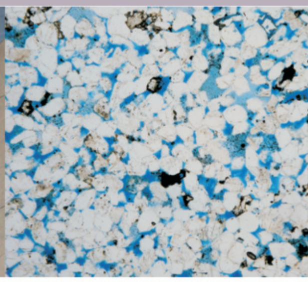
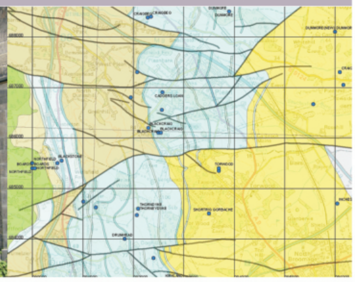
AN HISTORICAL AND GEOLOGICAL ASSESSMENT OF A SCOTTISH BUILDING STONE QUARRY:

DRUMHEAD QUARRY, DENNY





SCOTTISH STONE LIAISON GROUP

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

BRITISH GEOLOGICAL SURVEY

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OPEN REPORT OR/10/033

An historical and geological assessment of a Scottish building stone quarry: Drumhead Quarry, Denny

Emily A. Tracey, Luis Albornoz-Parra, Paul A. Everett & Ewan K. Hyslop

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Drumhead, sandstone, quarry, Scotland, building stone, resources, minerals, petrology.

Front cover

Main Image: Drumhead Quarry, Denny, September 2009. Smaller images (left to right): Block of Drumhead sandstone, April 2009; 1861 map of Drumhead Quarry (Stirling Archives); thin section image of uniform Drumhead sandstone; Alexander Bowie building, Allan Park, Stirling; BGS Geology map of Falkirk area.

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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

Kingsley Dunham 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
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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

Forde House, Park Five Business Centre, Harrier Way, Sowton EX2 7HU
Tel 01392 445271 Fax 01392 445371

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

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Summary

Drumhead Quarry, situated a few kilometres north-east of Denny in the Central Belt of Scotland, is one of several quarries in the Falkirk area which exploited the Cowie Rock, a pale-coloured sandstone in the Upper Limestone Formation (Clackmannan Group). The quarry supplied building stone from the very early 18th century, working fairly consistently until the late 19th century.

Historical evidence indicates that the stone was primarily used locally in the Falkirk and Stirling areas, until the opening of the Union Canal in 1822 which then allowed the sandstone to be shipped to Glasgow, Linlithgow and Edinburgh, mainly for use as paving stone. Drumhead sandstone was the first ever shipment along the Union Canal in 1822, landing in Edinburgh. The quarry was worked under several different operators throughout the 19th century and often shared the same operator as Thorneydyke Quarry (located c. 600m to the north) in the latter half of the 1800s. It was not uncommon for the quarry to be operated by local builders and architects, who were most likely to use the stone they were extracting from their own quarry as the main source of building material for their designed and built structures.

Drumhead Quarry exposes thick-bedded sandstone with some bedding lamination and wide joint spacing, well-suited to extracting large blocks. The possibility that a unit of limestone - the Calmy Limestone - encroaches near to the quarry's east and north boundaries (and might limit the prospects for future expansion) has been recently tested by drilling boreholes. Limestone was not encountered in the drilling exercise, but units of mudstone and shale interbedded with sandstone to the east of the quarry indicate a change in the depositional environment of the sedimentary rocks in this area, and suggest the limestone might be nearby. A borehole to the north of the quarry encountered only sandstone in the bedrock, hence extending the quarry in this direction would appear to offer the best prospect of encountering good reserves of sandstone.

Samples of Drumhead sandstone are quartz-rich, well compacted, and have a strong natural mineral cement resulting in a strongly cohesive (difficult to disaggregate) stone. The stone is therefore of good quality and likely to be durable. It has the potential to be a versatile building stone, suited to a range of uses including rubble walling, high quality ashlar and carving. There are two main varieties of the sandstone: a buff variety with faint-to-strong bedding lamination, and an off-white, freestone (uniform) variety. All of these factors will enhance the commercial viability of the stone.

