrographic examination of the stone.

No details have been provided about either the nature or extent of the planned repairs.

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 Collection of UK Building Stones, to constrain the source of the stone. Historical records (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 stones 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. Further details of the methodology applied to stone matching are provided in Appendix 2.

2 Petrographic description of sample ED11966

See Appendix 3 for notes describing each numbered item below.

Hand specimen observations

Stone type [1] (general classification): sandstone
Stone colour [2] – fresh stone: very light buff
Stone colour [2] – weathered stone: buff
Stone colour [2] – exterior surface: buff
Stone cohesion [3] – fresh stone: strongly cohesive
Stone cohesion [3] – weathered stone: strongly cohesive
Stone fabric [4]: uniform (some orientated grains)
Distinctive features: none

Thin section observations

Stone constituents [5]:

Granular (detrital) constituents		*Intergranular constituents*	
Quartz	55%	Silica (overgrowth)	3%
Feldspar	4%	Feldspar (overgrowth)	0%
Rock fragments	1%	Carbonate	8%
Mica	1%	Iron/manganese oxide	2%
Opaque material	<<1%	Clay	6%
Other	<<1%	Hydrocarbon	0%
Intragranular pores	5%	Intergranular pores	15%

Stone type [1] (detailed classification): subfeldspathic-arenite
Grain-size [6]: fine-sand-grade
Grain sorting [7]: well sorted
Grain roundness [8]: subangular to rounded
Stone permeability [9]: high
Cement distribution [10]: silica cement continuous; carbonate cement isolated
Supergene changes [11]: moderate dissolution of feldspar; weakly remobilised iron

