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A petrological examination of the provenance of stone masonry from three medieval churches in Shetland

Minerals and Waste Programme

Open Report OR/19/014

BRITISH GEOLOGICAL SURVEY

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A petrological examination of the provenance of stone masonry from three medieval churches in Shetland

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Editor

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Cover image

Ruins of St Laurence's Church, Papil, West Burra, Shetland; stone from an earlier medieval church was re-used within the masonry of this C19th church, including the red sandstone blocks visible in the belfry.

Bibliographical reference

EVERETT, P.A. 2019. A petrological examination of the provenance of stone masonry from three medieval churches in Shetland. *British Geological Survey Open Report*, OR/19/014. 42pp.

Keyworth, Nottingham British Geological Survey 2019

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1 Introduction

BGS has been commissioned by Allen Fraser and Jenny Murray, on behalf of Shetland Museum & Archives, to conduct a petrographic examination of sandstone masonry from three churches in Shetland and sandstone bedrock from two historic quarries in Orkney, and use the results to test a hypothesis that the stone forming the Shetland masonry was sourced from Orkney quarries.

The client has provided seven samples of sandstone from masonry blocks, and details of the sampled localities. The blocks are believed to originate from three medieval churches in Shetland, but are now spolia (stone fragments removed from one built structure and incorporated in the masonry of another, later structure). All three of the medieval churches were constructed in the C12th and demolished in either the C18th or C19th. Ashlar blocks and rubble from St Magnus's Church (Tingwall, Mainland) and St Laurence's Church (Papil, West Burra) were incorporated within the masonry of new churches that were built on the same sites. St Mary's Church (Ireland, near Bigton, Mainland) was not replaced after demolition, but stone blocks believed to be from the church have been found in the walls of nearby buildings.

The client has also provided one sample of sandstone from Head of Holland quarry (Mainland, Orkney). Four samples of sandstone bedrock from the BGS Rock Collection – two from Head of Holland quarry and two from Fersness quarry (Eday, Orkney) – have been included in the assessment, so that the full petrographic character of these two historic quarries can be assessed. Both quarries are sited within bedrock assigned to the Eday Group, a geological formation that crops out exclusively in parts of Orkney.

A thin section (a slice of stone cut thin enough to be transparent, so it can be examined by microscope) was prepared from each sample. The petrographic description for each sample includes information from the hand sample and the associated thin section.

Brief details of each sample, with a hand sample photograph, are provided in section 2 of this report. A full petrographic description for each sample, with thin section photographs, is provided in Appendix 1. The key petrographic characteristics are described in section 3, and these are discussed with reference to the provenance of the masonry samples in section 4. Key conclusions are summarised briefly in section 5.

2 Sample details

Brief details of the source and character of each hand sample are provided below. Details for samples collected by the client are based on information provided to BGS.

2.1 SAMPLES OF SPOLIA FROM ST MAGNUS'S CHURCH

The following samples were collected from the masonry of Tingwall Church but are believed to be spolia from the medieval St Magnus's Church. Tingwall Church dates from 1778[1] and is located at OS Grid Reference [HU 41921 43754].

- A 7 x 4 cm piece of dull reddish brown sandstone core, collected from an ashlar block measuring c. 30 x 19 x 19 cm (Figure 1a). The sample, labelled '**T1**' by the client, was assigned the BGS number **ED11910**.
- A 4 x 4 cm piece of mottled bright reddish brown sandstone core (now broken into two pieces), collected from an ashlar block measuring c. 40 x 20 x 15 cm (Figure 1b). The sample, labelled '**T2**' by the client, was assigned the BGS number **ED11911**.

2.2 SAMPLES OF SPOLIA FROM ST LAURENCE'S CHURCH

The 'new' St Laurence's Church (located at OS Grid Reference [HU 36883 31516]) dates from 1815[2] and is now a ruin. The following samples were collected from the ruins but are believed to be spolia from the medieval St Laurence's Church.

- An 8 x 4 cm piece of dull reddish brown sandstone core, collected from a rubble block measuring c. 18 x 16 x 11 cm (Figure 2a). The sample, labelled '**P1**' by the client, was assigned the BGS number **ED11912**.
- A 4 x 4 cm piece of very light yellowish buff sandstone core, collected from a dressed rubble block measuring c. 35 x 15 x 9 cm (Figure 2b). The sample, labelled '**P2**' by the client, was assigned the BGS number **ED11913**.
- A 9 x 5 x 4 cm fragment of dull reddish brown sandstone (Figure 2c), collected from rubble walling. The fragment, labelled '**P3**' by the client, was assigned the BGS number **ED11914**.

2.3 SAMPLES OF SPOLIA FROM ST MARY'S CHURCH

The following samples were obtained from stone artefacts held by Shetland Museum & Archives. The artefacts are reputed to represent spolia from St Mary's Church[3] (located at OS Grid Reference [HU 37610 21928]).

- A 3 x 2 cm piece of dull reddish brown sandstone core (now broken into two pieces), collected from a piece of a dressed masonry block measuring c. 20 x 15 x 15 cm (Figure 3a) that is reputed to be the cupola of the steeple of St Mary's Church. The sample, labelled '**IR1**' by the client, was assigned the BGS number **ED11915**.
- A 4 x 1 cm piece of mottled, dull reddish brown sandstone core, collected from a piece of a dressed masonry block measuring c. 25 x 20 x 12 cm (Figure 3b) found at a croft in Ireland, and

[1] *RCHAMS Canmore website:* https://canmore.org.uk/site/1114/tingwall-st-magnuss-church-and-churchyard

[2] *Moar, P. and Stewart, J. 1944. Newly discovered sculptured stones from Papil, Shetland. Proceedings of the Society of Antiquaries of Scotland. 78, (Nov. 1944), 91-99.* Available online at: https://archaeologydataservice.ac.uk/archiveDS/archiveDownload?t=arch-352-1/dissemination/pdf/vol_078/78_091_099.pdf

[3] *RCHAMS Canmore website:* https://canmore.org.uk/site/586/ireland-church-and-burial-ground

which is reputed to be an example of masonry from St Mary's Church. The sample, labelled '**IR2**' by the client, was assigned the BGS number **ED11916**.

2.4 SAMPLES FROM HEAD OF HOLLAND QUARRY

Head of Holland quarry (OS Grid Reference [HY 48994 12057]) on Mainland, Orkney, formerly extracted sandstone from beds assigned to the Upper Eday Sandstone Formation (part of the Eday Group). This geological formation consists primarily of sandstone strata that were deposited during the Devonian Period (c. 394–383 million years old; Middle Devonian Epoch).

The following sample representing stone currently exposed in the quarry was provided by the client.

- A 15 x 9 x 8 cm piece of dull reddish brown sandstone (Figure 4a), collected from a large worked block in the quarry spoil. The sample, labelled '**HH1**' by the client, was assigned the BGS number **ED11917**.

The following samples from Head of Holland quarry are held in the BGS Collection of UK Building Stones.

- A 15 x 7 x 4 cm rounded cobble of dull reddish brown sandstone (Figure 4b). The sample, labelled '**HH2**' for the purposes of this report, is registered as BGS sample **ECON15658**.
- A 3 x 3 x 2 cm fragment of bright reddish brown sandstone (Figure 4c). The fragment, labelled '**HH3**' for the purposes of this report, is registered as BGS sample **ECON15729**.

HH3 is too small to allow a thin section to be prepared without compromising the integrity of the sample, so the petrographic description is based on the hand specimen only.

2.5 SAMPLES FROM FERSNESS QUARRY

Fersness quarry (OS Grid Reference [HY 53605 33535]) on Eday, Orkney, formerly extracted sandstone from beds assigned to the Lower Eday Sandstone Formation (part of the Eday Group). This geological formation, which lies stratigraphically beneath the Upper Eday Sandstone Formation, also consists largely of sandstone strata that were deposited during the Middle Devonian Epoch of the Devonian Period (c. 394–383 million years old).

The following samples from Fersness quarry are held in the BGS Collection of UK Building Stones.

- A 14 x 7 x 5 cm block of light yellowish buff sandstone (Figure 5a). The block, labelled '**F1**' for ease of reference in this report, is registered as BGS sample **ECON7740**.
- A 10 x 10 x 6 cm block of light yellowish buff sandstone (Figure 5b). This block, labelled '**F2**' for ease of reference in this report, is registered as BGS sample **MC4167**.

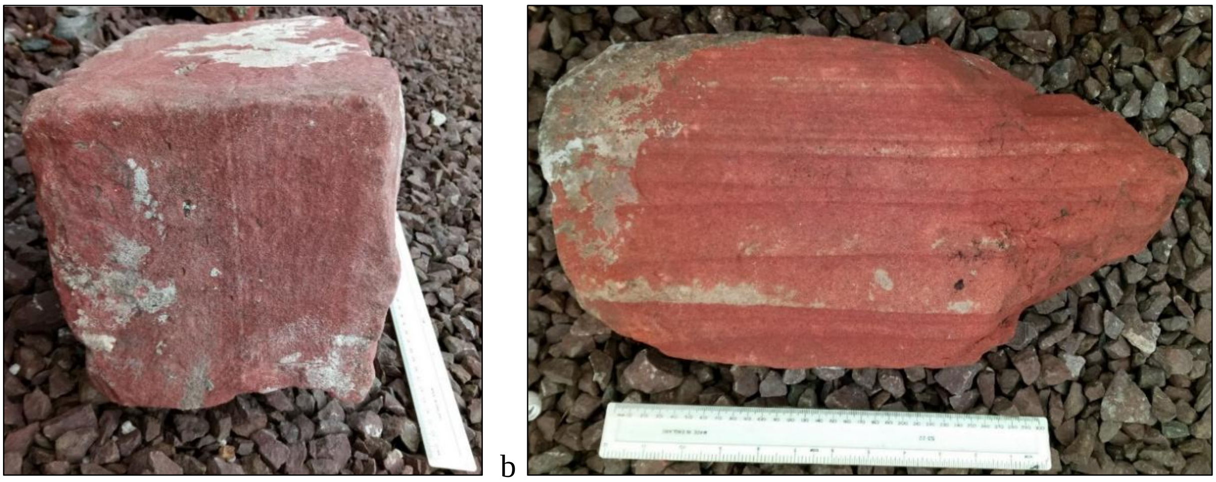
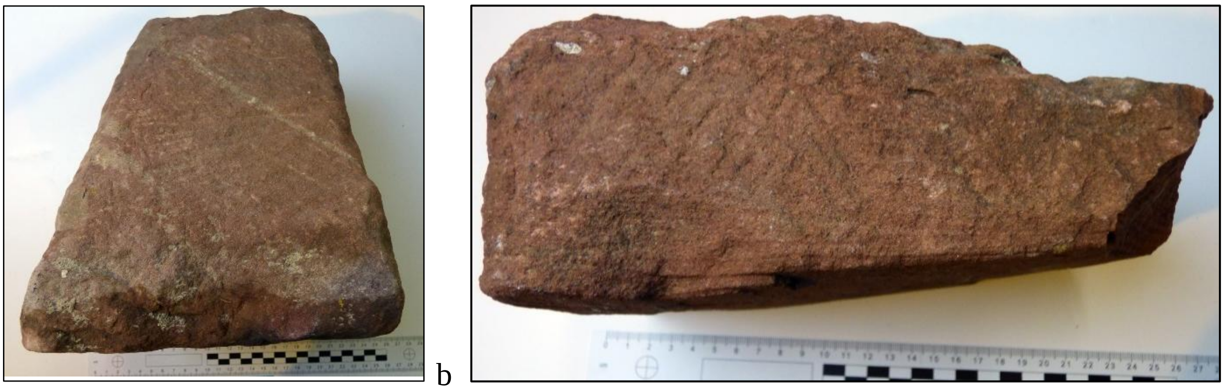


Figure 1. Sandstone samples believed to be spolia from the medieval St Magnus's Church

a) The block from which sample ED11910 ('T1') was cored. b) The block from which sample ED11911 ('T2') was cored. Photographs supplied by the client.

Figure 2. Sandstone samples believed to be spolia from the medieval St Laurence's Church

a) The block from which sample ED11912 ('P1') was cored. b) The block from which sample ED11913 ('P2') was cored. c) Sample ED11914 ('P3'), one fragment from a rubble masonry block. Photographs supplied by the client.



a b

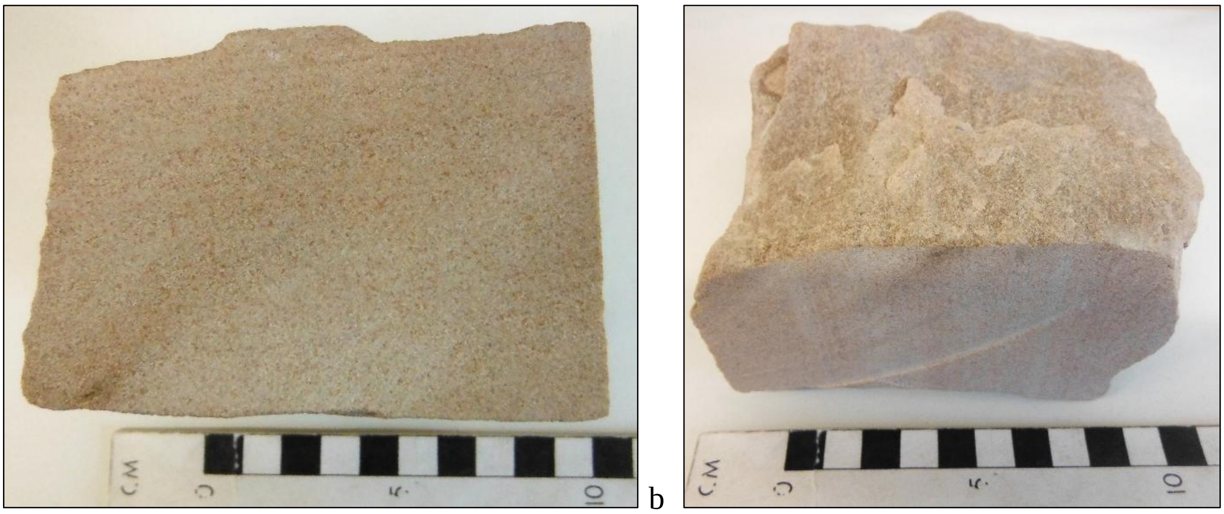
Figure 3. Sandstone samples believed to be spolia from the medieval St Mary's Church

a) The block from which sample ED11915 ('IR1') was cored. b) The block from which sample ED11916 ('IR2') was cored. Photographs supplied by the client.

a b c

Figure 4. Sandstone samples from Head of Holland quarry

a) Sample ED11917 ('HH1'). b) Sample ECON15658 ('HH2'). c) Sample ECON15729 ('HH3').



a b

Figure 5. Samples from Fersness quarry

a) Sample ECON7740 (‘F1’). b) Sample MC4167 (‘F2’).

3 Character and comparison of samples

3.1 FEATURES USED TO CHARACTERISE AND COMPARE SANDSTONES

Sandstones have a wide range of features that can be used to characterise them, and which can be compared. They include features that were 'locked in' at the time the original sandy sediment was deposited (usually called 'primary' or 'depositional' features), and features that develop later in the stone history as it is buried and then uplifted (usually called 'secondary' or 'diagenetic' features).

Primary features include the size, size-distribution, shape, and mineral composition of the original sand grains. These are usually referred to as *grain size*, *grain sorting*, *grain roundness*, and *granular constituents*, respectively. The sand grains in most sandstones are made of three main components – *quartz*, *feldspar* and *rock fragments*. Together, these three constituents typically form most of the volume of a sandstone, and their relative proportions are used to classify the type of sandstone.