The two varieties of Drumhead stone should provide a good substitute for a number of sandstones that were formerly sourced and used widely in the Central Belt, but are now unavailable. Sandstone of this type is in particular demand in the Stirling, Glasgow and Linlithgow areas.

Acknowledgements

Many individuals have contributed data, advice and local knowledge to this project. We would particularly like to thank Letitia and David Graham, Anne Smith, and Dr. Martin R. Gillespie.

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1 Introduction and aims of this study

The British Geological Survey (BGS) has been commissioned by the Scottish Stone Liaison Group to investigate the building stone resources at a number of sites in Scotland (Scottish Building Stone Resources Project). As part of this work BGS was asked to contribute to an investigation of the potential for reopening Drumhead Quarry, near Denny in the Central Belt of Scotland. This quarry is known to have been active from the early to mid 19th century.

Today there is a growing interest in the use of natural stone in Scotland and throughout the United Kingdom for a range of functions, including the repair of historic buildings, new construction, and stone for public realm works, streetscape improvements and infrastructure projects. An increasing awareness of the distinctiveness of Scottish stone and the importance of selecting appropriate stone that is ‘in keeping’ with the local stone-built heritage has led to an improving market for Scottish stone, in particular stone which has a proven historical pedigree. The reopening of historic dimension stone quarries at Swinton in Berwickshire (2000), Cullalo in Fife (2004) and Pitairlie in Angus (2009) is evidence of a potential resurgence of the Scottish stone industry. These three quarries each produce sandstone with distinctive characteristics to supply a particular market.

The purpose of this report is to document new and existing technical and historical information for the Drumhead Quarry sandstone, and to present the information in a form that will help determine the potential for Drumhead Quarry to supply stone to a wider market in the future; both for restoration/repairs and for new build. The work described in this study follows several visits to the quarry and to a number of buildings in the local area by representatives of the BGS Building Stones Team (Ewan Hyslop, Emily Tracey and Luis Albornoz-Parra) and the Scottish Stone Liaison Group (Colin Tennant), and discussions with the quarry owners (David and Letitia Graham), since the summer of 2009.

The report outlines the geological setting and documented history of sandstone production at Drumhead Quarry, based on archival records and survey maps held by BGS (Section 2). The geological setting and character of Drumhead Quarry are described (Section 3), and stone samples collected during the quarry visits are described briefly (Section 4). The geological character of the stone is assessed through petrographic analysis (Section 5), and Drumhead stone is compared with a selection of other building stone sandstones of broadly similar character that were sourced from quarries that are no longer active (Section 6). The results of compressive strength tests of Drumhead sandstone samples conducted as part of this study are reported (Appendix 1), and compared with the published values for reputable sandstones from other quarries in Scotland and Northern England (Section 7).

2 History and background of Drumhead Quarry

This section of the report outlines the history of Drumhead Quarry through an examination of land ownership, quarry operations, and quarry development. This research is based on information collected from archival records and historic maps. At the end of the section there is a list of buildings that are either known to be built from Drumhead sandstone or are associated with the architects and builders who were operating Drumhead Quarry at the time of their construction (and are therefore likely to be built from Drumhead sandstone). Reference details for all sources of information quoted in this section are included within the text due to their non-standard bibliographical format. Most reference materials were sourced from library archives.

Drumhead Quarry is located c.2km to the east of Dunipace near Falkirk [NS818840]. The town of Larbert lies to the east, Falkirk is to the south, and the village of Plean is to the north. Historically, Drumhead Quarry was part of Denovan Estate.

The first known reference to the Lands of Denovan occurred when Thomas Gardnar of Denovane signed as a witness on the 18th of May 1462 in a cartulary of Cambuskenneth, a village just east of Stirling. By the end of the 16th century the Lands of Denovan belonged to the Forresters of Torwood until 1 June 1773 when Denovan was sold by David Forrester of Denovan to John Johnstone of Alva. John Johnstone died in December 1795; his successor was son James Raymond Johnstone.