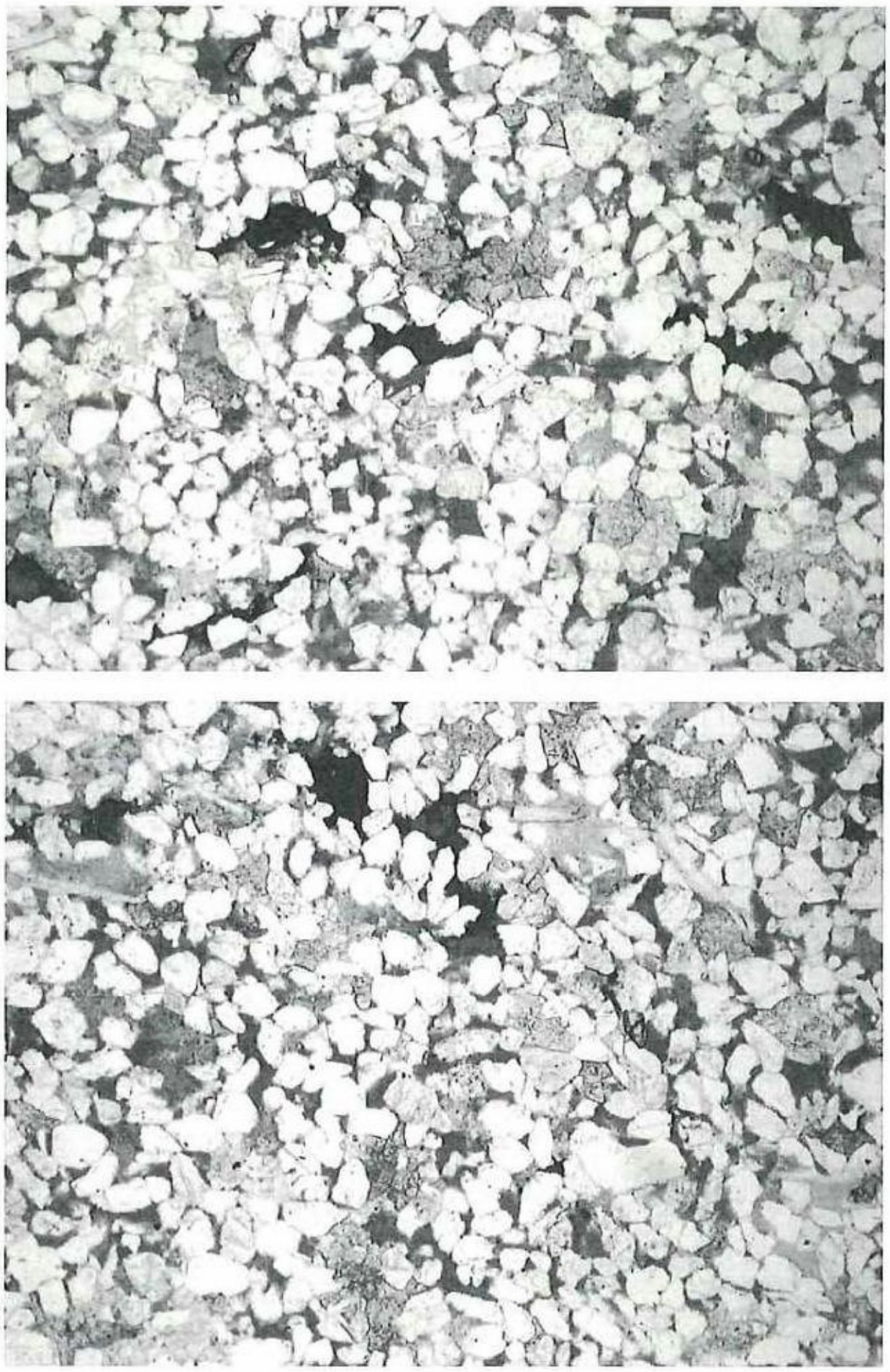
Comments

1) The stone at one end of the core sample (which presumably corresponds to the exterior surface of the sampled masonry block) has weathered to a stronger buff colour.

2) Flakes of mica are aligned parallel to, and indicate, the bedding orientation.

3) The minerals zircon, epidote and tourmaline are present in trace amounts (together accounting for <<1% of the total thin section area).

4) Most of the constituent 'clay' has formed through the natural chemical alteration of detrital feldspar grains (which were thus more abundant at one time); this has been taken into account in the detailed classification of the stone (see 'Stone type' above).



Thin section photographs of sample ED11966. Grains of quartz and feldspar appear white. Carbonate appears mottled grey to brown, and iron oxide appears brown to black. Open pore space appears a rich blue colour, whereas pore space that is (partially) infilled by growths of clay minerals appears light blue. The images were taken in plane-polarised light, and the field of view is *c.* 3.3 mm wide.

3 Source of the stone

Our assessment of the source of the 'original' stone (as represented by the supplied sample), in terms of bedrock geology, bedrock age and quarry, is summarised below. The letters D (definite), L (likely), P (possible) and NK (not known) indicate the level of confidence attached to the assessment. Identification of the bedrock unit is based on the similarity of the supplied stone sample to sample(s) of that unit held in the BGS Collection of UK Building Stones.

Bedrock unit:	Upper Limestone Formation	L
Age:	Carboniferous (359–299 million years ago)	L
Quarry area:	Bishopbriggs / Giffnock	L
Quarry name:		NK
Quarry status:	closed	

Comments

The mineral-textural characteristics of sample ED11966 closely resemble those of BGS samples originating from quarries in the Bishopbriggs and Giffnock areas of Glasgow. Together, the very light buff colour, low volume of rock fragments, and presence of a relatively fresh carbonate mineral are reasonably diagnostic features of stone from this area.

The Bishopbriggs and Giffnock quarries extracted sandstone from the Upper Limestone Formation. These quarries are known to have supplied significant volumes of building stone to Glasgow in the past. The Bishopbriggs- and Giffnock-produced stones are very similar, and it is not possible to distinguish them using petrographic evidence alone.

The Upper Limestone Formation, despite its name, is lithologically varied and contains substantial amounts of sandstone. It crops out across the Central Belt of Scotland, and has been quarried extensively in the Greater Glasgow area.

