British Geological Survey
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A Building Stone Assessment of The Engine Shed, Stirling

Minerals and Waste Programme

Commissioned Report

CR/14/088N

BRITISH GEOLOGICAL SURVEY

MINERALS AND WASTE PROGRAMME

COMMISSIONED REPORT CR/14/088 N

A Building Stone Assessment of The Engine Shed, Stirling

LJ Albornoz-Parra, EA Tracey and MR Gillespie

Keywords

The Engine Shed, Seaforth Place Bridge, Stirling, sandstone, building stone, stone matching, building repair, Historic Scotland.

National Grid Reference

Centre point 279970,693548

Bibliographical reference

Albornoz-Parra, LJ, Tracey, EA and Gillespie, MR. 2014. A Building Stone Assessment of The Engine Shed, Stirling. *British Geological Survey Commissioned Report*, CR/14/088. 29pp.

Keyworth, Nottingham British Geological Survey 2014

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British Geological Survey offices

BGS Central Enquiries Desk

Tel 0115 936 3143 Fax 0115 936 3276
email enquiries@bgs.ac.uk

Environmental Science Centre, Keyworth, Nottingham NG12 5GG

Tel 0115 936 3241 Fax 0115 936 3488
email sales@bgs.ac.uk

Murchison House, West Mains Road, Edinburgh EH9 3LA

Tel 0131 667 1000 Fax 0131 668 2683
email scotsales@bgs.ac.uk

Natural History Museum, Cromwell Road, London SW7 5BD

Tel 020 7589 4090 Fax 020 7584 8270
Tel 020 7942 5344/45 email bgslondon@bgs.ac.uk

Columbus House, Greenmeadow Springs, Tongwynlais, Cardiff CF15 7NE

Tel 029 2052 1962 Fax 029 2052 1963

Maclean Building, Crowmarsh Gifford, Wallingford OX10 8BB

Tel 01491 838800 Fax 01491 692345

Geological Survey of Northern Ireland, Colby House, Stranmillis Court, Belfast BT9 5BF

Tel 028 9038 8462 Fax 028 9038 8461

www.bgs.ac.uk/gsni/

Parent Body

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon SN2 1EU

Tel 01793 411500 Fax 01793 411501
www.nerc.ac.uk

Website www.bgs.ac.uk
Shop online at www.geologyshop.com

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Summary

This report describes the outcomes of a project commissioned by Historic Scotland to identify suitable stone to use in forthcoming repairs to the building known as The Engine Shed, in Stirling, which will become Historic Scotland's National Conservation Centre. A Building Stone Assessment has been conducted on three samples of sandstone supplied by Historic Scotland – two from different parts of The Engine Shed and one from the recently demolished Seaforth Place Bridge in Stirling – with a view to assessing whether stone recovered from the demolished bridge could be considered amongst the closest-matching currently available stones and therefore a suitable replacement stone. This assessment has shown that stone from the bridge is amongst the closest-matching stones, and should provide a good replacement stone for walling and copestones in The Engine Shed provided weathered stone is first removed from the recycled blocks and any blocks required to perform a load-bearing function are subjected to a geotechnical test to confirm they are sufficiently strong. Drumhead sandstone, which is currently quarried near Denny, should also provide a good replacement stone.

1 Introduction

The British Geological Survey (BGS) has been asked by Historic Scotland (HS) to conduct a Building Stone Assessment as part of a project to repair and convert the building known as The Engine Shed, in Stirling, which will become Historic Scotland's National Conservation Centre.

The purpose of a Building Stone Assessment is to identify the most suitable stone to use in projects to repair or convert stone-built structures. A BGS Building Stone Assessment is usually performed in three stages: a sample of the original stone is first subjected to a detailed petrographic examination, to establish the range and character of its intrinsic properties; 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, are also taken into account); 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. Using the closest-matching stone in repairs to stone structures maximises the likelihood that the replacement stone will co-exist harmoniously with the original stone and will weather sympathetically.

In this case, BGS has been asked by HS to include in the assessment (as a possible matching stone) a sample of stone recovered from Seaforth Place Bridge, which has been demolished and replaced recently. The demolished bridge was approximately 150 metres north of Stirling Railway Station and 300 metres north-west of The Engine Shed.

In support of the assessment, the client has provided three samples of sandstone for analysis, which are assumed to be representative of the structures they were collected from:

- a piece of sandstone rubble c.130 x 80 x 25 mm from external walling in The Engine Shed; the assigned BGS sample number is ED11316
- a piece of dressed sandstone c.130 x 80 x 25 mm from a copestone of The Engine Shed; the assigned BGS sample number is ED11317
- a piece of dressed sandstone c.140 x 120 x 60 mm recovered from the former (now demolished) Seaforth Place Bridge; the assigned BGS sample number is ED11318.

To meet the project objectives, it was agreed that BGS would:

- conduct a full petrographic characterisation of the three stone samples supplied by HS; a thin section of each sample (a slice of the stone thin enough to be transparent so it can be examined using a microscope) has been prepared as part of this task
- comment on the likely quarry source of each sample (based on a comparison with samples held in the BGS rock collections and a desktop review of archival records)
- identify the closest-matching currently available stones that could be used as a substitute for original stone used in The Engine Shed

- comment on whether stone from the demolished Seaforth Place Bridge could be counted amongst the closest-matching stones, and could therefore be considered for use in repairs to The Engine Shed.

The project has been conducted under the terms of the Memorandum of Agreement (2011-2016) between HS and Natural Environment Research Council (as represented by BGS).

Background information relating to a BGS Building Stone Assessment of sandstone is presented in Appendix 1. 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 Location and history

2.1 THE ENGINE SHED

The building known as The Engine Shed is located in the Forthside area of Stirling, approximately 150 metres east-south-east of Stirling Railway Station. The site on which The Engine Shed sits was undeveloped at the time the first edition Ordnance Survey (OS) map of the area was published (1865; Figure 1). Several unlabelled buildings on the second edition OS map (1899) are the first recorded structures on the site (Figure 2), and the building now forming The Engine Shed appears on the third edition OS map (1923) as part of an Ordnance Depot comprising approximately twenty built sites (Figure 3; site labelled “Ordnance Stores”). The building was therefore constructed at some time between 1896 and 1913 (the years in which the OS second and third edition maps were resurveyed and revised).

Today, only six buildings from the Ordnance Depot survive, three of which were on the second edition OS map and all of which were on the third edition map. None of the buildings on the site have ‘listed building’ status; however, details of the site (Stirling, Forthside, Ministry of Defence Ordnance Depot; Canmore ID 285840) were recorded between March and September 2013 as part of a project called ‘World War One Audit of Surviving Remains’ that was carried out in partnership between HS and Royal Commission on the Ancient and Historical Monuments of Scotland (RCAHMS).

The Engine Shed is the northern-most building on the former Ordnance Depot site, and now stands in relative isolation. The building has a distinctive raised lantern running the length of the roof, and a large south-facing door. The second edition OS map shows a rail siding running to, and perhaps through, the south-facing door; none of the rail sidings remain in place today.

2.2 SEAFORTH PLACE BRIDGE

Seaforth Place Bridge provides a vehicular crossing over the railway c. 150 metres north of Stirling Railway Station. Although the railway tracks are present on the first edition OS map (Figure 1) the bridge does not appear until the second edition OS map (Figure 2), making the bridge contemporary with construction of the Ordnance Depot and slightly earlier than the building now forming The Engine Shed.