As indicated in a sasine of 1708 (RS83/12 f.2, Falkirk Council Archives), the lands of Denovan Estate included: ‘Burnsyde & Muirdyke’, Drumhead, ‘Thorndyke’ and ‘Dog-hillock’, all within the barony of Herbertshire. Two quarries were located on the Denovan Estate: Thorneydyke and Drumhead; however, stone extraction did not begin simultaneously in these quarries.

The Denovan Estate Map of 1797 (Figure 1) illustrates the boundary of each farm located on the estate: Ingleston, Bankend, ‘Dog-hillock’, and Daleswood. Drumhead and Thorneydyke quarries were located to the west of Doghillock and Drumhead farms. Thorneydyke Quarry was in operation by 1797 and is present on the estate plan; however, Drumhead Quarry does not appear on the map, indicating that it was not yet in operation. James Johnstone was the land owner at the time this Estate map was drawn.

Early 19th century records of the Johnstone of Alva papers (Clackmannan Council Library: CCL) mention Drumhead Quarry as early as 1820; however, the correspondences indicate that the quarry was already in full operation by this time. Stone extraction at Drumhead Quarry most likely began shortly after the Denovan Estate Map was drawn, at the end of the 18th century.

The 1861 map of Drumhead Quarry (Stirling Archives) (Figure 2) has a crane in the northern half of the quarry, indicating the quarry as active and expanding to the north. The present day quarry site still retains a deep hole in its northern half—an indicator that historically the operators were chasing higher quality stone at deep levels.

The crane is still present on the 1865 Ordnance Survey (OS) map (Figure 3), but on the 1899 OS map (Figure 4) Drumhead Quarry is marked as ‘Old Quarry’ with little to no change in the quarry boundaries. This indicates that the quarry was inactive before the end of the 19th century, with minimal quarrying after the 1860s. Thorneydyke Quarry was still operating in 1899 and had expanded significantly to the north since the previous mapping survey in 1865. On the 1922 OS map (Figure 5) Drumhead Quarry remains marked as ‘Old Quarry’; Thorneydyke Quarry, however, shows a slight expansion towards the west, along the northernmost tip. This late expansion at Thorneydyke Quarry may have occurred in the early 20th century before it was known to close c.1903.

Figure 1: Denovan Estate Map, 1859, from a tracing by Alexander Black, Surveyor, Falkirk of a 1797 drawing by John Wilson, Surveyor (A727.4290 Falkirk Council Archives). Map illustrates the boundaries of each farm located within the estate: Ingleston, Bankend, Dog-hillock, and Daleswood. "Thornydike" Quarry is located northwest of Doghillock farm, Drumhead Quarry is not present. Map insert locates Drumhead and 'Dog-hillock' farms as well as 'Thornydike' Quarry; however, the map indicates that Drumhead Quarry was not in existence at this time. The quarry is located just west of Doghillock farm.