All of the quarries that once extracted sandstone from the Upper Limestone Formation in the Greater Glasgow area are now closed.

4 Closest-matching currently available stones

None of the quarries that potentially produced the sandstone represented by sample ED11966 is active today, so an assessment of the closest-matching currently available stones has been made. The selection of closest-matching stones provided in this section of the report has been arrived at by comparing the intrinsic properties of sample ED11966 with those of samples of currently available stones held in the BGS Collection of UK Building Stones.

Brief, relevant details for each stone are provided to enable a simple evaluation of how their appearance and character compares with the sample of stone from the building.

Unless stated otherwise, the grain-scale intrinsic properties (grain-size, mineral composition, texture etc.) of the closest-matching stones listed below are broadly similar to those of the 'original' stone. All of the photographs in this section were taken in plane-polarised light, and the field of view is *c.* 3.3 mm wide. Pore space appears blue.

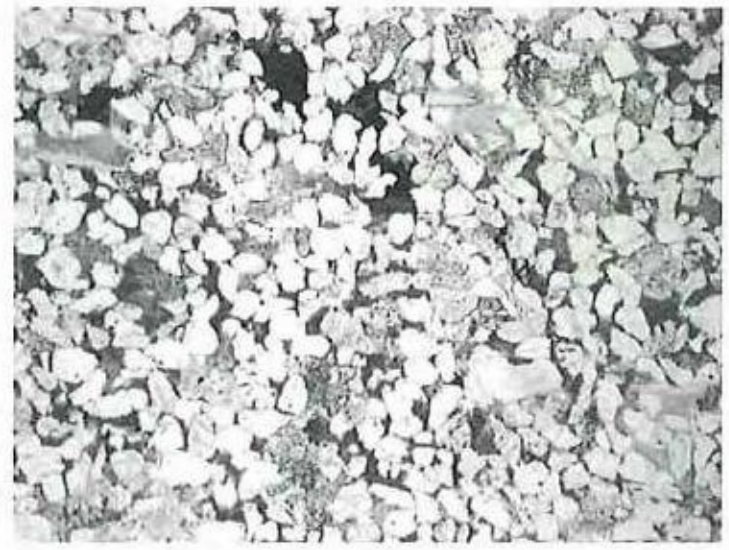
Please keep in mind the following points when considering the list of closest-matching stones.

- The list of closest-matching stones has been arrived at by comparing the stone to be repaired with samples of stone obtained from currently active quarries. 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 quarry stone held by BGS is representative of the stone currently being supplied by the quarry.
- 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.
- The mention of specific stone types should not be taken as an endorsement, or otherwise, of the quality of a particular product.
- Specific functional requirements, block dimension requirements, and the ability of a stone to give a particular masonry tooled finish should be discussed with the supplier prior to specification.
- The inclusion of any stone within the list of 'closest-matching stones' does not guarantee that it will weather sympathetically or co-exist harmoniously with the 'original' stone. The BGS Building Stone Assessment is designed to **maximise the likelihood** that a replacement stone and the 'original' stone will be compatible. However, the small number and range of currently available stones compared to those that have been used in the past mean that it is commonly not possible to identify an ideal match. Furthermore, several factors – including the highly variable character of natural stone, the wide range of natural and human factors that can influence stone decay, and the wide range of environmental settings and conditions that masonry can be subjected to – mean that it is not possible to predict with certainty how replacement stone will perform in masonry.

'Original' stone: 140 West George Street, Glasgow

The characteristics recorded here are based on the sample supplied by the client.

Colour (fresh stone):	very light buff
Stone fabric:	uniform (some orientated grains)
Grain-size:	fine-sand-grade
Distinctive features:	none
Cohesion (freshest stone):	strongly cohesive
Permeability:	high



Closest-matching stones

Sample ED11966 has been identified as an Upper Limestone Formation sandstone, which was likely sourced from one of the former building stone quarries in the Giffnock or Bishopbriggs quarrying areas. The sample has high permeability, contains carbonate, and is light buff in colour. Only one of the stones listed below – Drumhead sandstone – has comparable characteristics. No other quarries currently work Upper Limestone Formation sandstones for building stone.