Work to replace Seaforth Place Bridge took place between June 2013 and May 2014; at this time the original late 19th century bridge was demolished and replaced.

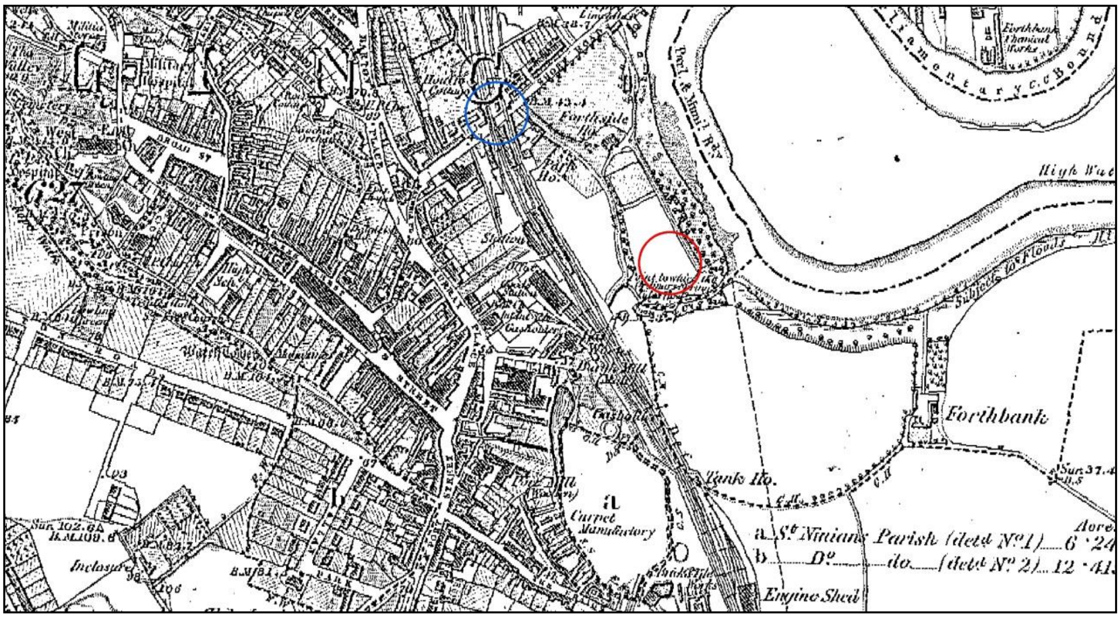


Figure 1 First edition Ordnance Survey map, Stirlingshire Sheet XVII, surveyed 1860, published 1865. The blue circle and red circle indicate the present locations of Seaforth Place Bridge and The Engine Shed, respectively; both structures were yet to be constructed at the time of the survey for the first edition OS map. Scale 1:4000.

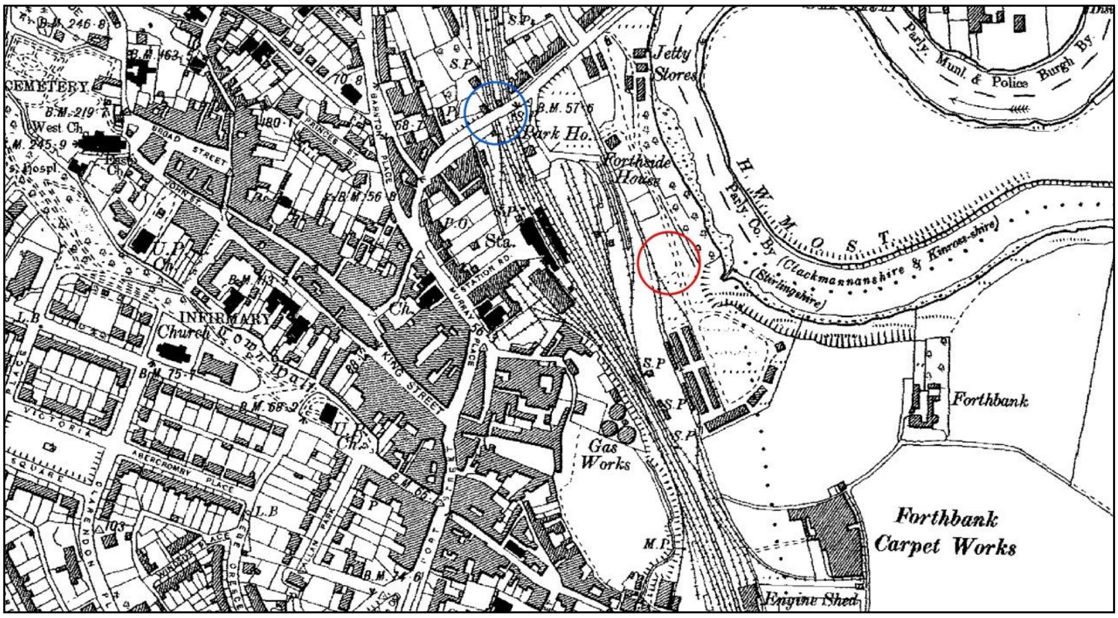


Figure 2 Second edition (or first revision) Ordnance Survey map, Stirlingshire Sheet XVII.NE, revised 1896, published 1899. The blue circle indicates the location of Seaforth Place Bridge and the red circle indicates the location of The Engine Shed. The bridge is present at this time; the building now forming The Engine Shed is still to be constructed. Scale 1:4000.

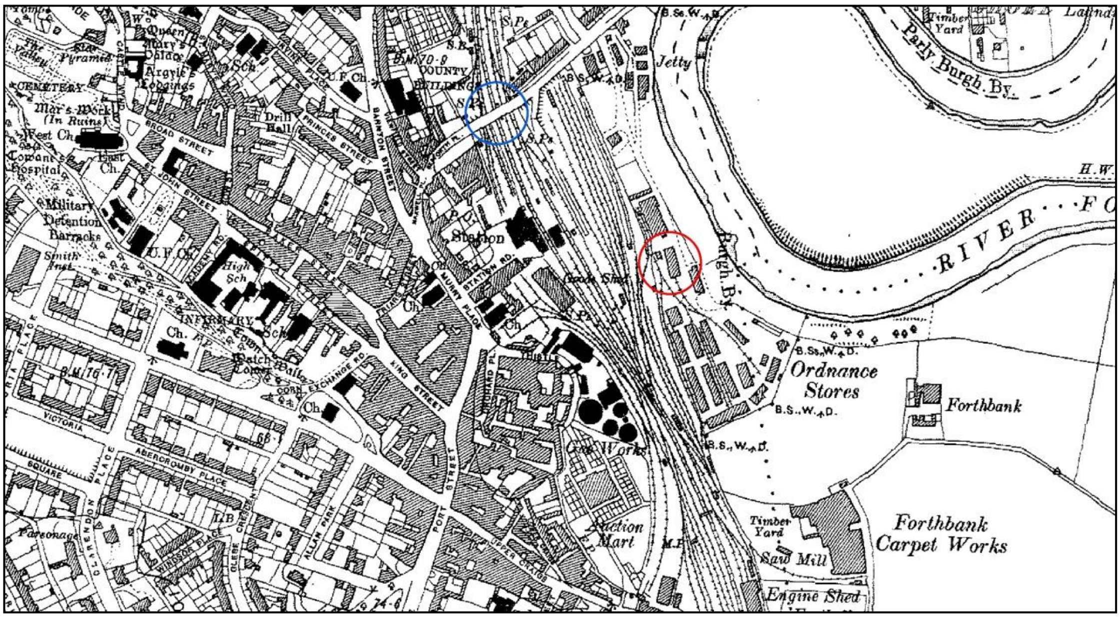


Figure 3 Third edition (or second revision) Ordnance Survey map, Stirlingshire Sheet XVII.N, revised 1913, published 1923. The blue circle indicates the location of Seaforth Place Bridge and the red circle indicates the location of The Engine Shed. Both structures are present at this time. Scale 1:4000.