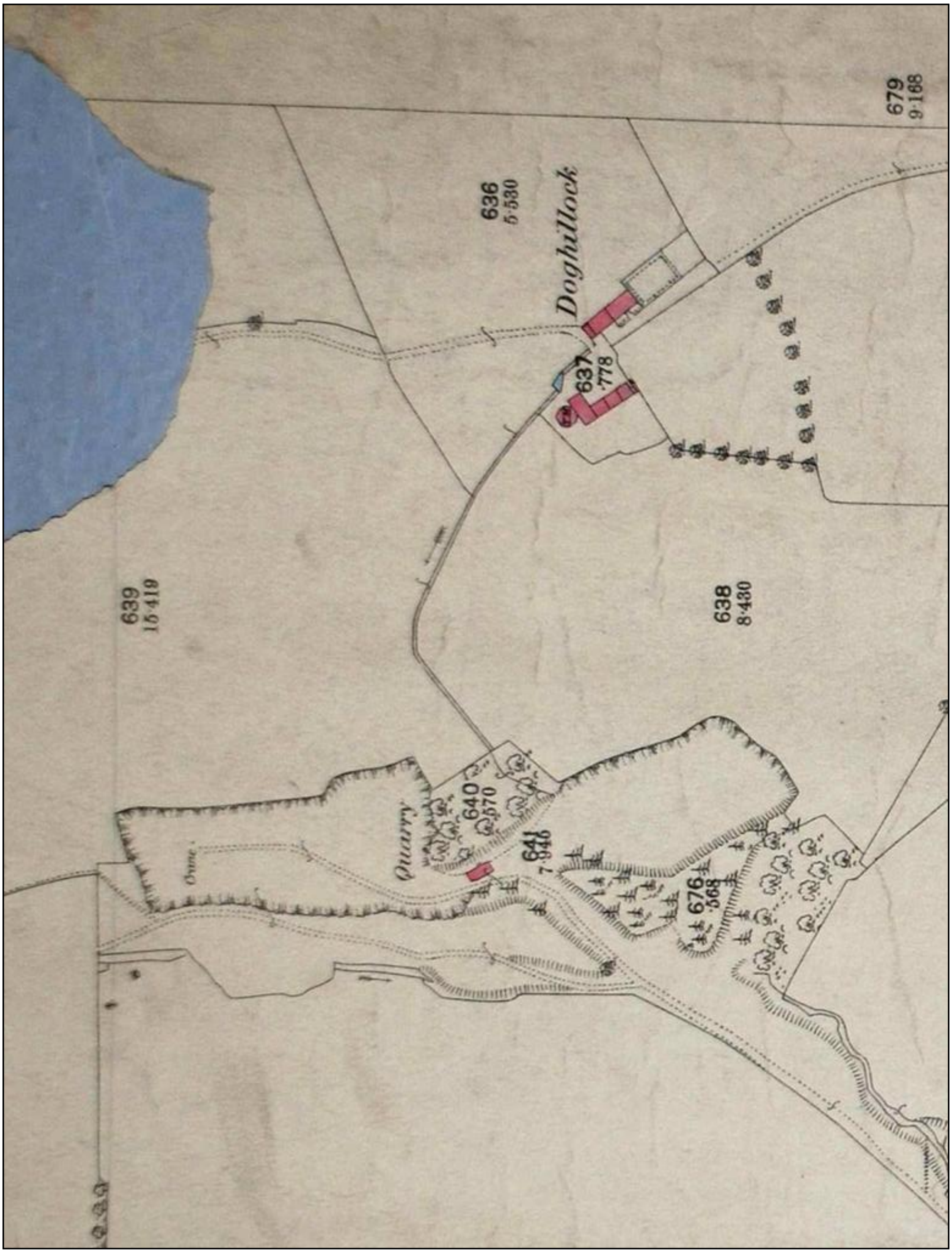
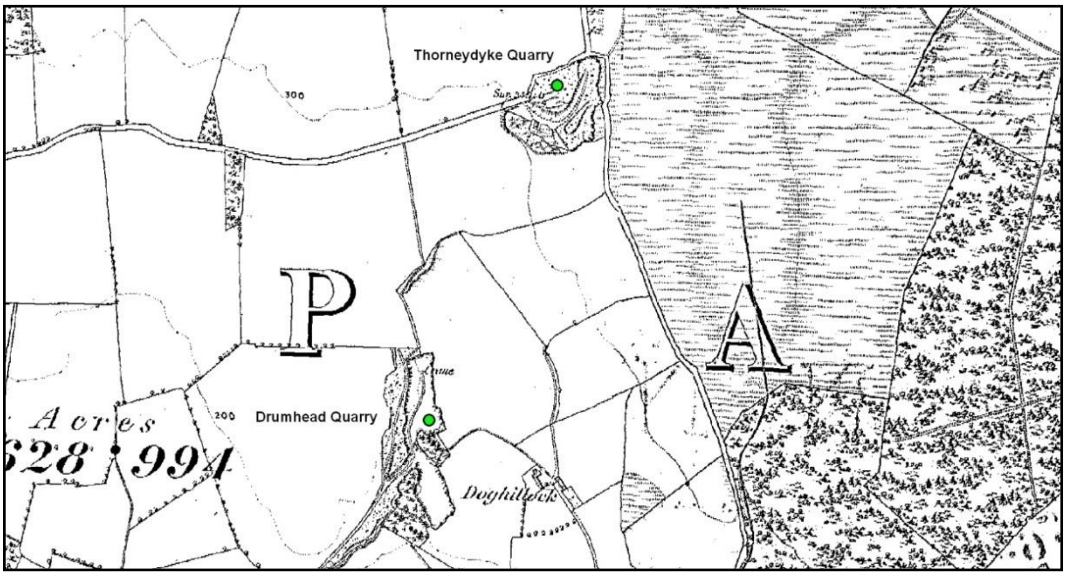