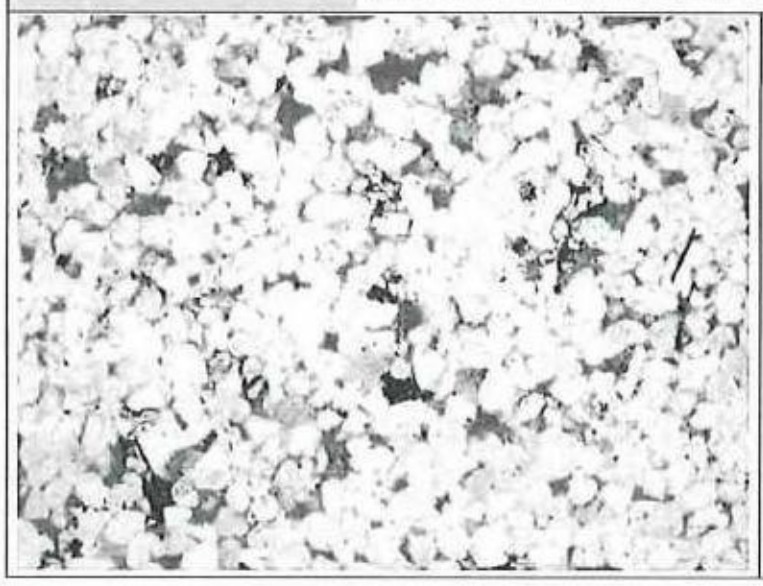
The descriptions below refer to the typical character of the stone supplied by each quarry, as represented by samples held in the BGS Collection of UK Building Stones, but will not encompass all of the variation that may be encountered.

Please also note:

Where a substitute stone is placed next to 'original' stone in stonework (particularly in ashlar) the two stones ideally should have similar permeability characteristics; if they do not, moisture and air might be prevented from moving freely through the stonework, which over time can lead to localised stone decay. For this reason, only stones that have a similar permeability character to the 'original' stone ('high' permeability, according to the simple qualitative test used by BGS) have been included in the list of closest-matching stones.

Mortar can also play an important role in inhibiting 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 chance of producing a long-lasting, successful outcome. Portland cement, which is essentially impermeable, should not be used as mortar in stonework.

Drumhead sandstone	
Colour:	Very light buff to buff.
Stone fabric:	Uniform to irregularly laminated (with cross and parallel lamination).
Grain-size:	Fine-sand-grade to medium-sand-grade.
Permeability:	High.
Distinctive features:	The buff stone contains occasional orangish iron oxide banding/staining.
Comments:	Drumhead quarry extracts stone from the Upper Limestone Formation, which is the likely bedrock source of the stone represented by sample ED11966. As such, it has the potential to provide a very good match for the existing stonework in terms of its geological characteristics. Stone is extracted from Drumhead quarry on a relatively small scale. Samples of the stone being supplied at present, and details of current constraints on production volumes and timescales, should be obtained from the operator at an early stage. Stone can only be supplied as rough block; cutting would need to be arranged separately. Drumhead sandstone can feature cross and parallel lamination, which if present would contrast visually with the existing stonework. The possibility of obtaining uniform stone (i.e. without any lamination) should therefore be discussed with the supplier.