Secondary features of a sandstone include the *colour*, *cohesion*, *intergranular constituents*, *porosity* and *permeability*. These are affected by chemical reactions in the stone, as groundwater percolates through the gaps (*pore spaces*) between sand grains under varying conditions of temperature, pressure, acidity and oxygenation. Under some conditions, new (secondary) minerals can grow in the pore spaces, and under other conditions both secondary minerals <u>and</u> some primary minerals can dissolve. When new quartz (also known as *silica*) and feldspar form in the stone, they usually do so by growing directly on sand grains formed of the same minerals, thereby forming *silica overgrowths* (on quartz grains) and *feldspar overgrowths* (on feldspar grains). Secondary *carbonate minerals* (e.g. calcite, dolomite, and ankerite) often form in pore spaces after overgrowths of quartz and feldspar have developed. *Clay minerals* commonly grow in pore spaces when primary feldspar breaks down due to chemical alteration. When minerals grow or dissolve in sandstone, the *porosity* (amount of pore space) and *permeability* (ease with which water and air move through connected pore spaces) generally decrease and increase, respectively. Carbonate minerals usually have a small proportion of iron in them, and when they dissolve the iron typically combines with oxygen to form iron oxide minerals such as *hematite* and *goethite*. These iron-rich minerals are strongly coloured, and they tend to coat the surfaces of sand grains and pore spaces in sandstones; for these reasons, they usually play the dominant role in determining the *colour* of sandstone. The main iron-bearing mineral in brown and orange sandstones is usually hematite, whereas in buff sandstones it is probably mainly goethite. *Stone cohesion* (i.e. how tightly bound the constituents are, and how well they resist disaggregation) reflects how compacted the sand grains are and how well they are bound together by secondary minerals (especially silica overgrowths).

Different sandstones tend to have distinct depositional and diagenetic histories, and they therefore have different ranges and combinations of primary and secondary features. These can be used (through petrographic analysis) to compare samples and determine (or at least constrain) the source (or *provenance*) of the stone.

3.2 PETROGRAPHIC CHARACTER AND COMPARISON OF SAMPLES

Full petrographic descriptions for all samples are presented in Appendix 1, and key features of the analysed samples are summarised in Table 1. The following observations are based on the information in Table 1 and Appendix 1. Photographs to illustrate the typical character of the samples in thin section are presented in Appendix 1 and Figure 6.

The primary features in all samples are closely similar. In particular:

- the grain-size of all samples is the same (fine-sand-grade);
- the absolute amounts of the three main granular constituents lie within narrow ranges (quartz = 44–52%; feldspar = 4–8%; rock fragments = 9–17%);
- the sand grains in all samples are moderately-well-sorted or well-sorted, and most are comprised of sub-rounded to angular grains;
- some form of bedding (parallel bedding or cross-bedding) is visible in nearly all the samples, typically defined by mm-scale thick layers of stone that vary slightly in grain-size; the small size of the samples (relative to the sandstone beds from which they were collected) means the observed variations in bedding character are not meaningful;
- all of the samples classify as *fine-grained sublithic-arenite*.

The secondary features in all samples are also closely similar. For example:

- most are strongly cohesive;
- all have moderately well-formed silica overgrowths;
- none contain secondary carbonate, but most have small proportions of iron (±manganese) oxide minerals whose presence, character and distribution suggest they formed when a formerly extensive pore-filling, iron-bearing carbonate mineral dissolved from the stone;
- most contain similar proportions of intragranular porosity and secondary clay, due to chemical alteration and partial dissolution of primary feldspar;
- the total (i.e. intergranular and intragranular) porosity in all samples is in a relatively narrow range (13–25%);
- based on the simple, qualitative test used by BGS, most samples have the same permeability character (‘moderate’ permeability).

The close similarity in this broad range of petrographic features suggests all the samples come from the same, or a very similar, source.

The feature that varies most obviously amongst the samples is their colour: most samples are homogenous dull reddish brown (T1, P1, P3, IR1, HH2 and HH3), some are homogenous light yellowish buff (P2, F1 and F2), and some (T2, IR2 and HH1) have a heterogeneous, mottled character in which the reddish brown and yellowish buff variants are both represented. Samples from Fersness quarry also appear to be slightly better sorted (well sorted) and somewhat more rounded (rounded to subrounded) than those from Head of Holland quarry.

A petrographic (Table 1) and visual (Figure 7) comparison of sample character suggests that the stone forming samples T1, T2, P1, P3, IR1, IR2 could have been sourced from Head of Holland quarry, while the stone forming sample P2 could have come from Fersness quarry.

Table 1 Summary of key petrographic characteristics in all samples

	Primary features								Secondary features				
Sample id	Grain size	Amounts of key constituents (%)			Grain sorting	Grain roundness	Stone fabric	Stone colour	Cohesion (fresh stone)	Silica o'growth (%)	Pore space (total %)	Permea-bility
		Quartz	Feldsp	Rock								
T1	fine-sand	44	5	16	mod well	subround-angular	parallel bedding	dull reddish brown	strong	3	18	moderate
T2	fine-sand	50	4	9	well	subround-angular	cross bedding	bright reddish brown	mod friable	1	25	high
P1	fine-sand	48	7	14	mod well	subround-angular	cross bedding	dull reddish brown	strong	3	15	moderate
P2	fine-sand	49	6	16	well	round-subround	parallel bedding	v light yellowish buff	strong	1	18	moderate
P3	fine-sand	48	4	16	mod well	subround-angular	parallel bedding	dull reddish brown	strong	4	18	moderate
IR1	fine-sand	47	7	15	mod well	subround-angular	parallel bedding	dull reddish brown	strong	4	17	moderate
IR2	fine-sand	52	4	17	mod well	subround-angular	parallel bedding	dull reddish brown	strong	2	15	moderate
HH1	fine-sand	48	7	17	mod well	subround-angular	cross bedding	dull reddish brown	strong	2	13	moderate
HH2	fine-sand	47	5	16	mod well	subround-angular	parallel bedding	dull reddish brown	strong	2	16	moderate
HH3	fine-sand	-	-	-	-	subround-angular	uniform	bright reddish brown	mod friable	-	-	-
F1	fine-sand	46	8	14	well	round-subround	parallel bedding	light yellowish buff	strong	1	22	high
F2	fine-sand	49	7	16	well	round-subround	parallel bedding	light yellowish buff	strong	1	19	moderate

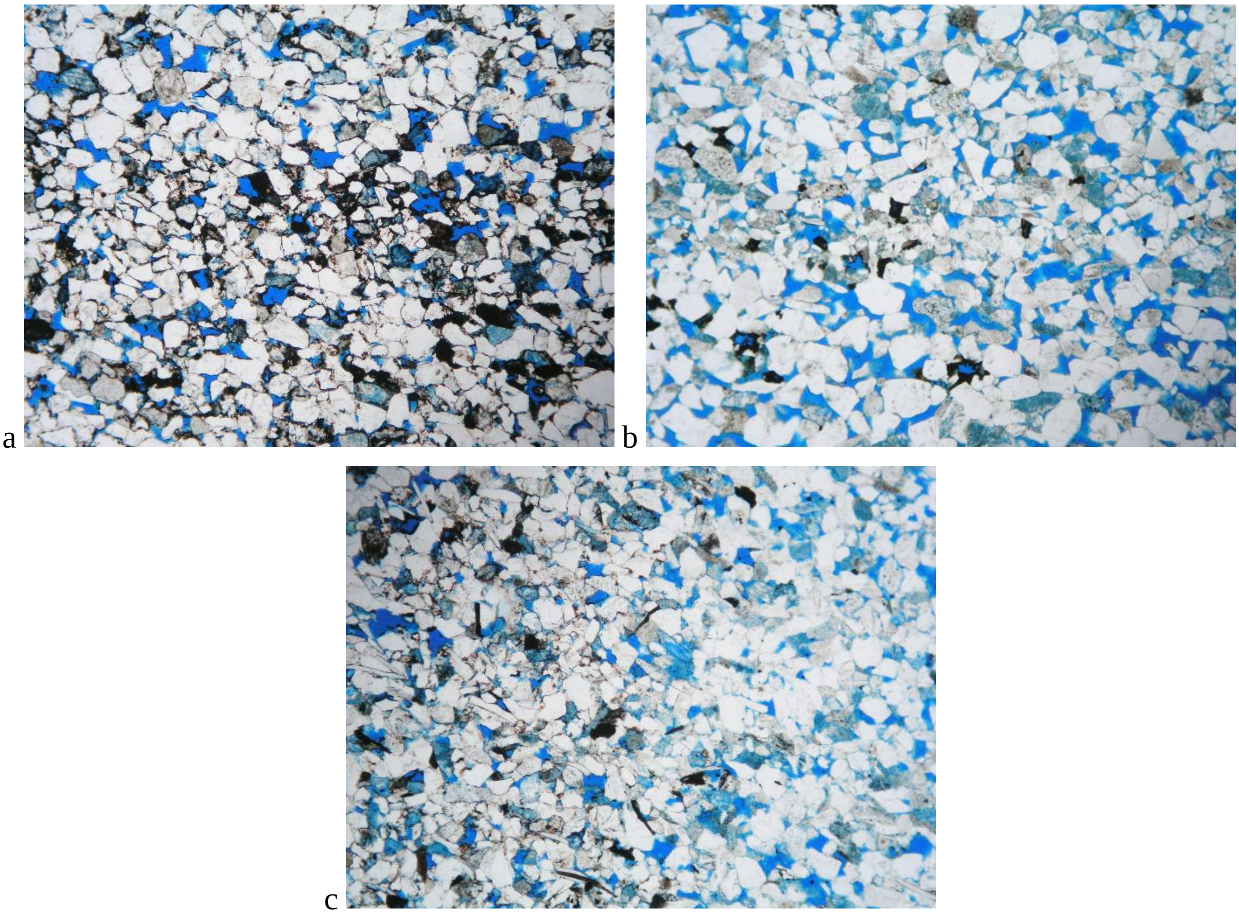


Figure 6. Thin section photographs comparing quarry samples.

a) Dull reddish brown stone in sample HH2 (Head of Holland quarry). b) Light yellowish buff stone in sample F1 (Fersness quarry). c) Boundary between dull reddish brown (left side) and yellowish buff (right side) stone in Sample HH1 (mottled sandstone from Head of Holland quarry). The grain size, grain sorting, grain shape, amount and distribution of pore space, and the proportions and types of granular constituents, are closely similar in all three samples. Iron oxide minerals appear black to brown in thin section. The dull reddish brown stones contain substantially more iron oxide, which typically forms a veneer on detrital grains and patches in pore spaces. By contrast, iron oxide forms only rare, scattered patches in the examples of yellowish buff stone.

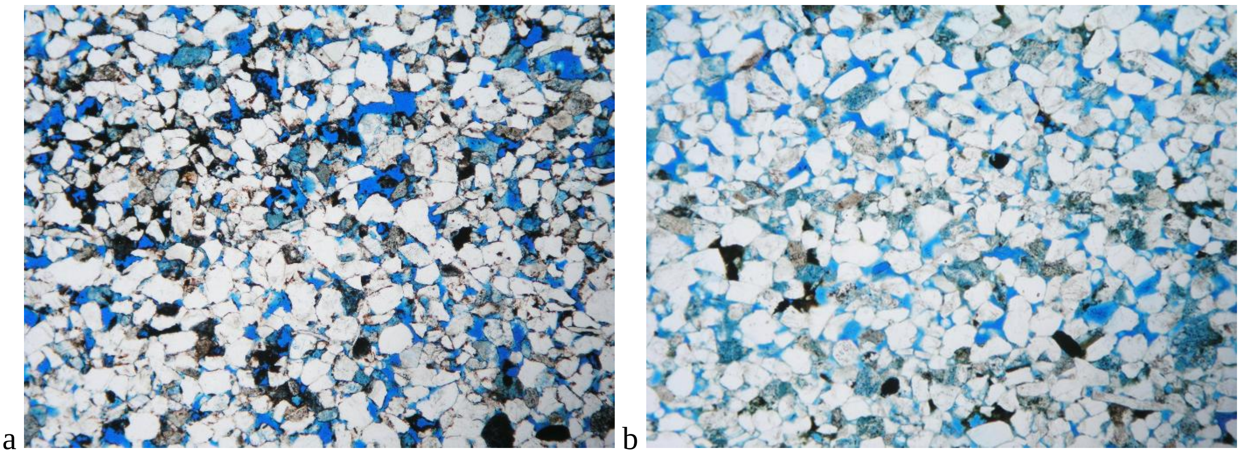


Figure 7. Thin section photographs comparing masonry samples.

a) Dull reddish brown stone in sample T1. b) Yellowish buff stone in sample P2. (a) is virtually identical to samples from Head of Holland quarry (see Figure 6a), while (b) is virtually identical to samples from Fersness quarry (see Figure 6b).

4 Discussion

The close similarity of many primary and secondary petrographic features (described in section 3.2) suggests the sandstone forming all the analysed samples was derived from a similar sediment source, deposited in a similar environment, and experienced a similar post-depositional history. The petrographic evidence therefore provides strong support for a hypothesis that the Shetland masonry samples and Orkney quarry samples are from the same bedrock unit (Eday Sandstone Group).

The most striking way in which the samples differ is in terms of their colour. Sandstone colour depends largely on the abundance and character of iron oxide minerals, and this in turn depends on the composition and history of groundwater in the stone, and its effect on iron-bearing minerals.

A detailed review of the groundwater history of sandstones in the Eday Group (and therefore the origin of the variations in stone colour) is beyond the scope of this study. However, the character and distribution of observed mineral-textural features and colour variations in the samples is consistent with the following explanation.

- An iron-bearing carbonate mineral, which at one time was probably present in all parts of the Eday Group, was dissolved completely due to a change in groundwater composition at some stage in the geological history of the Eday Group (probably related to a substantial geological event, such as regional uplift). As iron was released from the dissolving carbonate, the iron oxide mineral hematite was deposited on grain surfaces and pore surfaces, giving the stone a broadly homogeneous dull reddish brown colour. The stone samples from Head of Holland quarry are typical of stone in this condition.
- A later change in groundwater composition caused hematite to become unstable, and it was largely removed from parts of the Eday Group, producing stone with a yellowish buff colour. The stone samples from Fersness quarry are typical of stone in this condition. This process was distributed unevenly in the Eday Group, at all scales. Much of the Lower Eday Formation was affected (and is now mainly yellowish buff), whereas the Upper Eday Formation was largely unaffected (and is now mainly reddish brown). A mottled or spotted character, where both colours occur heterogeneously on the hand sample scale, developed locally where the groundwater was able to penetrate only certain parts of the rock.
- Stone with a bright reddish brown colour and moderately friable (less cohesive) character (exemplified by samples T2 and HH3) developed locally, where the stone has been affected by oxidising water. This is likely to be related to geologically recent weathering processes, but it is unclear if this took place before or after the stone was quarried.

Devonian sandstone strata also crop out in parts of Shetland, raising the possibility that the sandstone used in Shetland churches might have been sourced on Shetland. A detailed examination of potential sandstone sources in Shetland is beyond the scope of this study, but a brief inspection of a selection of BGS samples of Devonian sandstones from several localities representing different bedrock units in Shetland has shown that they are all of significantly different character to the samples examined in this study. The Shetland sandstones and the Orkney Eday Group sandstones were deposited in different sedimentary basins (Mykura 1976)[4], and therefore would be expected to have different and distinct petrographic characteristics. The available evidence therefore suggests it is unlikely that any of the examined masonry samples represent stone quarried in Shetland.