Figure 2: 1861 Map of Drumhead Quarry (Stirling Archives © Crown Copyright) located directly west of Doghillock Farm on Denovan Estate. The quarry was fairly large by this time and must have expanded significantly since the beginning of the 19th century.



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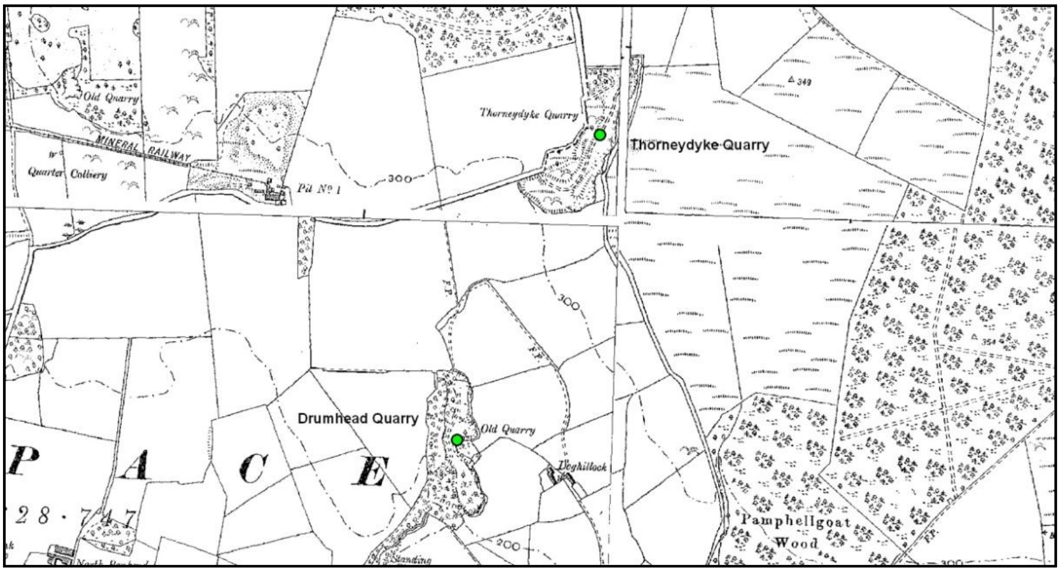

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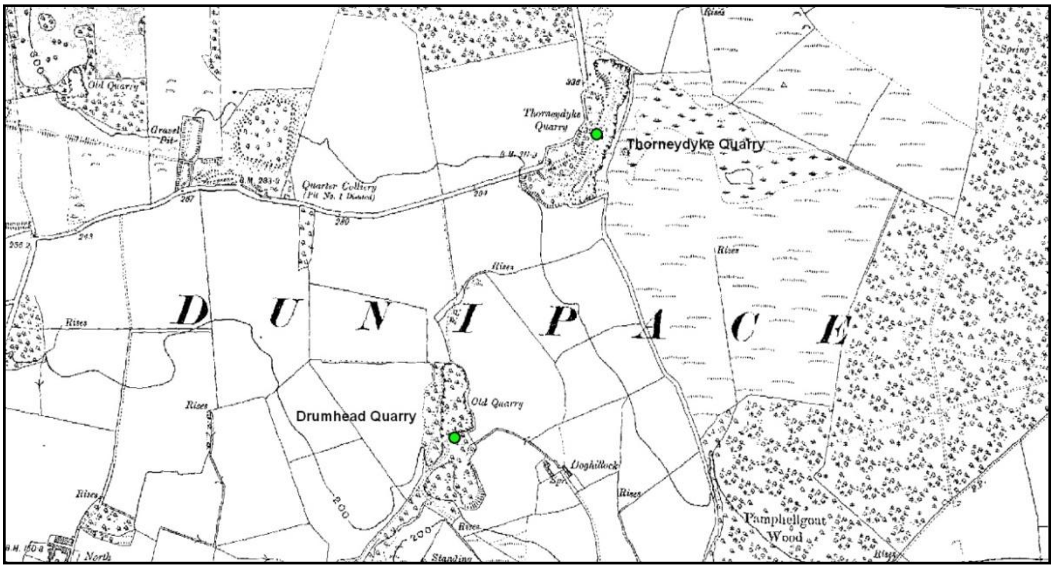