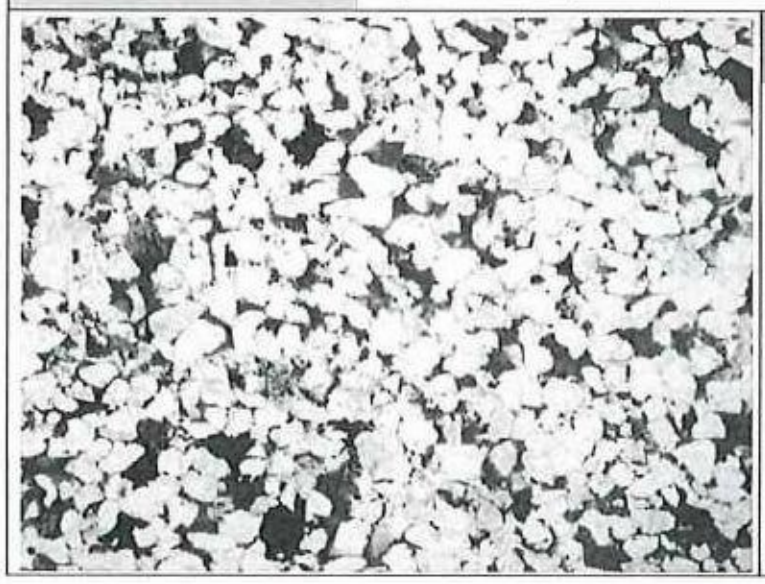


Supplier details:

David Graham
Drumhead Sandstone Ltd.
Denovan Mains
Stirlingshire
FK6 6GT
[redacted]

(continued on page 9)

Darney sandstone	
Colour:	Light buff (sold as 'Darney Cream sandstone') to buff with orangish banding (sold as 'Darney Gold sandstone').
Stone fabric:	Mostly uniform, occasionally with faint parallel bedding.
Grain-size:	Fine-sand-grade to medium-sand-grade.
Permeability:	High.
Distinctive features:	The stone can contain iron-rich nodules and iron oxide banding, though these are unlikely to affect its performance significantly.
Comments:	Darney sandstone varies somewhat in colour. Samples of the current production range should be obtained and inspected with the aim of achieving the best possible colour match. A light buff coloured variant should provide the best match for the stone represented by sample ED11966.



Supplier details:

Hutton Stone Co Ltd.
Masons & Stone Merchants
West Fishwick
Berwick-upon-Tweed
TD15 1XQ
Tel: 01289 386056
[redacted]

Dunhouse Buff sandstone	
Colour:	Light buff to buff.
Stone fabric:	Uniform (with some aligned grains indicating the bedding orientation).
Grain-size:	Fine-sand-grade to medium-sand-grade.
Permeability:	High.
Distinctive features:	The stone can contain scattered black carbonaceous flakes typically up to 10 mm long.
Comments:	None.

Supplier details:

Dunhouse Natural Stone
Dunhouse Quarry Ltd.
Darlington
County Durham
DL2 3QU
[redacted]

(continued on page 10)

High Nick sandstone

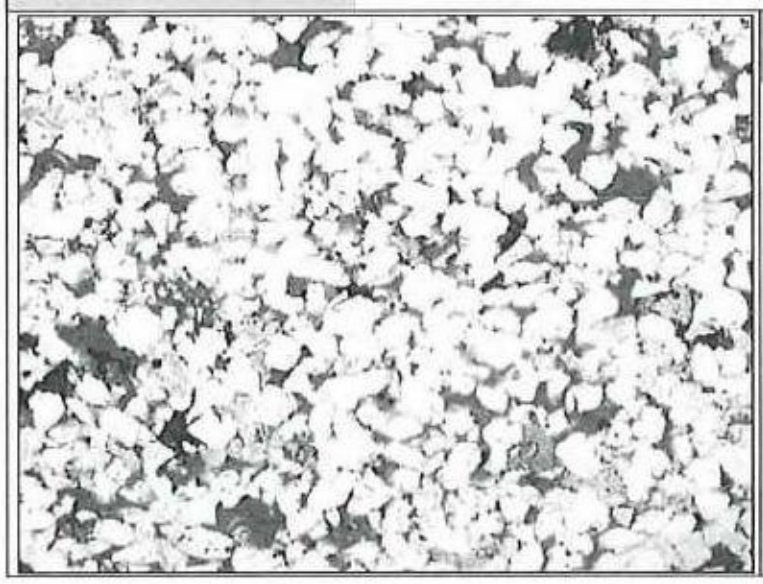
Colour:	Very light buff. A variety known as 'Tiger Stripes' contains strong, irregular ochreous iron oxide banding.
Stone fabric:	Uniform (with some aligned grains indicating the bedding orientation).
Grain-size:	Medium-sand-grade.
Permeability:	High.
Distinctive features:	High Nick sandstone can contain iron oxide nodules, typically of several millimetres to several centimetres diameter, which can be enclosed by 'halos' of brown iron-stained stone that are significantly larger than the nodules themselves; the size and frequency of these in the stone currently being quarried should be discussed with the supplier. The 'Tiger Stripes' variety is characterized by iron oxide banding and staining.
Comments:	Uniform light buff High Nick sandstone (*not* the 'Tiger Stripes' variety) should be specified in the present case. All High Nick stone can feature some natural iron staining; this is unlikely to affect its performance significantly, though it may create a visual contrast with the existing stonework of the building.