[4] *Mykura, W. 1976. British regional geology: Orkney and Shetland. Edinburgh, HMSO*. Available online at: http://earthwise.bgs.ac.uk/index.php/Middle_Old_Red_Sandstone_of_Orkney,_Eday_Beds

5 Conclusions

A petrographic and visual comparison of sandstone samples representing spolia from three medieval (C12th) churches in Shetland and two historical quarries on Orkney has shown that all samples are closely similar in many key geological characteristics. This leaves little doubt that all samples come from within the same bedrock unit, supporting a hypothesis that masonry used to build the Shetland churches came from quarries in Eday Group bedrock on Orkney.

Samples from Head of Holland quarry (Upper Eday Sandstone Formation) and Fersness quarry (Lower Eday Sandstone Formation) on Orkney display the full range of petrographic features displayed in the Shetland masonry samples. Both quarries are reputed to have provided sandstone for St Magnus's Cathedral in Kirkwall, Orkney[5], in which case they may have existed since the C12th when the earliest parts of St Magnus Cathedral were built. Thus, the petrographic and historical evidence suggests these quarries provided the sandstone used to build medieval sites of worship in Shetland. However, the possibility that some (or all) of the stone was sourced from other undocumented sites within the outcrop of the Eday Group on Orkney cannot be ruled out on the basis of the available geological evidence.

Sandstone samples from the Eday Group show significant variation in colour, which can be reddish brown, yellowish buff, or a mottled or spotted combination of the two. The colour variation is believed to reflect variations in the distribution and character of iron oxide minerals in the stone, which result from the uneven percolation of compositionally distinct groundwaters through the stone during its geological history.

[5] *St Magnus Cathedral website: https://www.stmagnus.org/building.html*

Appendix 1 Petrographic descriptions

A description for each sample, recorded on a standardised petrographic description form, is presented on the following pages. Each description is based on a visual examination of the hand sample (performed with the unaided eye and using a binocular microscope) and a microscope examination of the thin section (a slice of the stone cut thin enough to be transparent). Each description is accompanied by one or more photographs illustrating the typical character of the stone as it appears in thin section.

The microscope examination is performed using a polarizing microscope. Before preparing the thin section, the stone is impregnated with blue resin to highlight pore space. 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.

Each numbered item on the petrographic description form is described in the supporting notes at the end of this appendix.

SAMPLE ED11910 – 'T1' (ST MAGNUS'S CHURCH, TINGWALL)

Hand specimen observations

Stone type [1] (general classification):	sandstone
Stone colour [2] **–** fresh stone:	dull reddish brown (*visual*) 2.5 YR 5/4 (*Munsell*)
Stone colour [2] **–** weathered stone:	not applicable
Stone colour [2] **–** exterior surface:	not applicable
Stone cohesion [3] – fresh stone:	strongly cohesive
Stone cohesion [3] – weathered stone:	not applicable
Stone fabric [4]:	bedded (parallel bedding)
Distinctive features [5]:	mud flakes; coloured spots, dark grey patches

Thin section observations

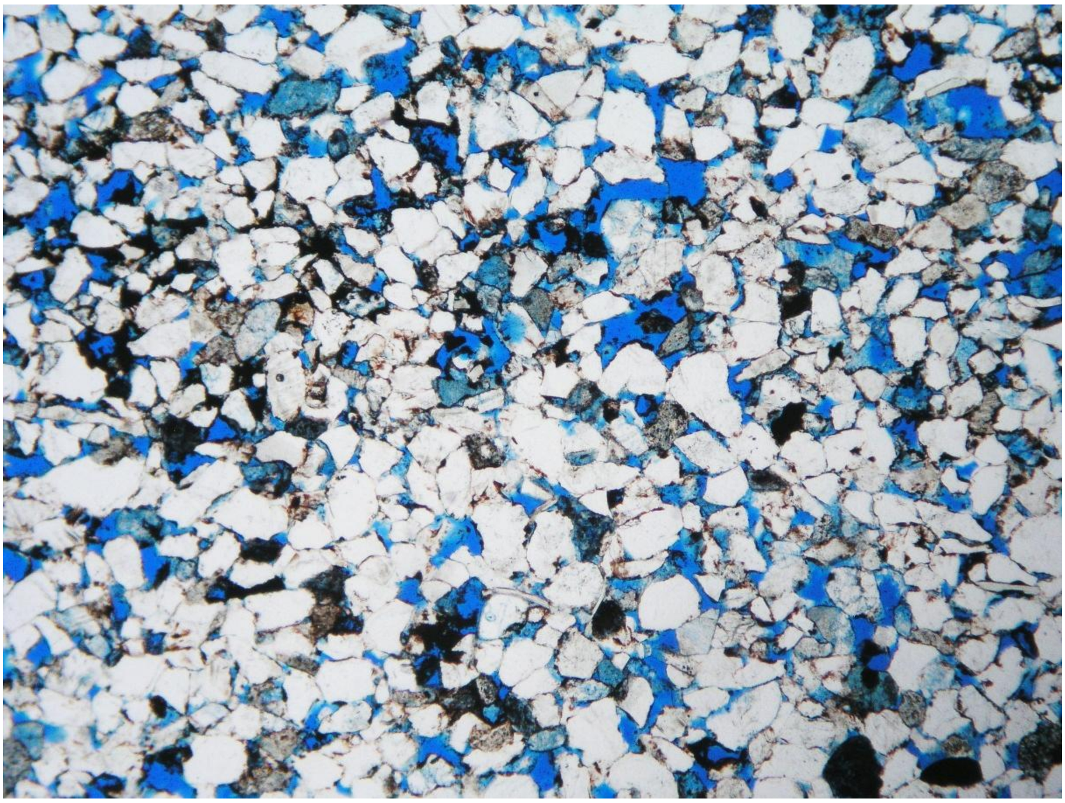
Stone constituents [6]:

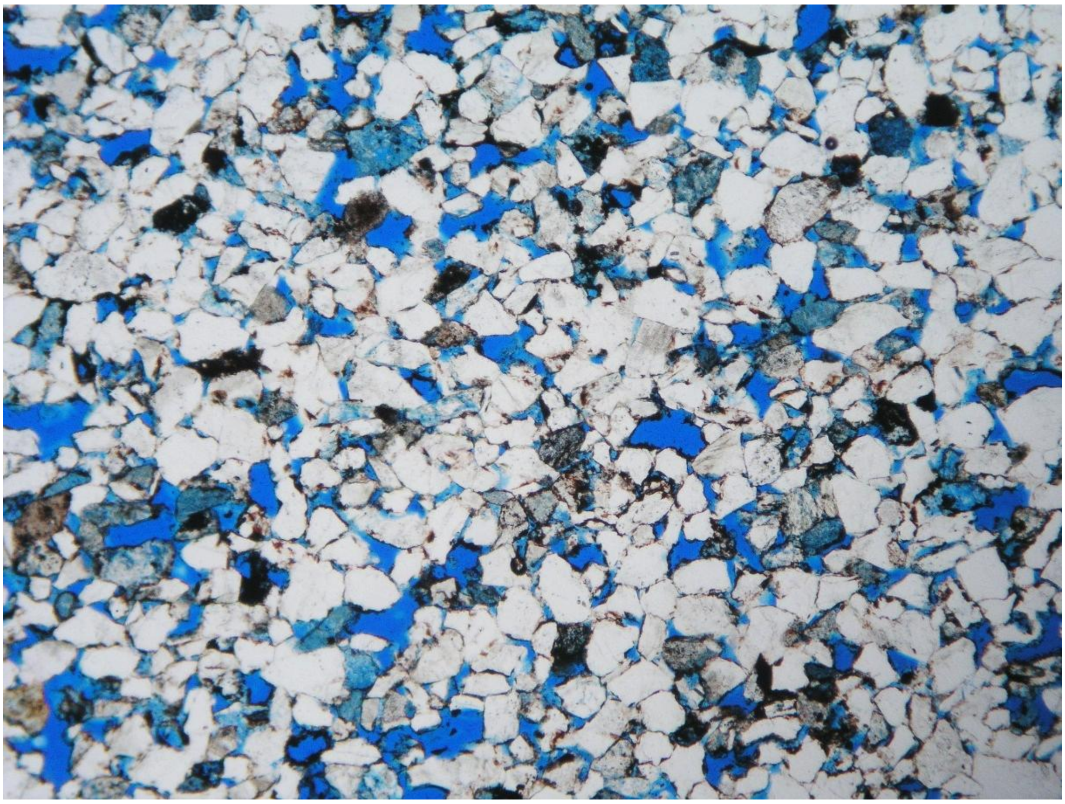
Granular constituents		*Intergranular constituents*	
Quartz	44%	Silica (overgrowth)	3%
Feldspar	5%	Feldspar (overgrowth)	0%
Rock fragments	16%	Carbonate	0%
Mica	1%	Iron/manganese oxide	9%
Opaque material	2%	Clay	2%
Other	<<1%	Hydrocarbon	0%
Intragranular pores	10%	Intergranular pores	8%

Stone type [1] (detailed classification):	sublithic-arenite
Grain-size [7]:	fine-sand-grade
Grain sorting [8]:	moderately well sorted
Grain roundness [9]:	sub-rounded to angular
Stone permeability [10]:	moderate
Cement distribution [11]:	silica cement discontinuous; iron oxide coatings on detrital grains
Supergene changes [12]:	strong dissolution of feldspar; strong dissolution of carbonate; strongly remobilised iron; weak dissolution of rock fragments

Comments

1. The sample consists entirely of fresh (un-weathered) stone.
2. A bedding fabric is defined by alternately lighter and darker, parallel layers of stone. In thin section, the darker layers are observed to contain a greater proportion of iron oxide minerals. Bedding is also represented by mm-scale thick layers of stone that vary slightly in grain size.
3. A single, dark purplish brown mud flake (c. 2mm in size) is featured in the hand sample.
4. The hand sample features a small light yellowish buff 'spot', and several patches of dark grey material (which are likely to be local concentrations of manganese oxide minerals).
5. The minerals zircon and tourmaline are present in trace amounts (together accounting for <<1% of the total thin section area).
6. The sample contains numerous 'moldic pores' (pores that preserve the shape of grains or crystals that have dissolved), which are fringed with iron oxide minerals. Almost all of the detrital grains have a thin coating of iron oxide. Together, these observations suggest that a significant volume of an intergranular, iron-bearing carbonate mineral was formerly present in the stone, but that this mineral has since dissolved due to chemical alteration.
7. The relatively high proportion of intragranular pores (i.e. formed within partly dissolved grains), and the presence of grains that appear to be 'floating' in the plane of the thin section, suggest that the stone formerly contained a greater volume of feldspar grains, which have since dissolved due to chemical alteration.





Thin section photographs of sample ED11910 ('T1': St Magnus's Church, Tingwall). Grains of quartz and feldspar appear white. Rock fragments appear mottled grey. Iron oxide appears brown to black, and forms very thin coatings on the detrital grains. Pore space appears blue. The images were taken in plane-polarised light, and the field of view is c.3.3 mm wide.

SAMPLE ED11911 – 'T2' (ST MAGNUS'S CHURCH, TINGWALL)

Hand specimen observations

Stone type [1] (general classification):	sandstone
Stone colour [2] **–** fresh stone:	bright reddish brown (*visual*) 2.5 YR 5/6 (*Munsell*)
Stone colour [2] **–** weathered stone:	not available
Stone colour [2] **–** exterior surface:	not available
Stone cohesion [3] – fresh stone:	moderately friable
Stone cohesion [3] – weathered stone:	not available
Stone fabric [4]:	bedded (cross bedding)
Distinctive features [5]:	coloured spots; colour mottling; dark grey patches

Thin section observations

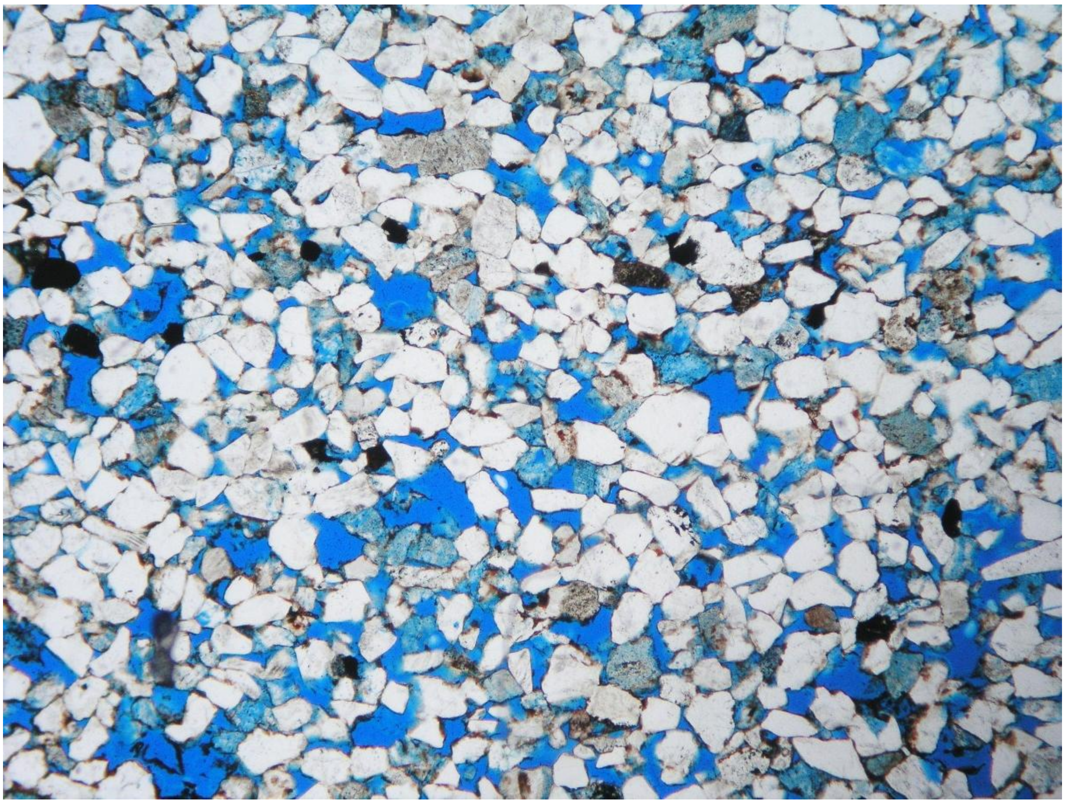
Stone constituents [6]:

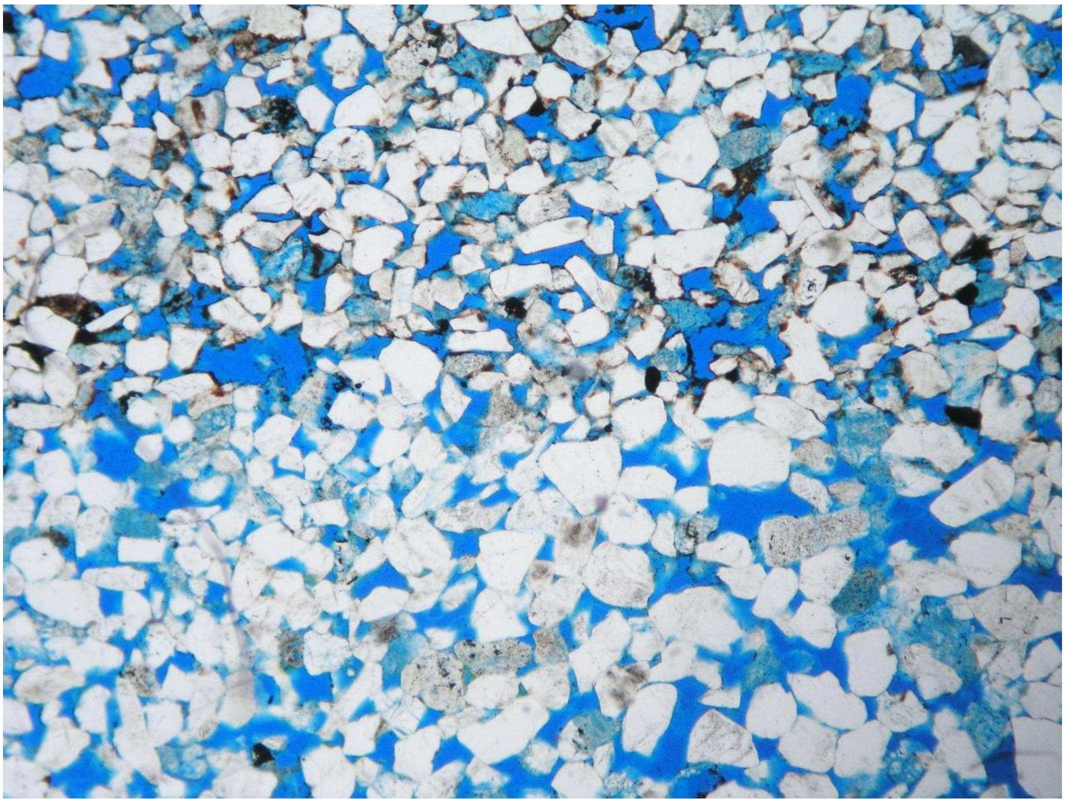
Granular constituents		***Intergranular constituents***	
Quartz	50%	Silica (overgrowth)	1%
Feldspar	4%	Feldspar (overgrowth)	0%
Rock fragments	9%	Carbonate	0%
Mica	<1%	Iron/manganese oxide	4%
Opaque material	1%	Clay	6%
Other	0%	Hydrocarbon	0%
Intragranular pores	11%	Intergranular pores	14%

Stone type [1] (detailed classification):	sublithic-arenite
Grain-size [7]:	fine-sand-grade
Grain sorting [8]:	well sorted
Grain roundness [9]:	sub-rounded to sub-angular
Stone permeability [10]:	high
Cement distribution [11]:	silica cement isolated; iron oxide coatings on detrital grains
Supergene changes [12]:	strong dissolution of feldspar; strong dissolution of carbonate; strong dissolution of rock fragments

Comments

1. The sample consists entirely of fresh (un-weathered) stone.
2. The block from which this sample was collected (see Figure 1b) exhibits a cross bedded fabric. Bedding is also represented by mm-scale layers of stone that vary slightly in grain size.
3. The sample contains numerous 'moldic pores', which are fringed with iron oxide minerals. Almost all of the detrital grains are also coated in iron oxide. Together, these observations suggest that a significant volume of an intergranular, iron-bearing carbonate mineral was formerly present in the stone, but that this mineral has since dissolved due to chemical alteration.
4. The hand sample features yellowish buff colour mottling and spots, and several patches of dark grey material (which are likely to represent local concentrations of manganese oxide minerals). In thin section, iron oxide coatings on detrital grains within the yellowish buff portions of stone are absent.
5. The relatively high proportion of intragranular pores, and the presence of grains which appear to be 'floating' in the plane of the thin section, suggest that the stone formerly contained a greater volume of feldspar grains which have since dissolved due to chemical alteration.





Thin section photographs of sample ED11911 (‘T2’: St Magnus’s Church, Tingwall). Grains of quartz and feldspar appear white. Rock fragments appear mottled grey. Iron oxide appears brown to black, and forms very thin coatings on many of the detrital grains. The bottom half of the lower image is of a portion of yellowish buff stone within which iron oxide coatings on detrital grains are absent. Pore space appears blue. The images were taken in plane-polarised light, and the field of view is c.3.3 mm wide.

SAMPLE ED11912 – 'P1' (ST LAURENCE'S CHURCH, PAPIL)

Hand specimen observations

Stone type [1] (general classification):	sandstone
Stone colour [2] **–** fresh stone:	dull reddish brown (*visual*) 2.5 YR 5/4 (*Munsell*)
Stone colour [2] **–** weathered stone:	greyish brown
Stone colour [2] **–** exterior surface:	greyish brown
Stone cohesion [3] – fresh stone:	strongly cohesive
Stone cohesion [3] – weathered stone:	strongly cohesive
Stone fabric [4]:	bedded (irregular cross bedding)
Distinctive features [5]:	mud flakes

Thin section observations

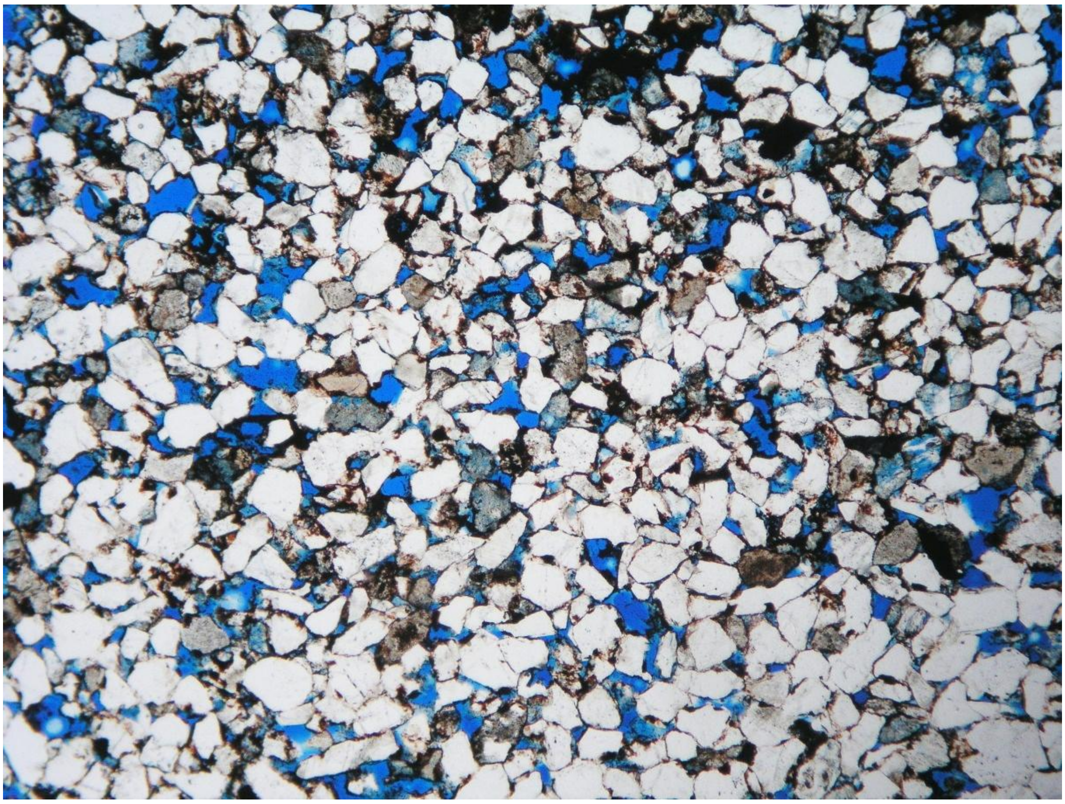
Stone constituents [6]:

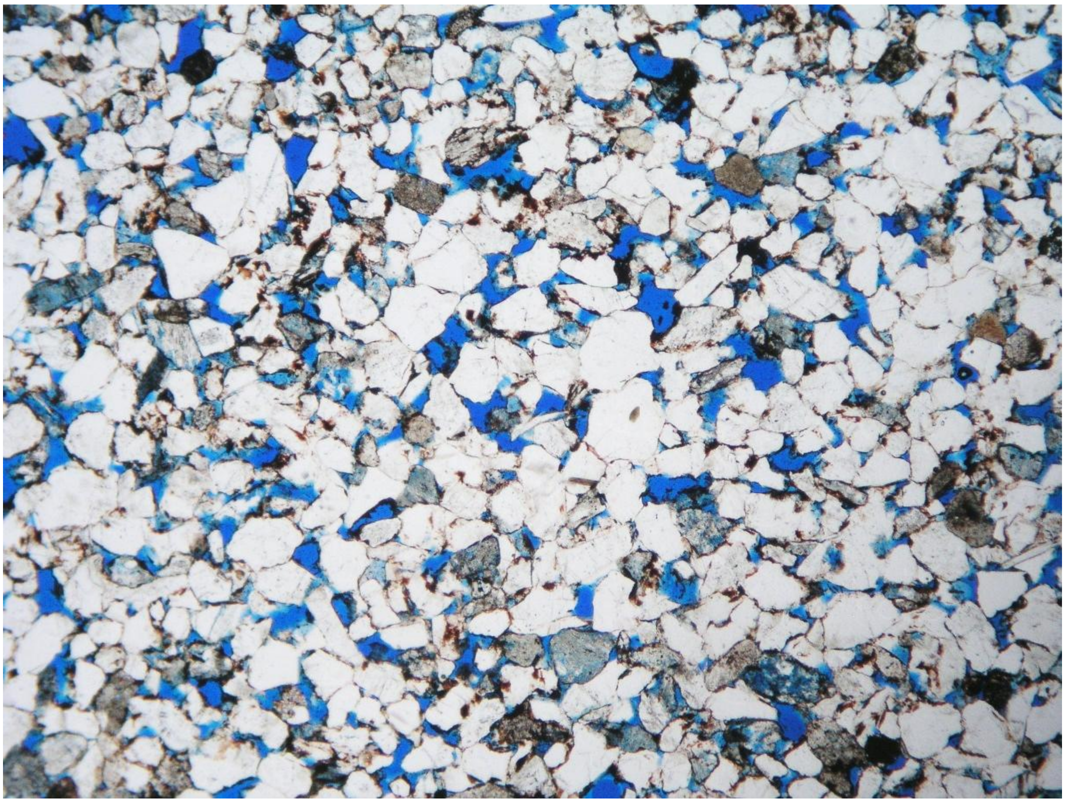
Granular constituents		***Intergranular constituents***	
Quartz	48%	Silica (overgrowth)	3%
Feldspar	7%	Feldspar (overgrowth)	0%
Rock fragments	14%	Carbonate	0%
Mica	1%	Iron/manganese oxide	10%
Opaque material	1%	Clay	1%
Other	<<1%	Hydrocarbon	0%
Intragranular pores	8%	Intergranular pores	7%

Stone type [1] (detailed classification):	sublithic-arenite
Grain-size [7]:	fine-sand-grade
Grain sorting [8]:	moderately well sorted
Grain roundness [9]:	sub-rounded to angular
Stone permeability [10]:	moderate
Cement distribution [11]:	silica cement discontinuous; iron oxide coatings on detrital grains
Supergene changes [12]:	strong dissolution of feldspar; strong dissolution of carbonate; weak dissolution of rock fragments

Comments

1. The stone at one end of the core sample is covered in a thin greyish brown patina; this is assumed to be the exterior surface of the sampled block.
2. An irregular cross-bedding fabric is defined by alternately lighter and darker layers of stone. In thin section, the darker layers are observed to contain a greater proportion of iron oxide minerals. Bedding is also represented by mm-scale thick layers of stone that vary slightly in grain size.
3. A few dark purplish brown mud flakes (<2mm in size) are featured in the hand sample.
4. The minerals zircon and tourmaline are present in trace amounts (together accounting for <<1% of the total thin section area).
5. The sample contains numerous 'moldic pores', which are fringed with iron oxide minerals. Almost all of the detrital grains are also coated in iron oxide. Together, these observations suggest that a significant volume of an intergranular, iron-bearing carbonate mineral was formerly present in the stone, but that this mineral has since dissolved due to chemical alteration.
6. The relatively high proportion of intragranular pores, and the presence of grains which appear to be 'floating' in the plane of the thin section, suggest that the stone formerly contained a greater volume of feldspar grains that have since dissolved due to chemical alteration.





Thin section photographs of sample ED11912 (‘P1’: St Laurence's Church, Papil). Grains of quartz and feldspar appear white. Rock fragments appear mottled grey. Iron oxide appears brown to black, and forms very thin coatings on the detrital grains. Pore space appears blue. The images were taken in plane-polarised light, and the field of view is c.3.3 mm wide.

SAMPLE ED11913 – 'P2' (ST LAURENCE'S CHURCH, PAPIL)

Hand specimen observations

Stone type [1] (general classification):	sandstone	
Stone colour [2] **–** fresh stone:	very light yellowish buff (*visual*)	10 YR 8/2 (*Munsell*)
Stone colour [2] **–** weathered stone:	not available	
Stone colour [2] **–** exterior surface:	not available	
Stone cohesion [3] – fresh stone:	strongly cohesive	
Stone cohesion [3] – weathered stone:	not available	
Stone fabric [4]:	very faintly bedded (parallel bedding)	
Distinctive features [5]:	dark grey patches	

Thin section observations

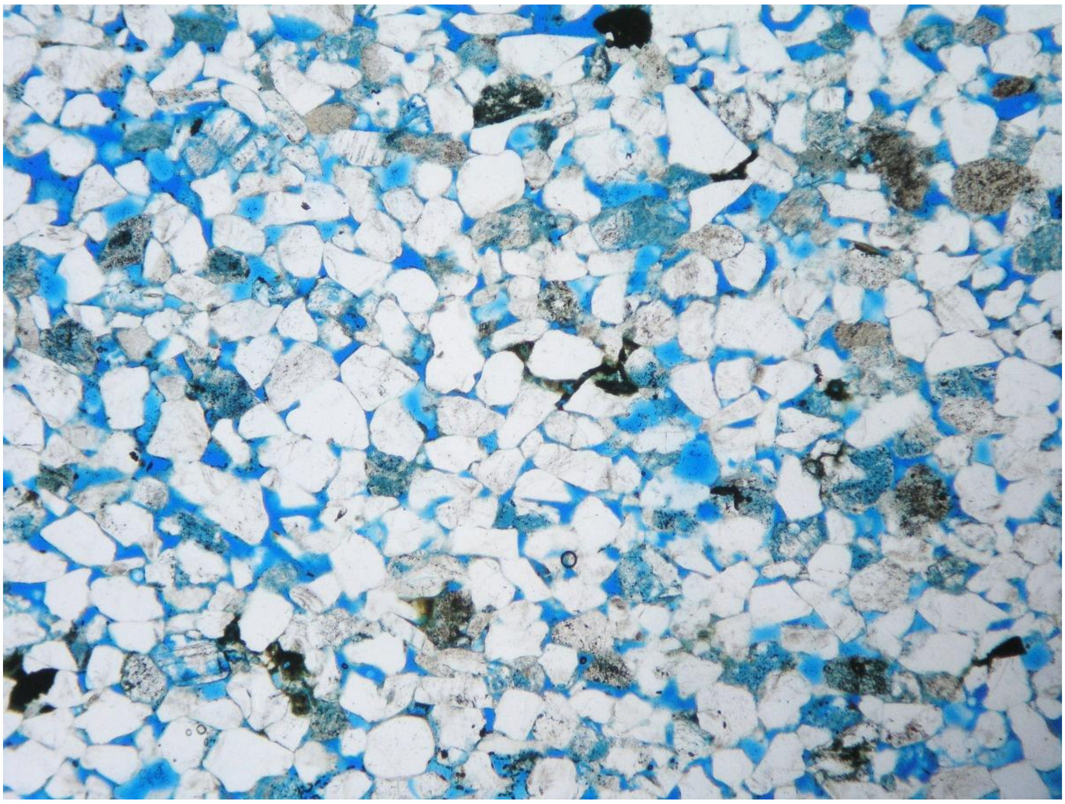
Stone constituents [6]:

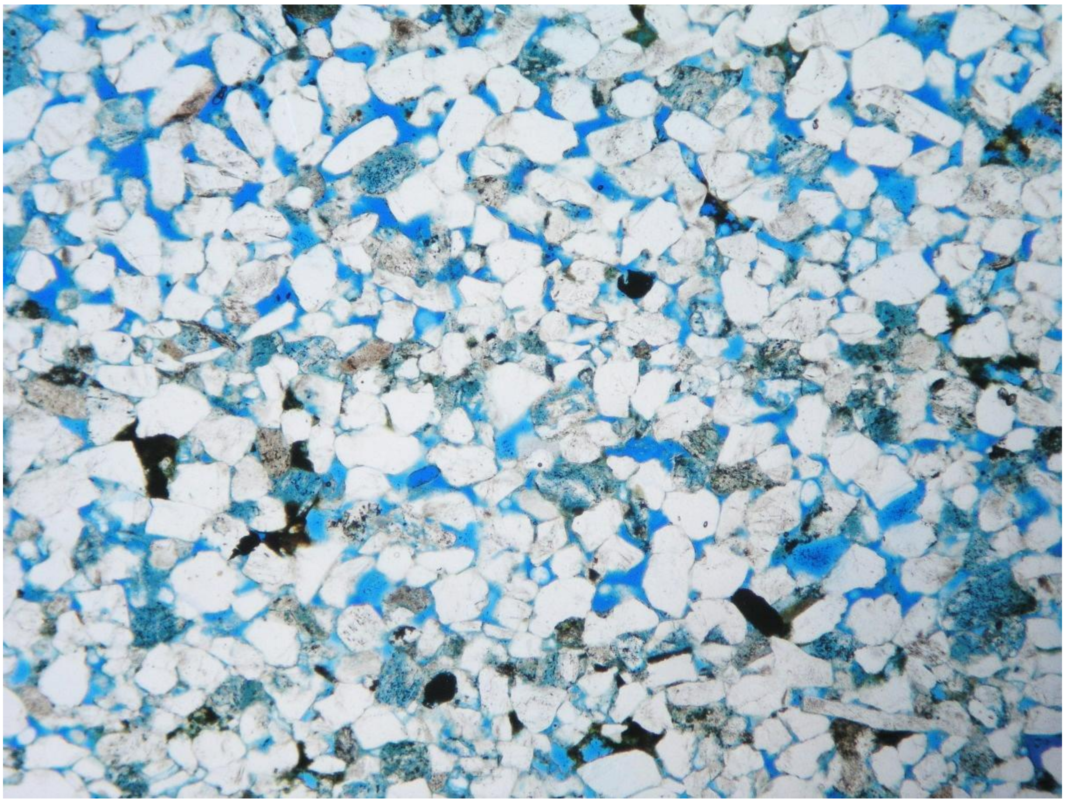
Granular constituents		***Intergranular constituents***	
Quartz	49%	Silica (overgrowth)	1%
Feldspar	6%	Feldspar (overgrowth)	0%
Rock fragments	16%	Carbonate	0%
Mica	<1%	Iron/manganese oxide	3%
Opaque material	<1%	Clay	7%
Other	<<1%	Hydrocarbon	0%
Intragranular pores	3%	Intergranular pores	15%

Stone type [1] (detailed classification):	sublithic-arenite
Grain-size [7]:	fine-sand-grade
Grain sorting [8]:	well sorted
Grain roundness [9]:	sub-rounded to rounded
Stone permeability [10]:	moderate
Cement distribution [11]:	silica cement discontinuous
Supergene changes [12]:	moderate dissolution of feldspar; strong dissolution of carbonate; moderate dissolution of rock fragments

Comments

1. The sample consists entirely of fresh (un-weathered) stone.
2. The stone displays a very faint parallel bedding fabric, which is produced by mm-scale thick layers of stone that vary slightly in grain size.
3. Several patches of dark grey material (which are likely to represent local concentrations of manganese oxide minerals) are featured in the hand sample. These patches appear to be concentrated along certain bedding planes.
4. The minerals zircon and tourmaline are present in trace amounts (together accounting for <<1% of the total thin section area).
5. The sample contains a few 'moldic pores', which are fringed with iron oxide minerals. Iron oxide is also distributed as intergranular patches throughout the stone. The presence of moldic pores, in particular, suggests that an intergranular, iron-bearing carbonate mineral was formerly present in the stone, but that this mineral has since dissolved due to chemical alteration.
6. The presence of intragranular pores, and grains which appear to be 'floating' in the plane of the thin section, suggest that the stone formerly contained a greater volume of feldspar grains that have since dissolved due to chemical alteration.





Thin section photographs of sample ED11913 (‘P2’: St Laurence's Church, Papil). Grains of quartz and feldspar appear white. Rock fragments appear mottled grey. Iron oxide appears brown to black, and is distributed in patches throughout the stone. Pore space appears blue. The images were taken in plane-polarised light, and the field of view is c.3.3 mm wide.

SAMPLE ED11914 – ‘P3’ (ST LAURENCE'S CHURCH, PAPIL)

Hand specimen observations

Stone type [1] (general classification):	sandstone
Stone colour [2] **–** fresh stone:	dull reddish brown (*visual*) 2.5 YR 5/3 (*Munsell*)
Stone colour [2] **–** weathered stone:	dark reddish brown
Stone colour [2] **–** exterior surface:	dark reddish brown
Stone cohesion [3] – fresh stone:	strongly cohesive
Stone cohesion [3] – weathered stone:	strongly cohesive
Stone fabric [4]:	bedded (parallel bedding)
Distinctive features [5]:	mud flakes

Thin section observations

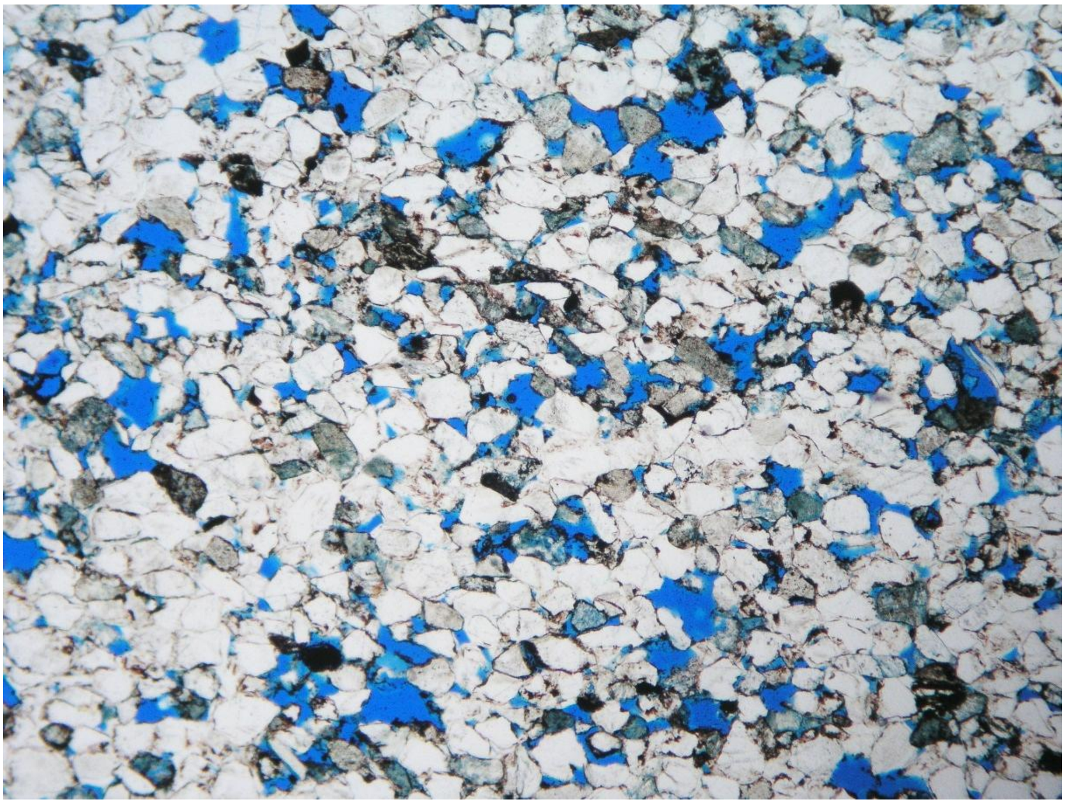
Stone constituents [6]:

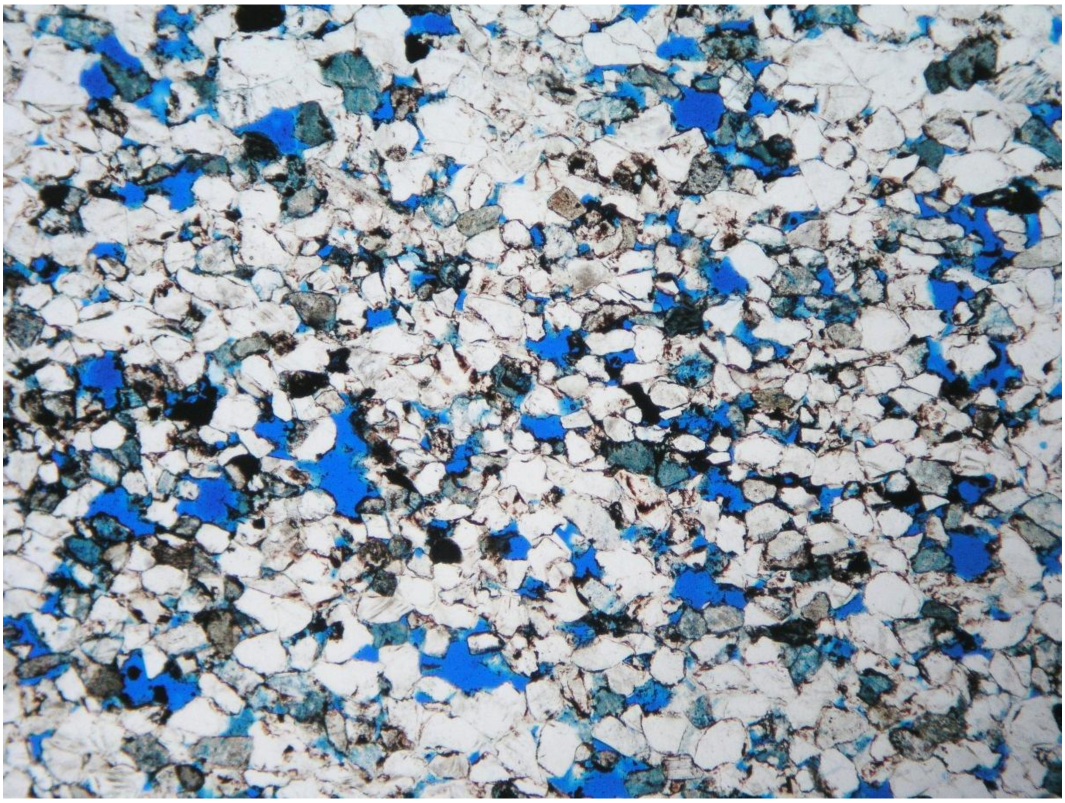
Granular constituents		*Intergranular constituents*	
Quartz	48%	Silica (overgrowth)	4%
Feldspar	4%	Feldspar (overgrowth)	0%
Rock fragments	16%	Carbonate	0%
Mica	<1%	Iron/manganese oxide	7%
Opaque material	2%	Clay	1%
Other	<<1%	Hydrocarbon	0%
Intragranular pores	12%	Intergranular pores	6%

Stone type [1] (detailed classification):	sublithic-arenite
Grain-size [7]:	fine-sand-grade
Grain sorting [8]:	moderately well sorted
Grain roundness [9]:	sub-rounded to angular
Stone permeability [10]:	moderate
Cement distribution [11]:	silica cement continuous; iron oxide coatings on detrital grains
Supergene changes [12]:	strong dissolution of feldspar; strong dissolution of carbonate; weak dissolution of rock fragments

Comments

1. Several surfaces of the sample are covered in a thin dark reddish brown patina; these are assumed to be the exterior (weathered) surfaces of the sampled block.
2. A parallel bedding fabric is defined by alternately lighter and darker layers of stone. In thin section, the darker layers are observed to contain a greater proportion of iron oxide minerals. Bedding is also represented by mm-scale layers of stone that vary slightly in grain size.
3. A few dark purplish brown mud flakes (<2mm in size) are featured in the hand sample.
4. The mineral zircon is present in trace amounts (accounting for <<1% of the total thin section area).
5. The sample contains numerous ‘moldic pores’, which are fringed with iron oxide minerals. Almost all of the detrital grains are also coated in iron oxide. Together, these observations suggest that a significant volume of an intergranular, iron-bearing carbonate mineral was formerly present in the stone, but that this mineral has since dissolved due to chemical alteration.
6. The relatively high proportion of intragranular pores, and the presence of grains that appear to be ‘floating’ in the plane of the thin section, suggest that the stone formerly contained a greater volume of feldspar grains, which have since dissolved due to chemical alteration.





Thin section photographs of sample ED11914 (‘P3’: St Laurence's Church, Papil). Grains of quartz and feldspar appear white. Rock fragments appear mottled grey. Iron oxide appears brown to black, and forms very thin coatings on the detrital grains. Pore space appears blue. The images were taken in plane-polarised light, and the field of view is c.3.3 mm wide.

SAMPLE ED11915 – 'IR1' (ST MARY'S CHURCH, IRELAND)

Hand specimen observations

Stone type [1] (general classification):	sandstone
Stone colour [2] – fresh stone:	dull reddish brown (*visual*) 2.5 YR 5/3 (*Munsell*)
Stone colour [2] – weathered stone:	not available
Stone colour [2] – exterior surface:	not available
Stone cohesion [3] – fresh stone:	strongly cohesive
Stone cohesion [3] – weathered stone:	not available
Stone fabric [4]:	bedded (parallel bedding)
Distinctive features [5]:	mud flakes

Thin section observations

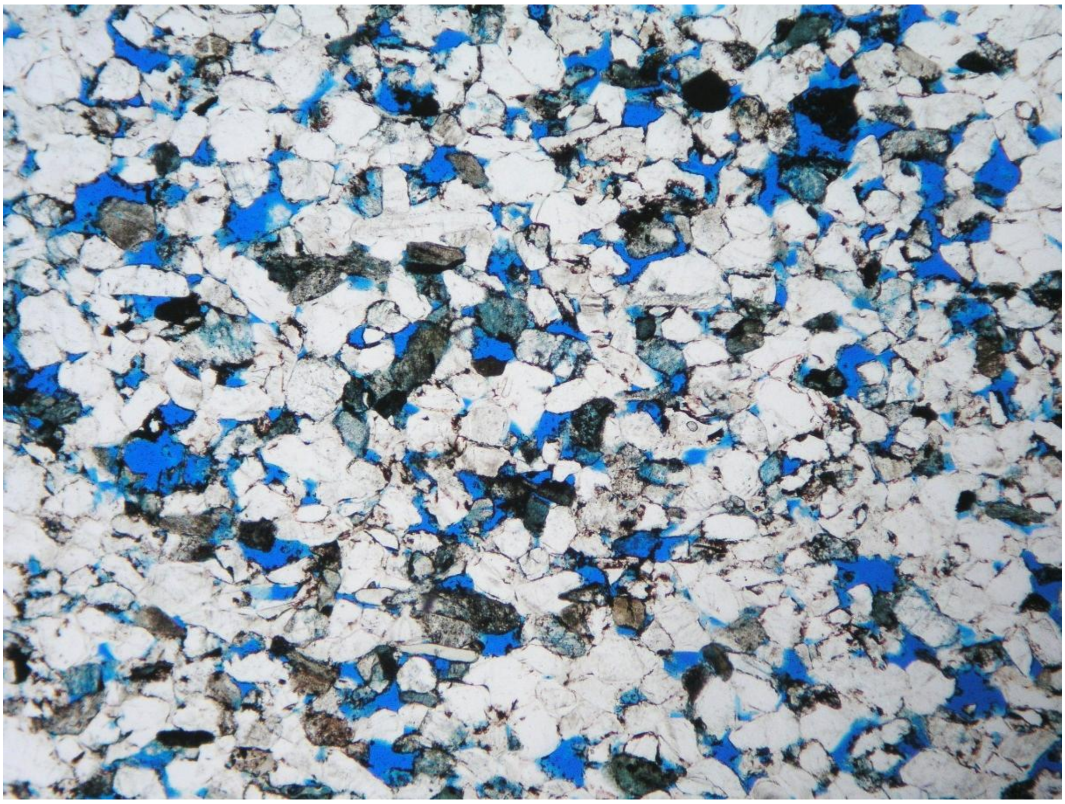
Stone constituents [6]:

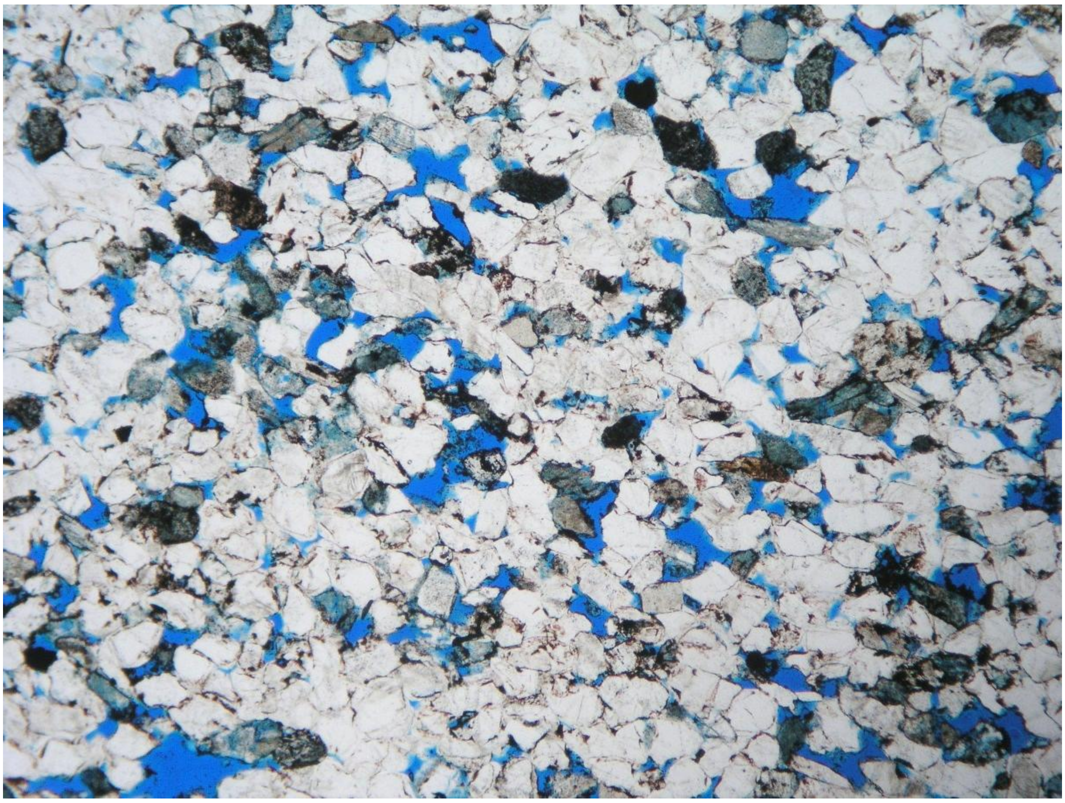
Granular constituents		*Intergranular constituents*	
Quartz	47%	Silica (overgrowth)	4%
Feldspar	7%	Feldspar (overgrowth)	0%
Rock fragments	15%	Carbonate	0%
Mica	1%	Iron/manganese oxide	6%
Opaque material	2%	Clay	1%
Other	0%	Hydrocarbon	0%
Intragranular pores	11%	Intergranular pores	6%

Stone type [1] (detailed classification):	sublithic-arenite
Grain-size [7]:	fine-sand-grade
Grain sorting [8]:	moderately well sorted
Grain roundness [9]:	sub-rounded to angular
Stone permeability [10]:	moderate
Cement distribution [11]:	silica cement continuous; iron oxide coatings on detrital grains
Supergene changes [12]:	strong dissolution of feldspar; strong dissolution of carbonate; weak dissolution of rock fragments

Comments

1. The sample consists entirely of fresh (un-weathered) stone.
2. The stone displays a bedding fabric produced by mm-scale layers of stone that vary slightly in grain size. Although the small size of the sample makes it impossible to determine if the fabric is cross-bedded or parallel-bedded, a photograph (see Figure 3a) of the block from which the sample was collected suggests it features parallel bedding.
3. Numerous dark purplish brown mud flakes (<3mm in size), which are concentrated in one bedding-parallel layer, are featured in the hand sample.
4. The sample contains numerous 'moldic pores', which are fringed with iron oxide minerals. Almost all of the detrital grains are also coated in iron oxide. Together, these observations suggest that a significant volume of an intergranular, iron-bearing carbonate mineral was formerly present in the stone, but that this mineral has since dissolved due to chemical alteration.
5. The relatively high proportion of intragranular pores, and the presence of grains which appear to be 'floating' in the plane of the thin section, suggest that the stone formerly contained a greater volume of feldspar grains, which have since dissolved due to chemical alteration.





Thin section photographs of sample ED11915 (‘IR1’: St Mary's Church, Ireland). Grains of quartz and feldspar appear white. Rock fragments appear mottled grey. Iron oxide appears brown to black, and forms very thin coatings on the detrital grains. Pore space appears blue. The images were taken in plane-polarised light, and the field of view is c.3.3 mm wide.

SAMPLE ED11916 – 'IR2' (ST MARY'S CHURCH, IRELAND)

Hand specimen observations

Stone type [1] (general classification):	sandstone
Stone colour [2] **–** fresh stone:	dull reddish brown (*visual*) 2.5 YR 5/3 (*Munsell*)
Stone colour [2] **–** weathered stone:	not available
Stone colour [2] **–** exterior surface:	not available
Stone cohesion [3] – fresh stone:	strongly cohesive
Stone cohesion [3] – weathered stone:	not available
Stone fabric [4]:	uniform
Distinctive features [5]:	coloured spots; colour mottling

Thin section observations

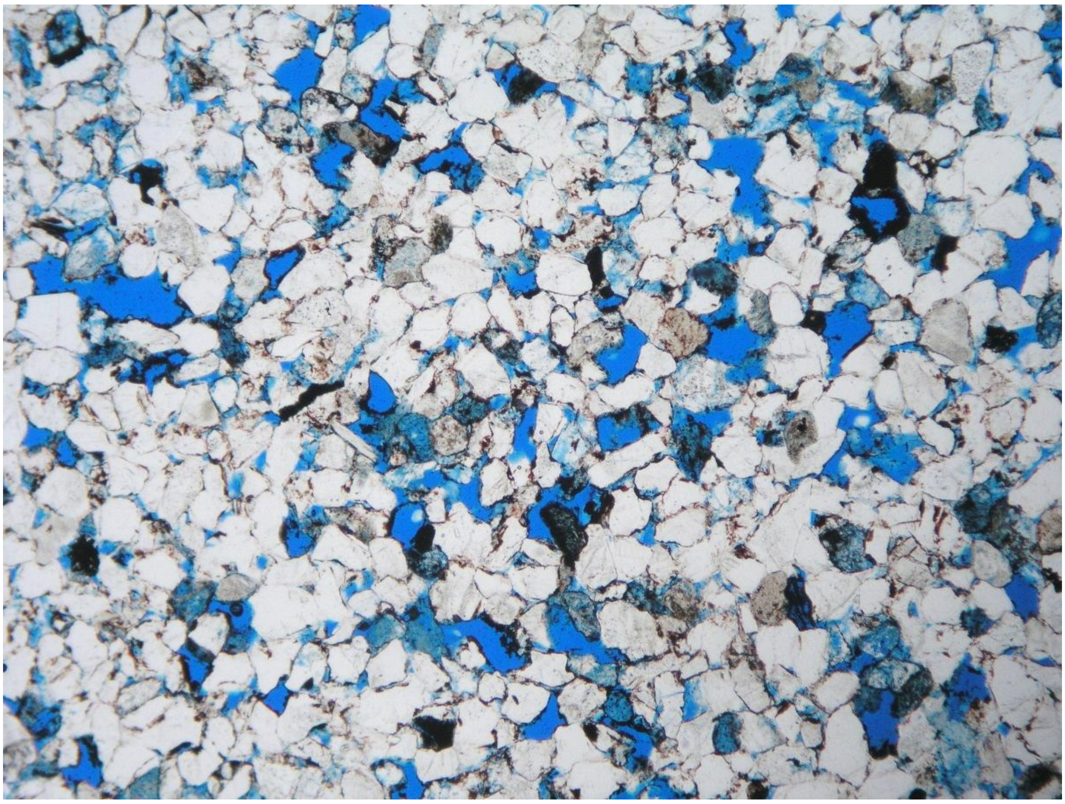
Stone constituents [6]:

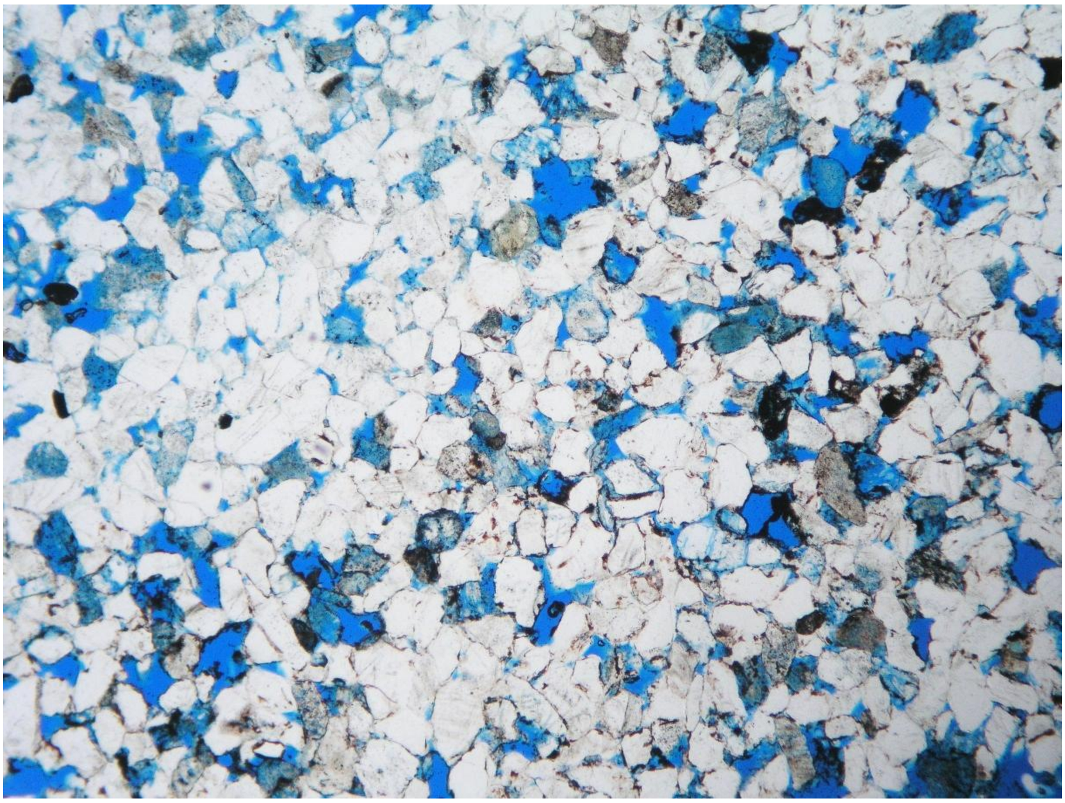
Granular constituents		*Intergranular constituents*	
Quartz	52%	Silica (overgrowth)	2%
Feldspar	5%	Feldspar (overgrowth)	0%
Rock fragments	17%	Carbonate	0%
Mica	<1%	Iron/manganese oxide	5%
Opaque material	1%	Clay	2%
Other	<<1%	Hydrocarbon	0%
Intragranular pores	9%	Intergranular pores	7%

Stone type [1] (detailed classification):	sublithic-arenite
Grain-size [7]:	fine-sand-grade
Grain sorting [8]:	moderately well sorted
Grain roundness [9]:	sub-rounded to angular
Stone permeability [10]:	moderate
Cement distribution [11]:	silica cement discontinuous; iron oxide coatings on detrital grains
Supergene changes [12]:	strong dissolution of feldspar; strong dissolution of carbonate; weak dissolution of rock fragments

Comments

1. The sample consists entirely of fresh (un-weathered) stone.
2. The small size of the sample means that it does not clearly display a bedding fabric. However, a photograph (see Figure 3b) of the block from which the sample was collected suggests it features parallel bedding.
3. The minerals zircon and tourmaline are present in trace amounts (together accounting for <<1% of the total thin section area).
4. The sample contains numerous 'moldic pores', which are fringed with iron oxide minerals. Almost all of the detrital grains are also coated in iron oxide. Together, these observations suggest that a significant volume of an intergranular, iron-bearing carbonate mineral was formerly present in the stone, but that this mineral has since dissolved due to chemical alteration.
5. The hand sample features yellowish buff colour mottling and spots. In thin section, iron oxide coatings on detrital grains within the yellowish buff portions of stone are observed to be absent.
6. The relatively high proportion of intragranular pores, and the presence of grains which appear to be 'floating' in the plane of the thin section, suggest that the stone formerly contained a greater volume of feldspar grains, which have since dissolved due to chemical alteration.





Thin section photographs of sample ED11916 (‘IR2’: St Mary's Church, Ireland). Grains of quartz and feldspar appear white. Rock fragments appear mottled grey. Iron oxide appears brown to black, and forms very thin coatings on many detrital grains. The upper left corner of the lower photograph displays a portion of stone within which iron oxide coatings on detrital grains are absent; this stone is yellowish buff in the hand sample. Pore space appears blue. The images were taken in plane-polarised light, and the field of view is c.3.3 mm wide.