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Figures 3, 4, 5: Sequence of Ordnance Survey maps dating from 1865 to 1922 showing the development of Drumhead and Thorneydyke quarries (green dots). Thorneydyke Quarry appears to be active in all of the maps, with expansion occurring between each survey; however, Drumhead is designated as an 'Old Quarry' by 1899, indicating a period of inactivity at this time.

It was historically known that the area produced good quality sandstone. The *Ordnance Gazetteer of Scotland* (1882-5) stated that the 'Dunipace' sandstone was "capital building material, partly of a character well suited for flag or pavement".

The Statistical Accounts of Scotland (1834-45) mentions four quarries in Dunipace (vol. 8, p. 380) "all producing superior freestone." According to this same Account, these quarries together employed around 40 individuals, implying fairly successful operations for the time. The Account continues to state that one of the quarries "abounds with excellent flag or pavement stone, which has an extensive sale. Considerable quantities of these flags are carried in carts and boats to a great distance."

Based on archival evidence, the aforementioned flag and pavement stone reference is most likely referring to Drumhead Quarry. This is supported by the following extract from the Johnstone of Alva papers (58/35 CCL) (20 April 1820) written by George Easton, the Denovan Estate factor, to James Johnstone:

> *John Ferguson will make a good deal of money in his quarry at Drumhead. It produces the best quality of any pavement ever known in this place from one to six inches of thickness without any heughing...*

John Ferguson is the first known operator of Drumhead Quarry. In 1822, Ferguson made a contract with the Glasgow architect John Baird "for a twelvemonth to deliver him 36 tons of pavement every week to be laid down at the canal for paving the streets of Glasgow" (60/55 CCL). The Forth & Clyde Canal would have taken Drumhead paving stone directly from the Falkirk area to Glasgow. The stone would have been transported by cart from the quarry to the canal, which was c.2km to the south.

By April of 1822, Ferguson was sending Drumhead paving stone to Linlithgow; additional stone was also waiting on Lock 16 to go to Edinburgh (60/55 CCL, 1 April 1822). The Union Canal joined the Forth & Clyde Canal at Lock 16 [NS852802] where it was reported on 9 May 1822 by both the *Glasgow Courier* and the *Edinburgh Evening Courant* that the canal was in water from end to end and that a boat loaded with flagstones from Denny Quarry had sailed into Edinburgh—the canal was open and Drumhead paving stone was the first shipment.

Drumhead sandstone was initially carted to Stirling and used locally around the Falkirk area; once the canals were functioning the building stone was shipped to Glasgow along the Forth & Clyde canal, and to Linlithgow and Edinburgh along the Union Canal. On 14 November 1822 (25/37 CCL) George Easton reported to James Johnstone on the influence of the canals on the demand for Drumhead stone:

> *The freestone quarries appear to be doing very well especially John Ferguson who has a great demand to Edinburgh by the New Canal and also to other places.*

And again on 17 January 1824 (60/77 CCL):

> *John Ferguson is undoubtedly making a good deal of money from [the quarry]. It is said he sometimes clears £10 per day if he is careful. He need not care whether he gets a new lease or not as he may make an independent fortune during the present one.*