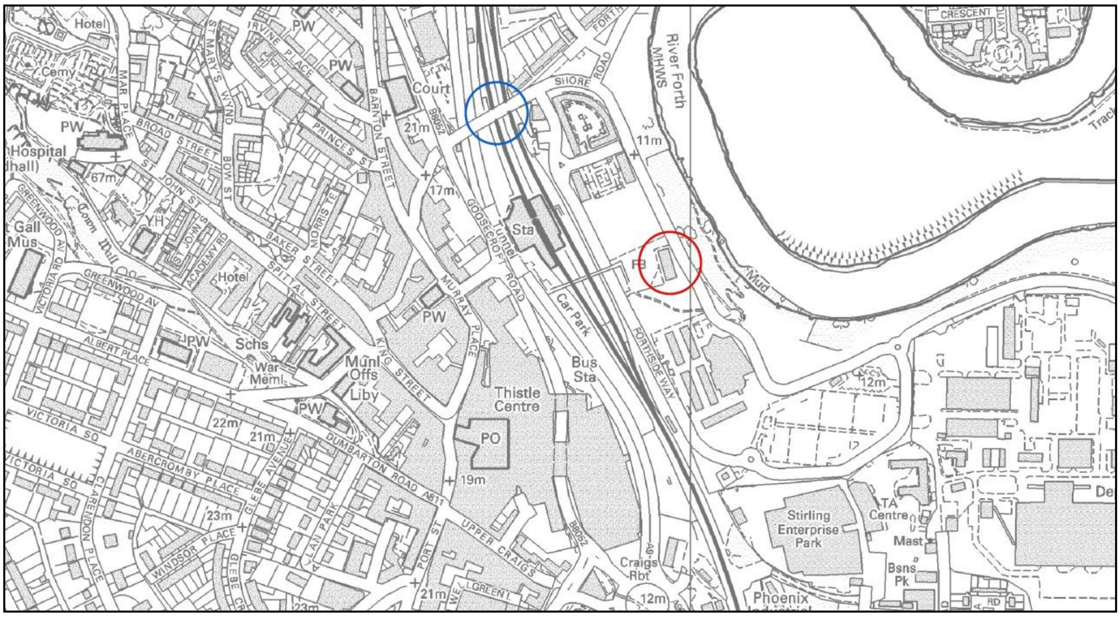


Figure 4 Present day OS map showing both Seaforth Place Bridge (blue circle) and The Engine Shed (red circle). The late 19th century Seaforth Place Bridge has recently been replaced. Scale 1:4000.

3 Petrographic characterisation of samples and possible quarry sources

Short summaries of the geological character of each sandstone sample are presented in this section, together with our assessment of the source of the stone. A desk-top review of archival sources (including the Pevsner Architectural Guide to Stirling and Central Scotland, the Statistical Accounts for Stirlingshire, and the RCAHMS 'Canmore' database) has revealed no historical records indicating which quarries supplied the stone used in either the building now forming The Engine Shed or the former Seaforth Place Bridge. The source of the stone used in both structures has therefore been assessed using geological criteria alone, and is described below in terms of bedrock geology, bedrock age, quarry area and quarry name. The source bedrock unit and potential source quarries have been identified on the basis of a comparison of the intrinsic properties of the supplied stone sample and reference samples of quarried stone held in the BGS Collection of UK Building Stones. The letters D (definite), L (likely), P (possible) and NK (not known) indicate the level of confidence attached to the assessment.

A full petrographic description for each sample is presented in Appendix 3, with supporting information in Appendix 4.

3.1 WALLING STONE FROM THE ENGINE SHED – SAMPLE ED11316

3.1.1 Stone character

The stone is very light greyish buff, strongly cohesive, fine- to medium-grained, quartz-rich and mica-bearing sandstone, with uniform texture (i.e. lacking obvious bedding in the hand specimen). The stone contains numerous fragments up to 5 mm long of black carbonaceous matter (fossilised plant fragments), and particles of dark brown iron oxide which give the stone a 'speckled' character. The mica flakes and fragments of carbonaceous matter are aligned and indicate the bedding orientation. The sand grains are bound by a mineral cement comprising small proportions of silica (~3%) and calcite (~2%). The stone has a moderate proportion of pore space for building stone sandstone (~15% of volume), and high permeability.

3.1.2 Stone source

Bedrock unit:	Scottish Lower (or Middle) Coal Measures Group	P
Age:	Carboniferous Period (359-299 million years old)	L
Quarry area:	North Lanarkshire	P
Quarry name:	Overwood	P

Quarry status: all of the quarries that once operated in this area are now closed.

Comments: The mineral-textural characteristics of the sample of walling masonry from The Engine Shed are similar to those of building stone samples from the Scottish Lower Coal Measures Group and Scottish Middle Coal Measures Group held within the BGS Collection of UK Building Stones. These two bedrock units crop out extensively in the Midland Valley of Scotland, and many quarries have produced sandstone from them. Amongst the BGS samples, sandstone from Overwood quarry (near Stonehouse, Lanarkshire) is the most similar. Some of the other possible source quarries include those at Auchinlea, Bellside, Braehead, Bredisholm and Budhill (all in Lanarkshire).

3.2 COPESTONE FROM THE ENGINE SHED – SAMPLE ED11317

3.2.1 Stone character

The stone is light buff, strongly cohesive, medium-grained, quartz-rich sandstone with uniform texture (i.e. lacking obvious bedding in the hand specimen). The sand grains are bound by a mineral cement comprising a small proportion of silica (~2%) and large proportions of calcite (~14%) and clay (~11%). The stone has a moderate proportion of pore space for building stone sandstone (~12% of volume), and high permeability. The stone is in good condition (not weathered).

3.2.2 Stone source

Bedrock unit:	Upper Limestone Formation	L
Age:	Carboniferous Period (359-299 million years old)	L
Quarry area:	North Lanarkshire	L
Quarry name:	Dullatur	P

Quarry status: all of the quarries that once operated in this area are now closed.

Comments: The mineral-textural characteristics of the copestone sample from The Engine Shed are closely similar to a sample of sandstone from Dullatur quarry held within the BGS Collection of UK Building Stones. However, many other quarries produced stone of similar character from the Upper Limestone Formation and it is not possible to identify the quarry source unambiguously.