SAMPLE ED11917 – 'HH1' (HEAD OF HOLLAND QUARRY)

Hand specimen observations

Stone type [1] (general classification):	sandstone
Stone colour [2] – fresh stone:	dull reddish brown (*visual*) 2.5 YR 5/3 (*Munsell*)
Stone colour [2] – weathered stone:	dark reddish brown
Stone colour [2] – exterior surface:	dark reddish brown
Stone cohesion [3] – fresh stone:	strongly cohesive
Stone cohesion [3] – weathered stone:	strongly cohesive
Stone fabric [4]:	bedded (irregular cross bedding)
Distinctive features [5]:	mud flakes; dark grey patches; colour mottling

Thin section observations

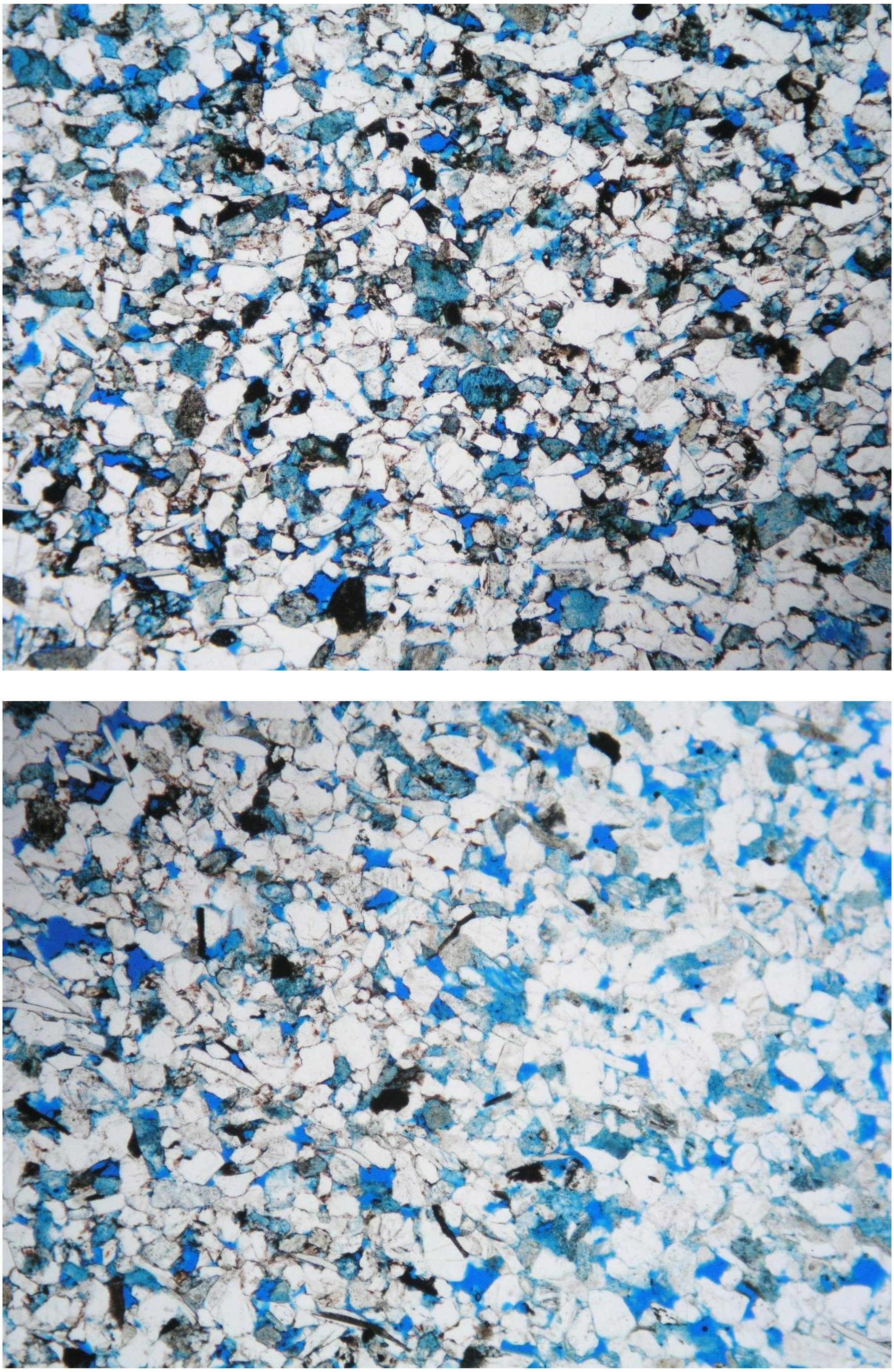
Stone constituents [6]:

Granular constituents		***Intergranular constituents***	
Quartz	48%	Silica (overgrowth)	2%
Feldspar	7%	Feldspar (overgrowth)	0%
Rock fragments	17%	Carbonate	0%
Mica	2%	Iron/manganese oxide	7%
Opaque material	2%	Clay	2%
Other	<<1%	Hydrocarbon	0%
Intragranular pores	6%	Intergranular pores	7%

Stone type [1] (detailed classification):	sublithic-arenite
Grain-size [7]:	fine-sand-grade
Grain sorting [8]:	moderately well sorted
Grain roundness [9]:	sub-rounded to angular
Stone permeability [10]:	moderate
Cement distribution [11]:	silica cement discontinuous; iron oxide coatings on detrital grains
Supergene changes [12]:	strong dissolution of feldspar; strong dissolution of carbonate; weak dissolution of rock fragments

Comments

1. Several surfaces of the sample are covered in a thin dark reddish brown patina; these are assumed to represent the exterior (weathered) surfaces of the sampled block.
2. Irregular cross-bedding is defined by alternately lighter and darker layers of stone. In thin section, the darker layers are observed to contain a greater proportion of iron oxide minerals. Bedding is also represented by mm-scale layers of stone that vary slightly in grain size.
3. Numerous dark purplish brown mud flakes (ranging from 2-15mm in size), which are concentrated in one bedding-parallel layer, are featured in the hand sample.
4. The mineral zircon is present in trace amounts (accounting for <<1% of the total thin section area).
5. The hand sample contains several patches of dark grey material (possibly manganese oxide mineral).
6. The sample contains numerous 'moldic pores', which are fringed with iron oxide minerals. Almost all of the detrital grains are also coated in iron oxide. Together, these observations suggest that a significant volume of an intergranular, iron-bearing carbonate mineral was formerly present in the stone, but that this mineral has since dissolved due to chemical alteration.
7. One edge of the sample is formed of yellowish buff stone. In thin section, iron oxide coatings on detrital grains within this part of the stone are observed to be absent.
8. The relatively high proportion of intragranular pores, and the presence of grains which appear to be 'floating' in the plane of the thin section, suggest that the stone formerly contained a greater volume of feldspar grains, which have since dissolved due to chemical alteration.



Thin section photographs of sample ED11917 (‘HH1’: Head of Holland quarry). Grains of quartz and feldspar appear white. Rock fragments appear mottled grey. Iron oxide appears brown to black, and forms very thin coatings on the detrital grains. The right half of the lower image is of a portion of yellowish buff stone within which iron oxide coatings on detrital grains are absent. Pore space appears blue. The images were taken in plane-polarised light, and the field of view is c.3.3 mm wide.

SAMPLE ECON15658 – 'HH2' (HEAD OF HOLLAND QUARRY)

Hand specimen observations

Stone type [1] (general classification):	sandstone
Stone colour [2] **–** fresh stone:	dull reddish brown (*visual*) 2.5 YR 5/3 (*Munsell*)
Stone colour [2] **–** weathered stone:	not available
Stone colour [2] **–** exterior surface:	not available
Stone cohesion [3] – fresh stone:	strongly cohesive
Stone cohesion [3] – weathered stone:	not available
Stone fabric [4]:	bedded (parallel bedding)
Distinctive features [5]:	coloured spots

Thin section observations

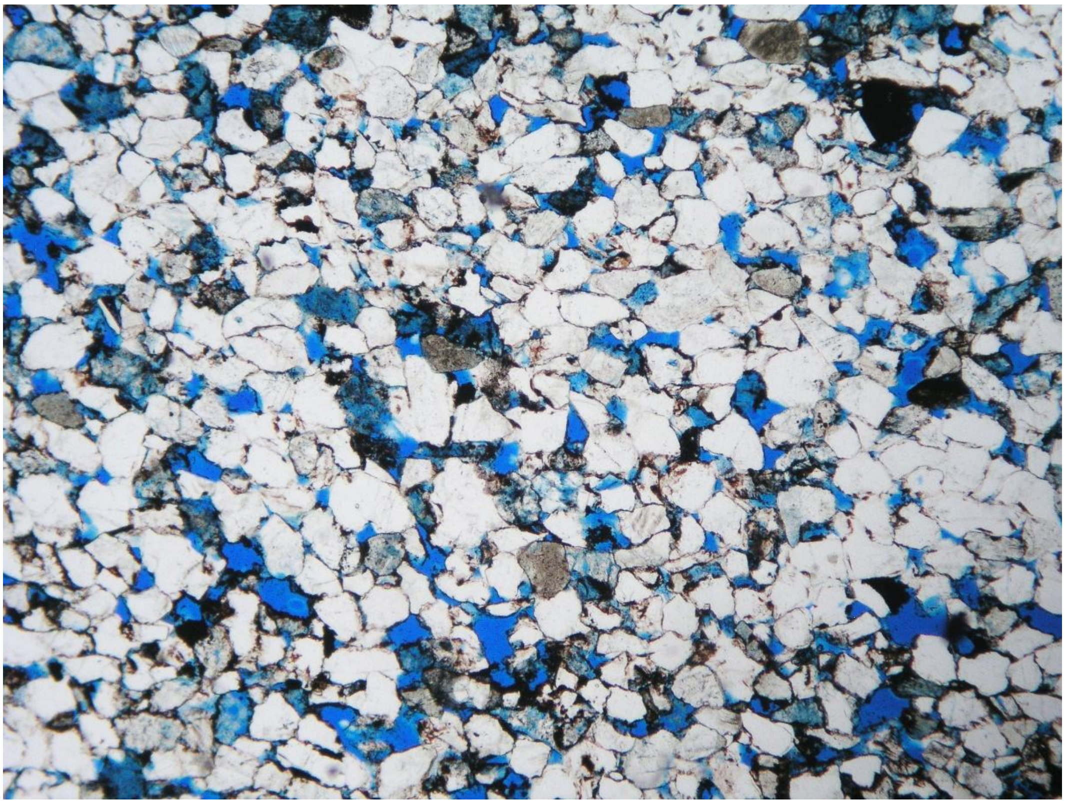
Stone constituents [6]:

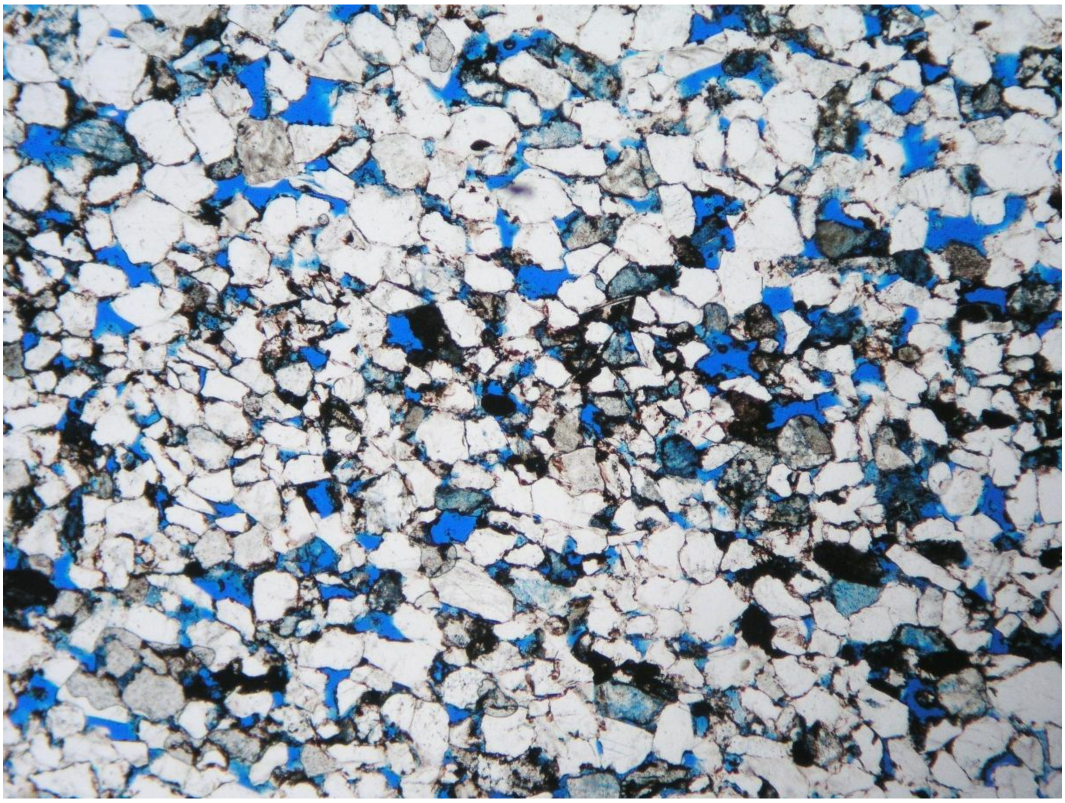
Granular constituents		*Intergranular constituents*	
Quartz	47%	Silica (overgrowth)	2%
Feldspar	5%	Feldspar (overgrowth)	0%
Rock fragments	16%	Carbonate	0%
Mica	1%	Iron/manganese oxide	9%
Opaque material	2%	Clay	2%
Other	<<1%	Hydrocarbon	0%
Intragranular pores	7%	Intergranular pores	9%

Stone type [1] (detailed classification):	sublithic-arenite
Grain-size [7]:	fine-sand-grade
Grain sorting [8]:	moderately well sorted
Grain roundness [9]:	sub-rounded to angular
Stone permeability [10]:	moderate
Cement distribution [11]:	silica cement discontinuous; iron oxide coatings on detrital grains
Supergene changes [12]:	strong dissolution of feldspar; strong dissolution of carbonate; weak dissolution of rock fragments

Comments

1. The sample consists entirely of fresh (un-weathered) stone.
2. A parallel bedding fabric is defined by alternately lighter and darker layers of stone. In thin section, the darker layers are observed to contain a greater proportion of iron oxide minerals. Bedding is also represented by mm-scale layers of stone that vary slightly in grain size.
3. The hand sample features one yellowish buff coloured spot c. 3mm in size.
4. The mineral zircon is present in trace amounts (accounting for <<1% of the total thin section area).
5. The sample contains numerous 'moldic pores', which are fringed with iron oxide minerals. Almost all of the detrital grains are also coated in iron oxide. Together, these observations suggest that a significant volume of an intergranular, iron-bearing carbonate mineral was formerly present in the stone, but that this mineral has since dissolved due to chemical alteration.
6. The relatively high proportion of intragranular pores, and the presence of grains which appear to be 'floating' in the plane of the thin section, suggest that the stone formerly contained a greater volume of feldspar grains, which have since dissolved due to chemical alteration.





Thin section photographs of sample ECON15658 (‘HH2’: Head of Holland quarry). Grains of quartz and feldspar appear white. Rock fragments appear mottled grey. Iron oxide appears brown to black, and forms very thin coatings on the detrital grains. Pore space appears blue. The images were taken in plane-polarised light, and the field of view is c.3.3 mm wide.

SAMPLE ECON15729 – 'HH3' (HEAD OF HOLLAND QUARRY)

Hand specimen observations

Stone type [1] (general classification):	sandstone
Stone colour [2] **–** fresh stone:	bright reddish brown (*visual*) 2.5 YR 5/6 (*Munsell*)
Stone colour [2] **–** weathered stone:	not available
Stone colour [2] **–** exterior surface:	not available
Stone cohesion [3] – fresh stone:	moderately friable
Stone cohesion [3] – weathered stone:	not available
Stone fabric [4]:	uniform
Distinctive features [5]:	none

Thin section observations

Not available – a thin section was not prepared from this sample (see section 2.4)

Comments

1. The sample consists entirely of fresh (un-weathered) stone.
2. The sample appears to consist of texturally uniform stone; however its small size means it is difficult to be sure whether or not the parent block from which it was sampled would have featured a bedding fabric.