Supplier details:

Robert Charlton
Border Stone Quarries
Haltwhistle
Northumberland
NE49 0HQ
Tel: 01434 322140
Email: enquiries@borderstonequarries.com
Web page: www.borderstonequarries.com

Hazeldean sandstone

Colour:	White to light grey with buff and pink tones.
Stone fabric:	Uniform (with some aligned grains indicating the bedding orientation).
Grain-size:	Fine-sand-grade to medium-sand-grade.
Permeability:	High.
Distinctive features:	None.
Comments:	Samples representing the current production range in full should be obtained in order to assess which provides the closest match in terms of appearance.



Supplier details:

Hutton Stone Co Ltd.
Masons & Stone Merchants
West Fishwick
Berwick-upon-Tweed
TD15 1XQ
Tel: 01289 386056
Email: info@huttonstone.co.uk
Web page: www.huttonstone.co.uk

Analysis by: Paul Everett

Checked by: Dr Stephen F. Parry

Date: 13/06/2019

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Research Avenue South
Edinburgh
EH14 4AP

Appendix 1 Background to a BGS Building Stone Assessment of sandstone

Sandstone consists of adhering sand grains with unfilled gaps (pore spaces) and/or a mineral 'cement' between the grains. Sand grains are small – between 2 and 0.064 millimetres in diameter – so many of the intrinsic properties of a sandstone, including the relative proportions of the various constituent minerals, the grain-size and textural arrangement of the constituents, and the porosity (pore space) characteristics, can only be determined accurately by microscope examination. Some properties, including the colour and fabric of the stone, can be determined adequately with the unaided eye. Still others, including the cohesiveness and permeability of the stone, require a simple test to make an adequate evaluation. Each property can vary considerably from one sandstone to another, and no two sandstones are identical.

Each of the intrinsic properties of sandstone plays a role in determining how any one stone responds to the complex physical and chemical processes associated with weathering. The result is that no two sandstones respond to weathering in exactly the same way and at the same rate. If more than one type of sandstone is used in a stone structure, obvious contrasts in the appearance and condition of masonry blocks commonly become apparent over time. Furthermore, placing two sandstones of contrasting permeability next to each other in masonry can lead one (usually the more permeable stone) to suffer accelerated decay. For these reasons, it is generally considered good practice to repair or replace 'original' sandstone masonry with sandstone that is the closest achievable match in terms of the properties that govern how the stone responds to weathering ('weathering properties'). This maximises the likelihood that the replacement stone will co-exist harmoniously with the 'original' stone and will weather sympathetically. The poorer the match between the weathering properties of the replacement stone and the 'original' stone, the greater is the likelihood that the condition and appearance of the two stones will diverge over time.

The purpose of a Building Stone Assessment is to identify which stones from the range currently being supplied by quarries in the UK most closely match the stone requiring repair or replacement. Special requirements of the replacement stone – for example, load-bearing capacity, suitability for carving or tooling, and salt resistance – are taken into consideration if requested.

Appendix 2 Methodology

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 Collection of UK Building Stones, to constrain the source of the stone. Historical records (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 stones 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.