3.3 STONE FROM SEAFORTH PLACE BRIDGE – SAMPLE ED11318

3.3.1 Stone character

The stone is very light buff, strongly cohesive, fine-grained, quartz-rich sandstone with a weakly laminated character imparted by several parallel, light grey laminae ~1mm thick and 3-5 centimetres apart in otherwise uniform sandstone. The sand grains are bound by a mineral cement comprising small proportions of silica (~3%), calcite (~4%) and clay (~5%). The stone has a moderately high proportion of pore space for building stone sandstone (~17% of volume), and high permeability. The stone is in good condition (not weathered) and has the characteristics of good quality building sandstone.

3.3.2 Stone source

Bedrock unit:	Upper Limestone Formation	L
Age:	Carboniferous Period (359-299 million years old)	L
Quarry area:	Stirling	L
Quarry name:	Plean (Blackcraig)	P

Quarry status: with just one exception (Drumhead quarry, near Denny), all of the quarries that once operated in this area (including Plean quarry) are now closed.

Comments: The mineral-textural characteristics of the Seaforth Place Bridge sample are closely similar to those of building stone samples from Plean quarry (also known as Blackcraig quarry) held within the BGS Collection of UK Building Stones. Plean quarry is approximately 7 km south-south-east of the site of Seaforth Place Bridge. However, many other quarries produced stone of similar character from the Upper Limestone Formation and it is not possible to identify the quarry source unambiguously.

3.4 COMPARISON OF SAMPLE CHARACTERISTICS

The key characteristics of the three analysed sandstone sample are summarised in Table 1. The two samples from The Engine Shed almost certainly come from Carboniferous strata in the central part of the Midland Valley of Scotland, but their characteristics are sufficiently different to suggest they come from different geological formations. The characteristics of the Seaforth Place Bridge sample suggest it probably comes from the Upper Limestone Formation but from a different quarry than the copestone from The Engine Shed.

	Engine Shed walling	**Engine Shed copestone**	**Seaforth Place Bridge**
Source area	Midland Valley of Scotland (possibly North Lanarkshire)	Midland Valley of Scotland (probably North Lanarkshire)	Midland Valley of Scotland (likely Stirlingshire)
Geological formation	Scottish Lower (or Middle) Coal Measures Group (Carboniferous Period)	Upper Limestone Formation (Carboniferous Period)	Upper Limestone Formation (Carboniferous Period)
Colour (fresh stone)	Very light greyish buff	Light buff	Very light buff
Texture	Uniform	Uniform	Faintly laminated
Grain-size	Fine-grained to medium-grained	Medium-grained	Fine-grained (grading to medium-grained)
Stone type	Sublithic-arenite, with rare carbonate minerals and a moderate proportion of clay minerals	Quartz-arenite with relatively abundant carbonate and clay minerals	Sublithic-arenite with a small proportion of carbonate and clay minerals
Porosity	c. 15%	c. 12%	c. 17%
Permeability	High	High	High

Table 1: Comparison of key characteristics in the three analysed sandstone samples

4 Closest-matching currently available stones

The quarries that produced the stone used in The Engine Shed have not been identified unambiguously, but the characteristics of the walling stone and copestone samples indicate they were sourced from Carboniferous strata in the central part of the Midland Valley of Scotland. All the possible candidate quarries have been closed for many years and it is therefore not possible to obtain new supplies of the original stone. An assessment of the closest-matching stones from active quarries in the UK has therefore been made, and the properties of these stones have been compared with the Seaforth Place Bridge stone to determine whether the latter should be considered amongst the closest-matching stones.

4.1 STONE FROM ACTIVE QUARRIES

Only two quarries in the Midland Valley currently produce Carboniferous sandstone for building stone: Cullalo quarry in Fife and Drumhead quarry near Denny. Cullalo sandstone is not a good match for The Engine Shed sandstone and can be discounted. Drumhead sandstone is from the Upper Limestone Formation and would provide a good match for the copestone sample and a reasonable match for the walling sample.

Swinton quarry, near Kelso, is the only other active quarry in Scotland currently producing Carboniferous sandstone. Swinton sandstone is mica-bearing and as such would provide a reasonable match for the walling stone used in The Engine Shed.

Several other currently available stones would provide a reasonable match for stone used in The Engine Shed, all of which come from quarries exploiting Carboniferous strata in the north of England; these are High Nick sandstone, Blaxter sandstone, Dunhouse Buff sandstone, Prudham sandstone and Stainton sandstone. However, in terms of their intrinsic properties these stones would provide a poorer match than Drumhead sandstone.

Summary descriptions of the stones mentioned above, and contact details for the suppliers, are presented in Appendix 5.

4.2 STONE FROM SEAFORTH PLACE BRIDGE

A comparison of the stone from Seaforth Place Bridge with samples from The Engine Shed and samples representing the closest-matching stones from active quarries indicates that the bridge stone can be considered one of the closest-matching stones, and in fact should provide a closer match than any of the stones from active quarries with the possible exception of Drumhead sandstone.

5 Conclusions

All three analysed samples of stone – two from The Engine Shed and one from Seaforth Place Bridge – were almost certainly sourced from Carboniferous strata underlying the central part of the Midland Valley of Scotland. They all consist of broadly similar sandstone with only relatively small differences in colour, grain-size, texture and composition, but the differences nevertheless suggest each was sourced from a different quarry. The copestone sample from The Engine Shed and the Seaforth Place Bridge sample are likely to have been sourced from Upper Limestone Formation strata, whereas the walling sample from The Engine Shed is likely to have been sourced from Scottish Lower (or Middle) Coal Measures Formation strata.

A desktop review of archival sources has revealed no historical records indicating which quarries produced the stones used in The Engine Shed and Seaforth Place Bridge. Several possible candidate quarries have been identified using geological criteria, but it has not been possible to identify the source quarries unambiguously. All the possible candidate quarries have been closed for many years and it therefore will not be possible to obtain new supplies of the original stone.

An assessment of sandstones from all the active quarries in the UK has shown that Drumhead sandstone, which is quarried near Denny, is the closest-matching stone. This stone should provide a good match for the copestone sample and a reasonable match for the walling sample from The Engine Shed. Drumhead sandstone is from the Upper Limestone Formation.

Swinton quarry, near Kelso, is the only other active quarry in Scotland currently producing Carboniferous sandstone. Swinton sandstone is broadly similar in many respects to both samples from The Engine Shed; the sandstone is mica-bearing and as such would provide a reasonable match for the walling stone used in The Engine Shed.

High Nick sandstone, Blaxter sandstone, Dunhouse Buff sandstone, Prudham sandstone and Stainton sandstone, all of which come from quarries exploiting Carboniferous strata in the north of England, are also included in a list of the closest-matching stones, and any of these could be considered a reasonable substitute for the original stone (copestone and walling stone) in The Engine Shed. However, in terms of their intrinsic properties these stones would provide a poorer match than Drumhead sandstone.

A comparison of the stone from Seaforth Place Bridge with samples from The Engine Shed and samples of the closest-matching stones from active quarries indicates that the bridge stone can be considered one of the closest-matching stones, and in fact should provide a closer match than any of the stones from active quarries with the possible exception of Drumhead sandstone.

The two stones from The Engine Shed are distinct and were clearly sourced from different quarries, but they nevertheless are reasonably similar in terms of their colour and intrinsic properties; it is likely therefore that one carefully chosen replacement stone could be used as a substitute for both original stones.