SAMPLE ECON7740 – 'F1' (FERSNESS QUARRY)

Hand specimen observations

Stone type [1] (general classification):	sandstone
Stone colour [2] **–** fresh stone:	light yellowish buff (*visual*) 10 YR 8/3 (*Munsell*)
Stone colour [2] **–** weathered stone:	dark buff
Stone colour [2] **–** exterior surface:	dark buff
Stone cohesion [3] – fresh stone:	strongly cohesive
Stone cohesion [3] – weathered stone:	strongly cohesive
Stone fabric [4]:	faintly bedded (parallel bedding)
Distinctive features [5]:	none

Thin section observations

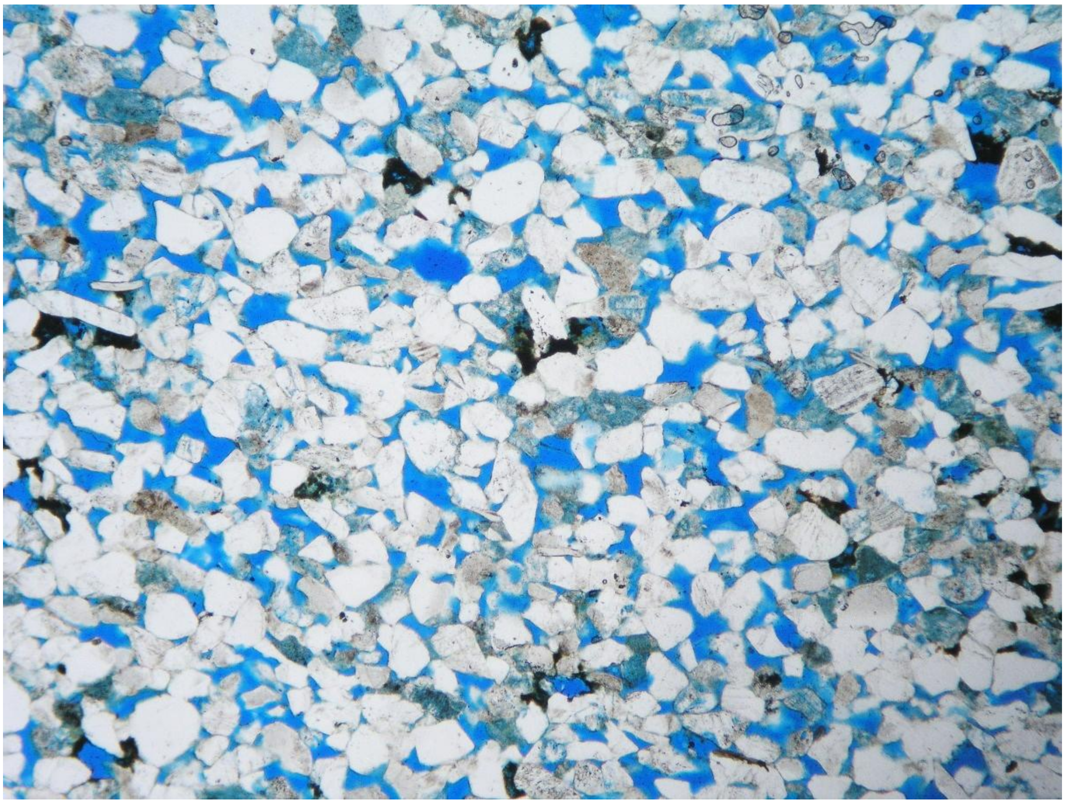
Stone constituents [6]:

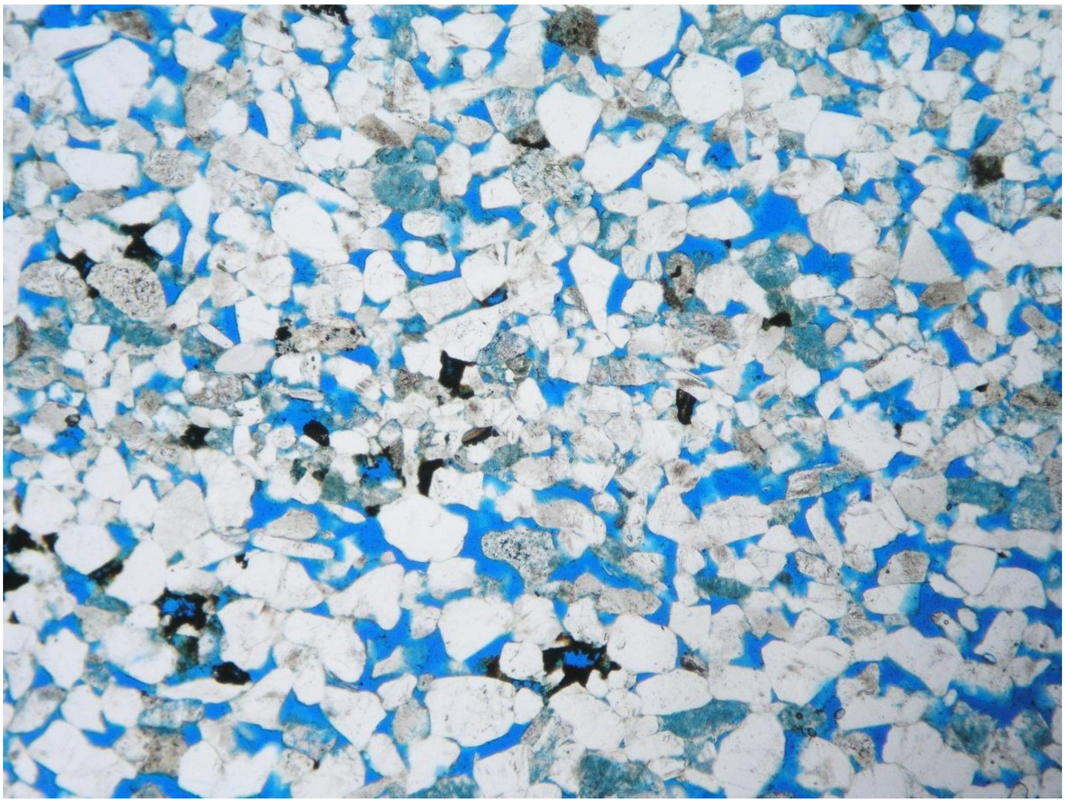
Granular constituents		*Intergranular constituents*	
Quartz	46%	Silica (overgrowth)	1%
Feldspar	8%	Feldspar (overgrowth)	0%
Rock fragments	14%	Carbonate	0%
Mica	1%	Iron/manganese oxide	4%
Opaque material	<1%	Clay	4%
Other	<<1%	Hydrocarbon	0%
Intragranular pores	6%	Intergranular pores	16%

Stone type [1] (detailed classification):	sublithic-arenite
Grain-size [7]:	fine-sand-grade
Grain sorting [8]:	well sorted
Grain roundness [9]:	sub-rounded to rounded
Stone permeability [10]:	high
Cement distribution [11]:	silica cement discontinuous
Supergene changes [12]:	moderate dissolution of feldspar; strong dissolution of carbonate; moderate dissolution of rock fragments

Comments

1. The exterior surfaces of the sample are covered in a thin dark buff patina.
2. The stone displays a faint parallel bedding fabric, which is produced by mm-scale thick layers of stone that vary slightly in grain size.
3. The mineral zircon is present in trace amounts (accounting for <<1% of the total thin section area).
4. The sample contains a few 'moldic pores', which are fringed with iron oxide minerals. Iron oxide is also distributed as intergranular patches throughout the stone. The presence of moldic pores, in particular, suggests that an intergranular, iron-bearing carbonate mineral was formerly present in the stone, but that this mineral has since dissolved due to chemical alteration.
5. The relatively high proportion of intragranular pores, and the presence of grains which appear to be 'floating' in the plane of the thin section, suggest that the stone formerly contained a greater volume of feldspar grains, which have since dissolved due to chemical alteration.





Thin section photographs of sample ECON7740 (‘F1’: Fersness quarry). Grains of quartz and feldspar appear white. Rock fragments appear mottled grey. Iron oxide appears brown to black, and is distributed in patches throughout the stone. Pore space appears blue. The images were taken in plane-polarised light, and the field of view is c.3.3 mm wide.

SAMPLE MC4167 – 'F2' (FERSNESS QUARRY)

Hand specimen observations

Stone type [1] (general classification):	sandstone
Stone colour [2] – fresh stone:	light yellowish buff (*visual*) 10 YR 7/3 (*Munsell*)
Stone colour [2] – weathered stone:	dark buff
Stone colour [2] – exterior surface:	dark buff
Stone cohesion [3] – fresh stone:	strongly cohesive
Stone cohesion [3] – weathered stone:	strongly cohesive
Stone fabric [4]:	faintly bedded (parallel bedding)
Distinctive features [5]:	none

Thin section observations

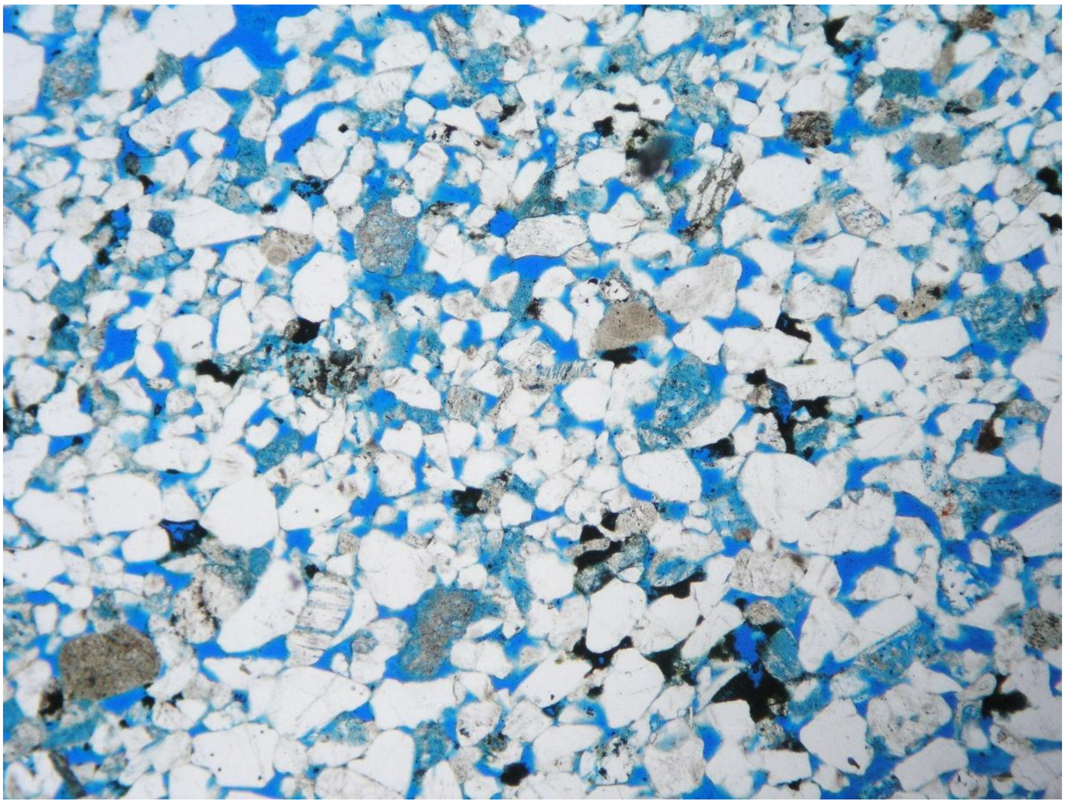
Stone constituents [6]:

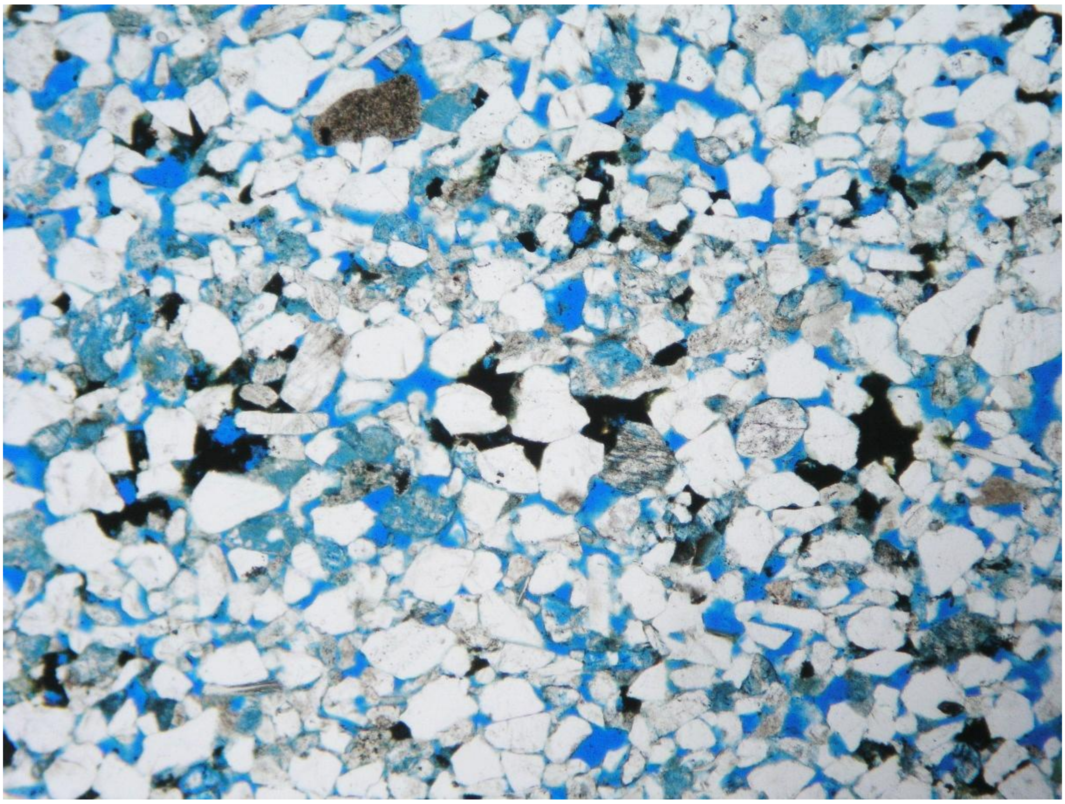
Granular constituents		***Intergranular constituents***	
Quartz	49%	Silica (overgrowth)	1%
Feldspar	7%	Feldspar (overgrowth)	0%
Rock fragments	16%	Carbonate	0%
Mica	<1%	Iron/manganese oxide	4%
Opaque material	<1%	Clay	4%
Other	<<1%	Hydrocarbon	0%
Intragranular pores	7%	Intergranular pores	12%

Stone type [1] (detailed classification):	sublithic-arenite
Grain-size [7]:	fine-sand-grade
Grain sorting [8]:	well sorted sub-rounded to rounded
Grain roundness [9]:	sub-rounded to rounded
Stone permeability [10]:	moderate
Cement distribution [11]:	silica cement isolated
Supergene changes [12]:	moderate dissolution of feldspar; strong dissolution of carbonate; moderate dissolution of rock fragments

Comments

1. The exterior surfaces of the sample are covered in a thin dark buff patina.
2. The stone displays a faint parallel bedding fabric, which is produced by mm-scale layers of stone that vary slightly in grain size.
3. The mineral zircon is present in trace amounts (accounting for <<1% of the total thin section area).
4. The sample contains a few 'moldic pores', which are fringed with iron oxide minerals. Iron oxide is also distributed as intergranular patches throughout the stone. The presence of moldic pores, in particular, suggests that an intergranular, iron-bearing carbonate mineral was formerly present in the stone, but that this mineral has since dissolved due to chemical alteration.
5. The relatively high proportion of intragranular pores, and the presence of grains which appear to be 'floating' in the plane of the thin section, suggest that the stone formerly contained a greater volume of feldspar grains, which have since dissolved due to chemical alteration.





Thin section photographs of sample MC4167 (‘F2’: Fersness quarry). Grains of quartz and feldspar appear white. Rock fragments appear mottled grey. Iron oxide appears brown to black, and is distributed in patches throughout the stone. Pore space appears blue. The images were taken in plane-polarised light, and the field of view is c.3.3 mm wide.

SUPPORTING NOTES FOR THE PETROGRAPHIC DESCRIPTIONS

Each numbered note below relates to a superscript number in the Petrographic Description Forms (Appendix 1).

1 The determination of stone composition 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 whether the sample contains mineral or textural features that are distinctive.

6 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.

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

8 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).

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

10 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.

11 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.

12 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.