Later that year (20 April 1824) (22/21 CCL) it was recorded that Drumhead Quarry was expanding to the east and northwest. The lease remained under Ferguson until 1828, by which time Ferguson had requested a further 5 year lease on Drumhead Quarry; however, an article from the *Stirling Journal* dated 18 March 1830 indicates that there was a new operator of the 'Denovan Flag':

John Gow, builder in Denny, begs leave respectfully to intimate that, having lately taken from James Raymond Johnstone, Esq of Alva, his Flag Quarry of Denovan, as well known throughout the whole country for the excellent quality of the Flagstones, he has at present on hand and will always keep a regular supply of flag stones from one inch to one foot thick for jambs, hearths, and flats and stones of all dimensions for stairs, cisterns, oven soles and division for byres, etc. The quality of the stone is excellent... and J.G. can confidently assure the public that they are well worthy of their attention... The prices are very moderate. Orders addressed to J.G. or to his Overseer at the Quarry, will meet with the most prompt attention Denovan Flag Quarry.

As Drumhead Quarry was located just north of Denovan Mains and was known to produce building stone suitable for flags, it can be assumed that the 'Denovan Flag' quarry was indeed Drumhead Quarry. John Gow was known as 'the builder of Milton' (part of Dunipace); he was born in Thornhill.

Thorneydyke Quarry was also up for lease in 1830 (Stirling Journal: 14/01/1830 and 03/06/1830). Prior to this, Thorneydyke Quarry was leased by Alexander Bowie, a builder from Stirling. Bowie also had a stone yard in Stirling off Dumbarton Road located to the rear of 1-9 Allan Park, conveniently behind the builder's Stirling residence (as identified in 'Plan of the Town of Stirling', 1820, National Library of Scotland EU.31.W). A yard was still operating at this location in 1858 (Town Plan of Stirling 1858: XVII.3.15); however, by then it was used for timber rather than stone.

The stone available in the yard was probably from Thorneydyke Quarry, as Bowie also leased Thorneydyke. The following sales advert for Bowie's sandstone from Thorneydyke Quarry was placed in the *Stirling Journal*, 1/02/1821:

Thornidyke Quarry

Reduced Prices of Free Stones Alex. Bowie is happy in being able to announce to his numerous Friends and the Public, that owing to the particular state of the above quarry, he is now enabled to reduce the prices of FREE STONES, both at the Quarry and his Stone Yard in Stirling. The Prices will be found considerably cheaper than formerly: and the public, having had long proof of the Superior Quality, Durability and Beautiful Colour of the Stone, A. Bowie hope for a continuance of public favour.

Several buildings in Stirling are attributed to Bowie: Craigs House, The Craigs, c.1817; Commercial Bank, Spittal Street, c.1827; and 14 of the 22 houses on Allan Park, c.1820s, all constructed prior to Bowie's death in 1829. All these buildings were surveyed in the course of this study, in an effort to determine if either Thorneydyke sandstone or Drumhead sandstone was used in their construction (see Table 1 and 'Site visit to Stirling', below).

Shortly after Alexander Bowie died in 1829 an advert was placed in the *Stirling Journal* for the lease of the stone yard in Stirling and for Thorneydyke Quarry (14 January 1830):

Lease of stone yard in Stirling, a quantity of stone, and remainder of lease (1 year) for Thorniedyke Quarry.

A second advert was run on 3 June 1830, indicating that there had been no successful applicant. On 29 July 1830, an advert was placed solely for the lease of Bowie's Stirling stone yard. The quarry had presumably been leased, but the stone yard remained unoccupied.

In 1831 Drumhead Quarry was being expanded; estimates were being called upon for drilling a 900 foot mine (or leavel) (Stirling Journal: 27/01/1831). This would assist in draining the quarry, as the sandstone was being 'chased' below the water line. The quarry was known to have had water problems in the past under Ferguson's ownership, as Easton (Denovan Estate factor) reported on 17 January 1824 to landowner James Johnstone (60/77 CCL): "[Ferguson] now sees his error in not making his leavel deeper as it will soon fail him in carrying the water as the rock dips so greatly in the east..." They were chasing the higher quality sandstone downwards in an easterly direction.