The sandstone in the sample from Seaforth Place Bridge is in good (unweathered) condition, but parts of the recovered blocks of sandstone are likely to be weathered to some degree (and possibly to varying degrees depending on their original position in the bridge). If blocks recovered from the bridge are used in The Engine Shed it will be important to remove weathered stone. If the replacement blocks are to perform a load-bearing function they should be subjected to a geotechnical test to confirm they are sufficiently strong.

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 used in a 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 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 Petrographic descriptions

SAMPLE ED11316 – WALLING STONE FROM THE ENGINE SHED

See Appendix 4 for notes describing each numbered item below.

Hand specimen observations

Stone type [1] (general classification):	sandstone
Stone colour [2] **–** fresh stone:	very light greyish buff
Stone colour [2] **–** weathered stone:	not applicable
Stone colour [2] **–** exterior surface:	greyish buff
Stone cohesion [3] **–** fresh stone:	strongly cohesive
Stone cohesion [3] **–** weathered stone:	not applicable
Stone fabric [4]:	uniform (some orientated grains)
Distinctive features:	carbonaceous material

Thin section observations

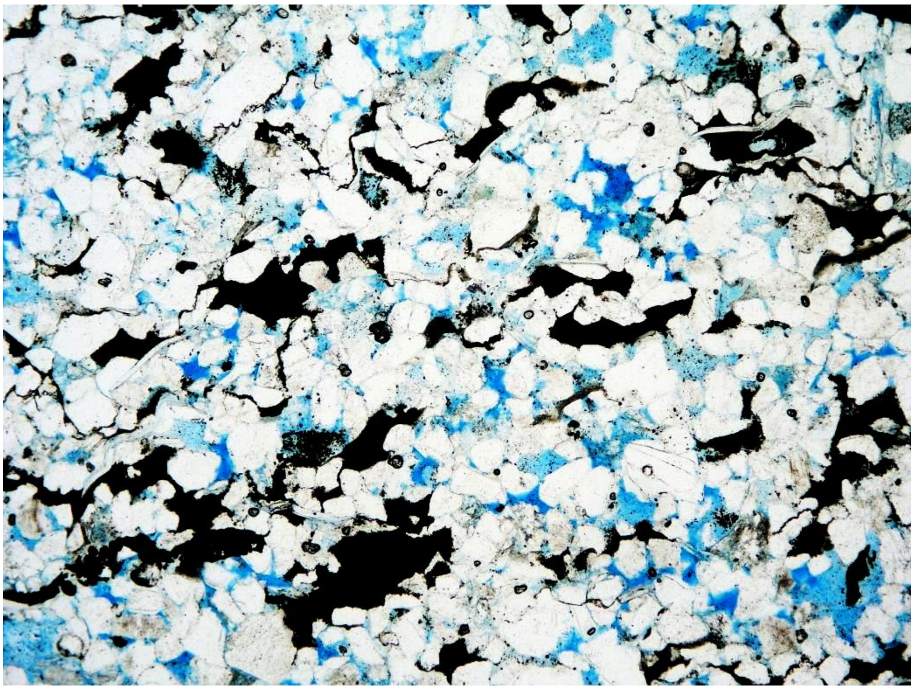
Stone constituents [5]:

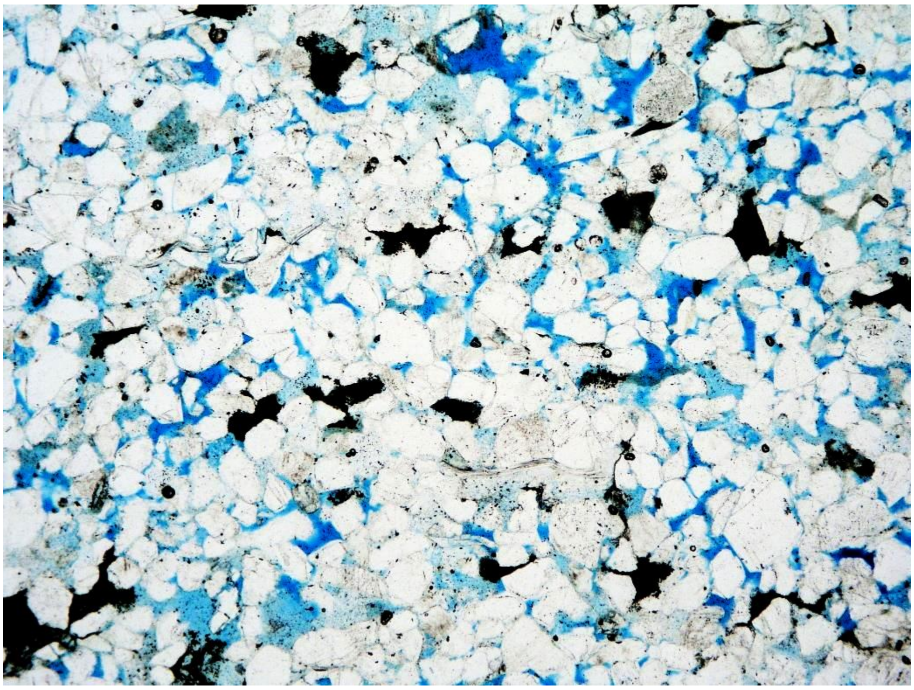
Granular (detrital) constituents		*Intergranular constituents*	
Quartz	51%	Silica (overgrowth)	3%
Feldspar	4%	Feldspar (overgrowth)	0%
Rock fragments	7%	Carbonate	2%
Mica	2%	Iron/manganese oxide	3%
Opaque material	4%	Clay	9%
Other	<<1%	Hydrocarbon	0%
Intragranular pores	3%	Intergranular pores	12%

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

Comments

1) The minerals zircon and tourmaline are present in accessory proportions (<<1%).
2) The sample reacts strongly to 10% hydrochloric acid (HCl) solution, indicating that the carbonate mineral is likely to be largely or entirely calcite.





Thin section photographs of sample ED11316. The images were taken in plane-polarised light, and the field of view is c.3.3 mm wide. White grains are mainly quartz, with a small proportion of feldspar and rock fragments. Black patches are iron oxide and carbonaceous material. Pore space appears blue.

SAMPLE ED11317 – COPE STONE FROM THE ENGINE SHED

See Appendix 4 for notes describing each numbered item below.