Petrographic examination

A macroscopic examination of the sample of 'original' stone is performed with the unaided eye and using a binocular microscope. A microscope examination is performed on a thin section (a slice of the stone sample cut thin enough to be transparent), using a polarizing microscope. Before preparing the thin section, the stone is impregnated with blue resin to highlight pore spaces. The thin section is cut perpendicular to the bedding fabric of the stone (where this is visible), and is positioned to be as representative as possible of the sample. The thin section is typically cut to include the freshest part of the supplied stone sample, and also any weathered part and/or exposed (exterior) surface where these are present.

Observations from these examinations are recorded on a Petrographic Description Form designed for building stones, to ensure the description is systematic and consistent with the procedures set out in British Standard BS EN 12407:2000 (*Natural stone test methods – Petrographic examination*). The completed Petrographic Description Form is included in this report, with a set of accompanying notes describing each of the recorded properties. The description is accompanied by one or more photographs illustrating the typical character of the stone as it appears in the thin section.

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 Collection of UK Building Stones; historical records (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 stones 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. Particular attention is paid to those minerals and textural features that are known to play a significant role in sandstone decay and discolouration.

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. A brief description and a thin section photograph are provided for each.

Appendix 3 Supporting notes for the petrographic description

Each numbered note below relates to a superscript number in the Petrographic Description Form (Section 2).

1 The determination of stone type follows the classification and nomenclature of the BGS Rock Classification Scheme.

2 The 'visual' determination of stone colour is based on a simple assessment with the unaided eye in natural light. The 'Munsell' determination is obtained by matching the stone colour to one of the coloured patches in a Munsell Rock Colour Chart; each patch has a unique colour and a unique code (the 'Munsell code'), which incorporates values for hue and chroma. In stones displaying variable colour, both the 'visual' and 'Munsell' determinations record the colour deemed by the geologist to be most representative. The determination of stone colour is made on a broken (not sawn), dry surface.

3 A simple, non-quantitative assessment of the degree to which the stone is cohesive. This property is recorded in terms of four conditions, each representing one segment of a continuum: *strongly cohesive*, *moderately cohesive*, *moderately friable*, and *very friable*. The grains in a *strongly cohesive* stone cannot be disaggregated by hand, whereas the grains in a *very friable* stone can be readily disaggregated by hand.

4 A record of whether the distribution of granular (detrital) constituents in the sample is essentially isotropic (uniform) or anisotropic (non-uniform). The type of anisotropic fabric is recorded.

5 A record of the identity and relative proportions of all granular (detrital) and intergranular (authigenic materials and pore space) constituents currently in the stone. The proportions are estimates, expressed in %, which are based on a visual assessment of the whole thin section area.

6 The terms are those used for grain-size divisions in the BGS Rock Classification Scheme.

7 A simple, non-quantitative assessment of the degree to which detrital constituents display similarity in terms of physical characteristics (in particular the size and shape of grains).

8 A simple, non-quantitative assessment of the degree to which detrital constituents are abraded.

9 A simple, non-quantitative assessment of stone permeability, presented as one of five conditions (*very low*, *low*, *moderate*, *high*, *very high*) expressed relative to a nominal 'average' permeability in building stone sandstones. The assessment is based on: (i) a water bead test; (ii) the proportion of pore space in the stone; (iii) a visual assessment of the degree to which pore spaces appear connected in the thin section.

10 A record of the type and extent of authigenic mineral cement that acts to bind detrital grains, as observed in thin section. *Isolated* means the cement occurs in discrete locations (e.g. as overgrowths on individual detrital grains) that are typically not connected in the plane of the thin section. *Discontinuous* means the cement is formed in patches, each of which typically encloses several to many detrital grains. *Continuous* means the cement is more-or-less connected across the thin section.

11 A record of the evidence observed in thin section for mineral alteration that occurs in the stone when it is near the ground surface. Such alteration processes typically begin before stone is quarried, but some may continue, or be initiated, after stone is extracted from the ground.

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- 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 quite 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.

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