Hand specimen observations

Stone type [1] (general classification):	sandstone
Stone colour [2] **–** fresh stone:	light buff
Stone colour [2] **–** weathered stone:	orangeish brown
Stone colour [2] **–** exterior surface:	greenish grey
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

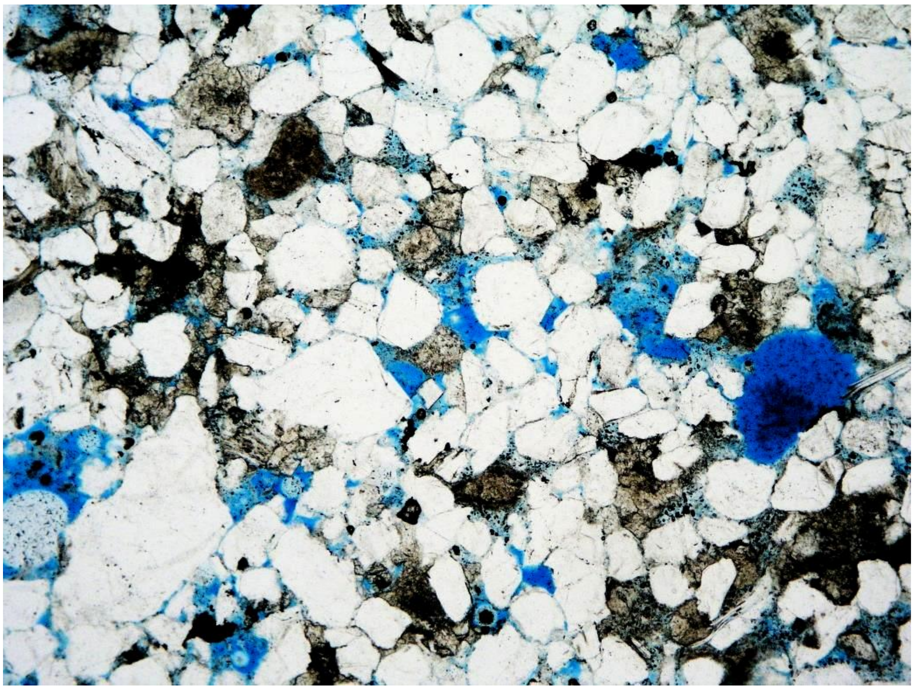
Stone constituents [5]:

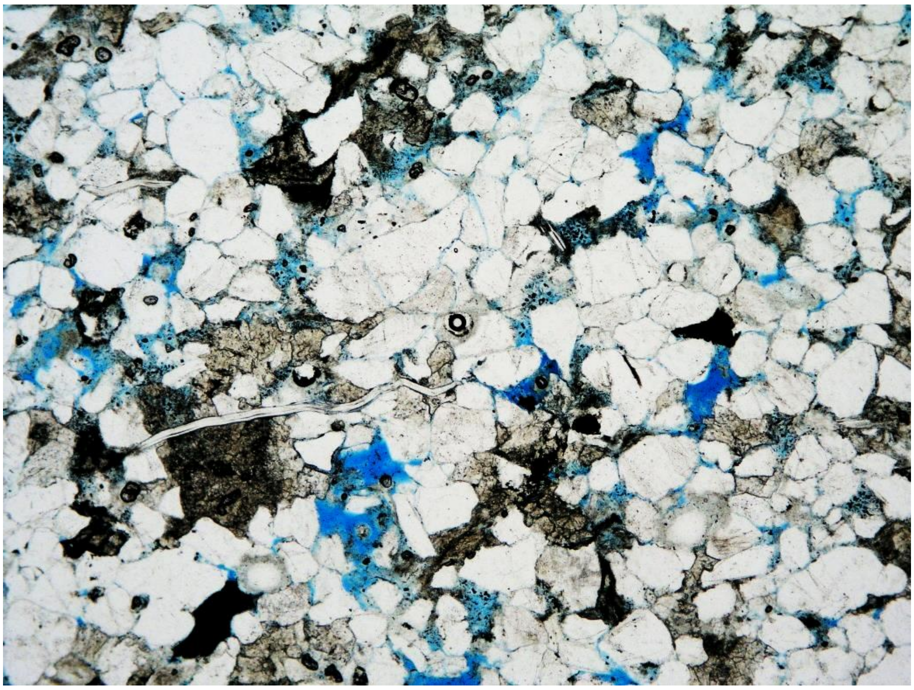
Granular (detrital) constituents		*Intergranular constituents*	
Quartz	54%	Silica (overgrowth)	2%
Feldspar	1%	Feldspar (overgrowth)	0%
Rock fragments	2%	Carbonate	14%
Mica	2%	Iron/manganese oxide	1%
Opaque material	1%	Clay	11%
Other	<1%	Hydrocarbon	0%
Intragranular pores	6%	Intergranular pores	6%

Stone type [1] (detailed classification):	quartz-arenite
Grain-size [6]:	medium-sand-grade
Grain sorting [7]:	moderately well sorted
Grain roundness [8]:	subangular to rounded
Stone permeability [9]:	high
Cement distribution [10]:	silica cement continuous; carbonate cement discontinuous
Supergene changes [11]:	moderate dissolution of feldspar; moderate dissolution of rock fragments; weakly mobilised iron oxides

Comments

1) The mineral zircon is present in accessory proportion (<<1%).
2) The sample reacts strongly with 10% HCl solution, indicating that the carbonate mineral is likely to be largely or entirely calcite.
3) The weathered stone appears reddish brown to a depth of c.2mm, probably due to alteration of iron-bearing carbonate mineral, with the released iron crystallizing as iron oxide on and just below the surface.
4) The colour of the exterior surface is greenish grey due to a combination of biological colonization (algae) and soiling.





Thin section photographs of sample ED11317. The images were taken in plane-polarised light, and the field of view is c.3.3 mm wide. White grains are mainly quartz, with a very small proportion of feldspar and rock fragments. Grey, dirty looking grains are carbonate mineral, and black patches are iron oxide; The iron oxide is largely a product of alteration of the carbonate mineral, and the two minerals commonly occur together. Pore space appears blue.

SAMPLE ED11318 – SEAFORTH PLACE BRIDGE

See Appendix 4 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:	not applicable
Stone colour [2] **–** exterior surface:	light grey
Stone cohesion [3] **–** fresh stone:	strongly cohesive
Stone cohesion [3] **–** weathered stone:	not applicable
Stone fabric [4]:	parallel laminae
Distinctive features:	none

Thin section observations

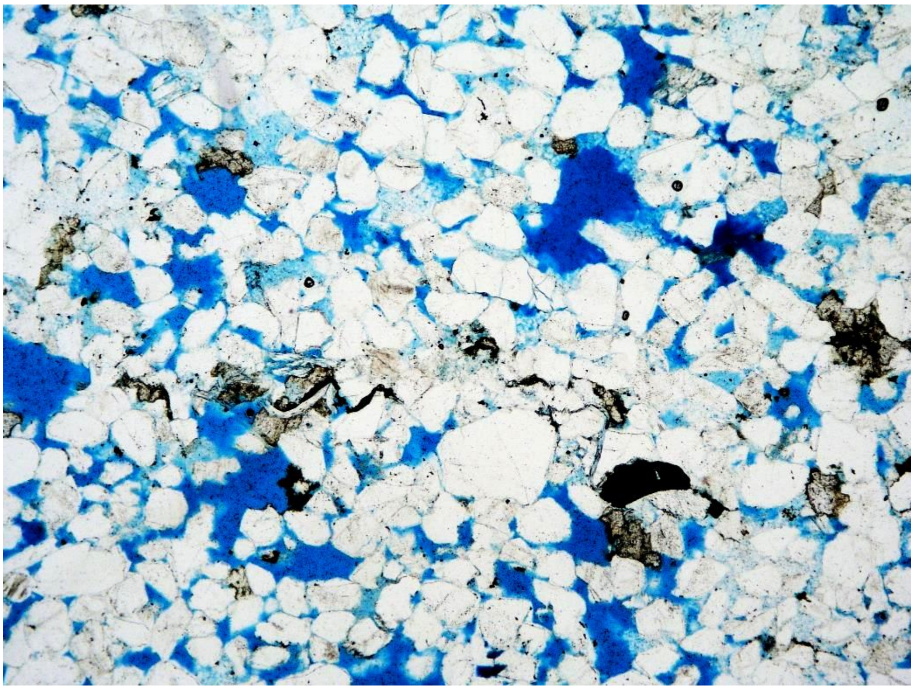
Stone constituents [5]:

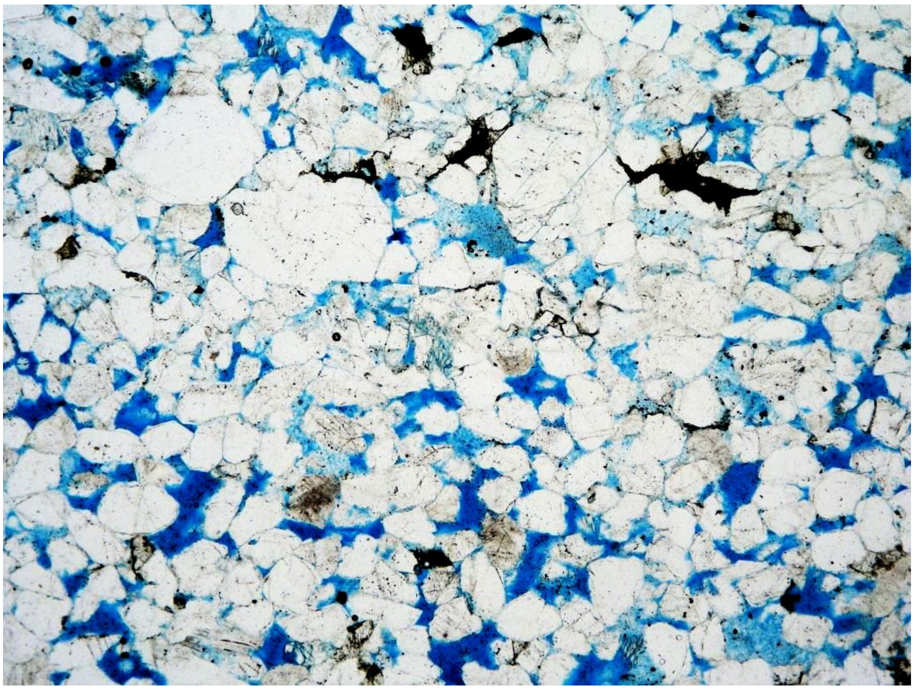
Granular (detrital) constituents		*Intergranular constituents*	
Quartz	62%	Silica (overgrowth)	3%
Feldspar	2%	Feldspar (overgrowth)	0%
Rock fragments	4%	Carbonate	4%
Mica	1%	Iron/manganese oxide	1%
Opaque material	1%	Clay	5%
Other	0%	Hydrocarbon	0%
Intragranular pores	3%	Intergranular pores	14%

Stone type [1] (detailed classification):	sublithic-arenite
Grain-size [6]:	fine-sand-grade
Grain sorting [7]:	moderately 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

Comments

1) The sample reacts strongly to 10% HCl solution, indicating that the carbonate mineral is likely to be largely or entirely calcite.
2) The overall grain-size is fine-sand-grade, but the sample includes a significant proportion of coarser (medium-sand-grade) grains.





Thin section photographs of sample ED11318. The images were taken in plane-polarised light, and the field of view is c.3.3 mm wide. White grains are mainly quartz, with a small proportion of feldspar and rock fragments. Grey, dirty looking grains are mostly carbonate mineral, and black patches are iron oxide. Pore space appears blue.

Appendix 4 Supporting notes for the petrographic descriptions

Each numbered note below relates to a superscript number in the Petrographic Description Form (Appendix 3).

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.

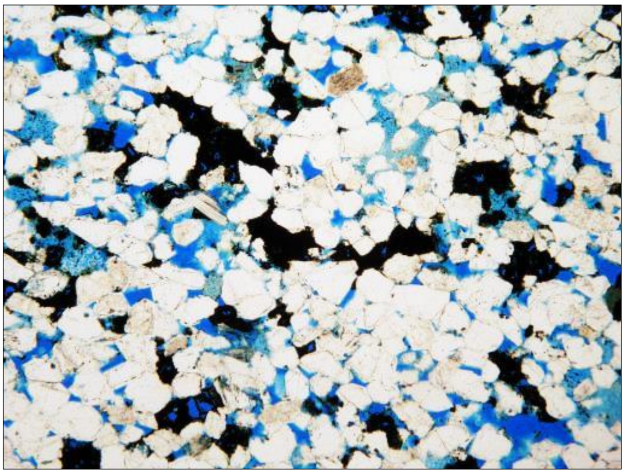
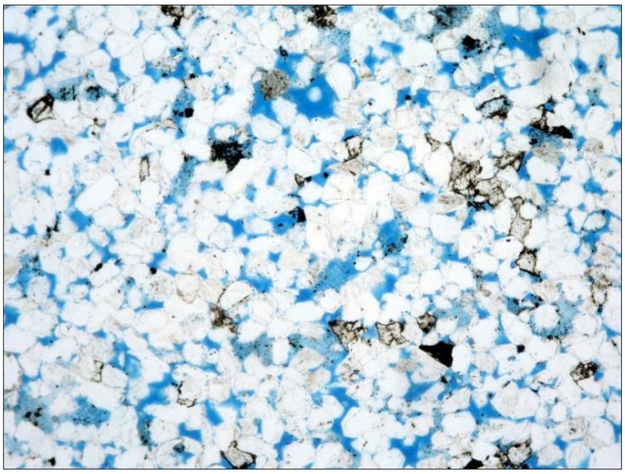
9 A simple, non-quantitative assessment of stone permeability, presented as one of five conditions (*very low*, *low*, *moderate*, *high*, *very high*) expressed relative to a nominal 'average' permeability in building stone sandstones. The assessment is based on: (i) a water bead test; (ii) the proportion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

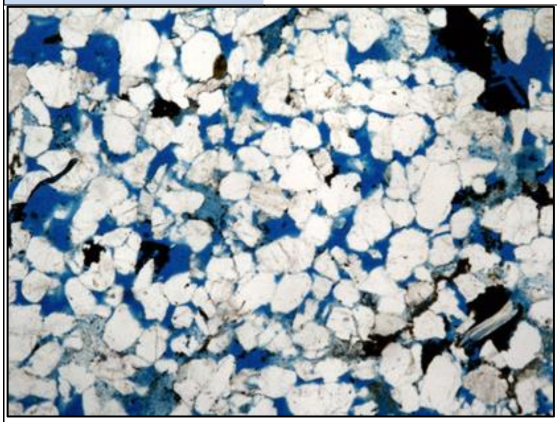
Appendix 5 Summary descriptions of the closest-matching currently available stones

Drumhead sandstone	
Colour (fresh stone):	Drumhead sandstone is supplied in two main colour variants: buff and very light buff.
Stone fabric:	The very light buff stone tends to be uniform. The buff stone ranges from uniform to irregularly laminated (with cross and parallel lamination).
Grain-size:	The very light buff stone is typically fine-sand-grade. The buff stone is typically fine-to medium-sand-grade.
Permeability:	High
Distinctive features:	The buff stone contains occasional orangeish iron oxide banding/staining.
Comments:	Drumhead sandstone is produced from a quarry in the Upper Limestone Formation, near Denny. Samples of both variants of Drumhead sandstone should be obtained for on-site comparison.
Supplier details:	David Graham Drumhead Sandstone Ltd Denovan Mains, Stirlingshire FK6 6GT Tel: 07967 799253 Email: denovanmains@aol.com

Drumhead buff (left) and Drumhead very light buff (right). The photographs were taken in plane-polarised light, and the field of view is c.3.3 mm wide. Pore space appears blue.

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:	Moderate to high
Distinctive features:	High Nick sandstone can contain iron oxide nodules, typically of several millimetres to several centimetres diameter, which can be enclosed in 'halos' of brown iron-stained stone that are significantly larger than the nodules; 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. All High Nick stone can feature some natural iron staining; this is unlikely to affect its performance significantly.



Supplier details:

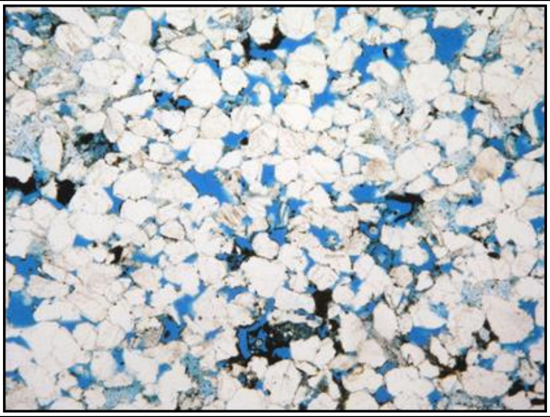
Stancliffe Stone
Keypoint Office Village
Keys Road
Nixs Hill Industrial Estate
Alfreton
Derbyshire
DE55 7FQ

Tel: 0845 302 0702

Email: info@stancliffe.com

Web page: www.stancliffe.com

Blaxter sandstone	
Colour:	Buff
Stone fabric:	Uniform (with some aligned grains indicating the bedding orientation)
Grain-size:	Fine-sand-grade to medium-sand-grade
Permeability:	Generally high but moderate locally
Distinctive features:	Blaxter sandstone can feature some natural iron staining (including curved, parallel bands known as Liesegang bands) and scattered, elongate, brown to green clay nodules that usually do not exceed 2-3 cm in diameter.
Comments:	The iron staining is unlikely to affect the weathering performance significantly. The possibility of obtaining non-stained stone should be discussed with the supplier.



Supplier details:

Dunhouse Natural Stone
Dunhouse Quarry Ltd
Darlington
County Durham
DL2 3QU

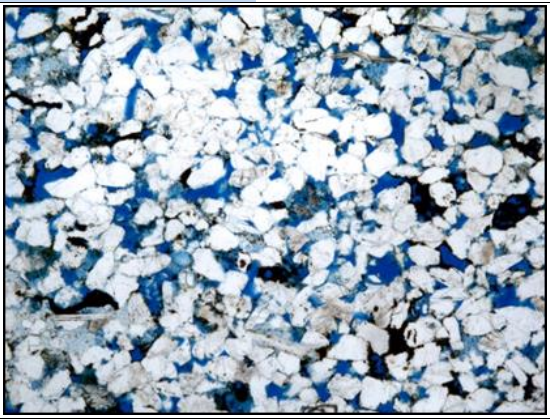
Tel: 01833 660208

Email: enquiries@dunhouse.co.uk

Web page: www.dunhouse.co.uk

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

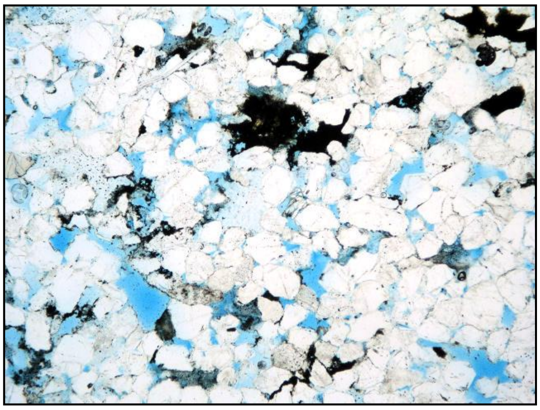
Tel: 01833 660208

Email: enquiries@dunhouse.co.uk

Web page: www.dunhouse.co.uk

Prudham sandstone

Colour:	Buff, pinkish buff, orangeish buff
Stone fabric:	Uniform (some orientated grains)
Grain-size:	Medium-sand-grade
Permeability:	High
Distinctive features:	Faintly speckled
Comments:	None



Supplier details:

Robert Charlton
Border Stone Quarries
Haltwhistle
Northumberland
NE49 0HQ

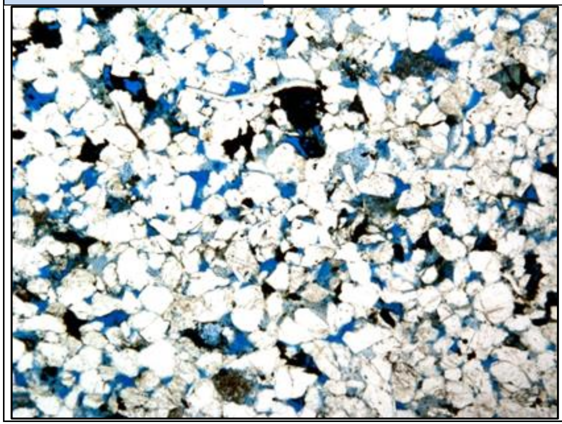
Tel: 01434 322140

Email: enquiries@borderstonequarries.com

Web page: www.borderstonequarries.com

Stainton sandstone

Colour:	Very light buff to light greyish buff
Stone fabric:	Uniform
Grain-size:	Fine-sand-grade to medium-sand-grade
Permeability:	Moderate to high
Distinctive features:	Faintly speckled due to scattered, fine particles of iron oxide
Comments:	None



Supplier details:

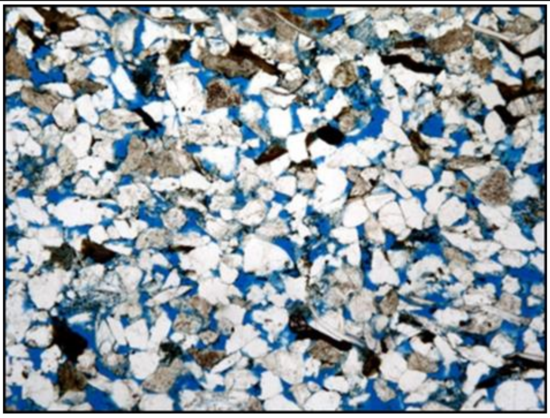
Alvan Scott
Stainton Quarry
Stainton
Barnard Castle
DL12 8RB

Tel: 01833 690444

Email: enquiries@staintonquarry.co.uk

Swinton sandstone

Colour:	Mainly light buff to buff
Stone fabric:	Typically uniform with orientated mica grains (muscovite and biotite); can be faintly bedded or laminated.
Grain-size:	Fine-sand-grade to medium-sand-grade
Permeability:	Very high
Distinctive features:	None
Comments:	None



Supplier details:

Hutton Stone Co Ltd.
Masons & Stone Merchants
West Fishwick
Berwick-upon-Tweed
TD15 1XQ

Tel: 01289 386056

Email: huttonstone@aol.com

Web page: www.huttonstone.co.uk