As previously mentioned, John Gow took over operations at Drumhead Quarry in 1830. By the time of the 1865/6 Scottish valuation rolls (SC4/3/3), Drumhead Quarry was occupied by the heirs of John Gow and maintaining a lease for less than 19 years. By the time of this valuation roll, Denovan Estate owner James Johnstone had passed away (1830) and his successor, son James Johnstone (b. 4 July 1801), had sold the lands of his father's Estate to William Forbes (1839). Forbes had purchased the lands of neighbouring Herbertshire Estate in 1836. The valuation rolls confirm this purchase by indicating the Proprietor of Drumhead Quarry to be William Forbes of Callender.

John Gow also took over operations at Thorneydyke Quarry, presumably shortly after he began the lease at Drumhead. According to a much later *Stirling Journal and Advertiser* article, dated 8 May 1874, the late heirs of John Gow were operating both quarry sites at the time of their death.

Freestone Quarries

To let on lease with entry at Whitsunday 1874

1. *The well known freestone quarry of Thornydyke near Denny in the parish of Dunipace and County of Stirling about half a mile from the Inglistone Branch of the Caledonian Railway for many years wrought by the late Messrs Gow. There is a large face of rock and very little tiering on it. The rock is soft and easily worked, of a fine warm colour, well known in Edinburgh and Glasgow, and many fronts of the finest buildings in Stirling are built with this stone.*
2. *The flag quarry of Drumhead near to Thornydyke from which large flags or pavement can be taken out of various thicknesses. This quarry which was also wrought for many years by Messrs Gow will be let along with Thornydyke or separately.*

Offers for these quarries may be sent to William Forbes Esquire of Callendar, Falkirk on or before the 15th day of May 1874: or they may be left with William F. Hamilton, Callendar Park, Falkirk from whom further particulars may be learned.

Shortly after the above advert was published, the *Stirling Journal and Advertiser* released the following advert on 3 July 1874:

To Architects Builders etc:
William Simpson Jun.

Having become lessee of Thornydyke Quarry near Denny so long and successfully carried on by the late Mr Gow and well known as a first class stone for building purposes is now prepared to supply any quantity of stones.

Orders addressed to him at 61 King Street, Stirling or to the quarry by Denny will be immediately attended to.

The Scottish valuation roll of 1880/1 (SC4/3/4) stated the Proprietor of Drumhead Quarry to still be William Forbes of Callender, but William Simpson was the new occupier, until 1885/6. Simpson picked up the lease for both Drumhead and Thorneydyke quarries even though the 1861 Stirling Archives map and the 1865 OS map indicate that Drumhead Quarry had been inactive for some time by this date. It is not uncommon for quarries to fluctuate between inactivity and activity, depending on the demand for the building stone.

William Simpson was a Stirling architect practising from c.1870. He designed the following buildings: Whins of Milton, Milton Grove (c.1879); the Former Custom House, Union and Register Street, Bo'ness (c.1880); Albert Hall (c.1881), one of Stirling's grandest buildings; and Dunipace Parish Church (c.1888), located on the corner of Stirling Street and Barnego Road, Dunipace.

The aforementioned buildings associated with William Simpson may have been constructed from Drumhead/Thorneydyke sandstone, based on the evidence that Simpson was operating these quarries at the time of their construction. One source states that Albert Hall was constructed with rubble from Dunblane and dressings from Polmaise and Plean (Stirling Observer, 27/09/1883); however, a much later source states that Albert Hall was constructed using stone from Thorneydyke Quarry, along with several other buildings: "Stone from Thorneydyke Quarry was used in Stirling for the North Parish Church, the Albert Halls, and the Union Bank, for Pitt Terrace, and some houses on the road to Cambusbarron" (Economic geology of the Stirling and Clackmannan coalfields, C.H. Dinham, 1932). Further investigation of these buildings (probably involving petrographic analysis) would be necessary to draw a robust conclusion.

The final mention of "the quarry at Denovan" (Drumhead Quarry was often referred to as the Denovan flag quarry) was in the late 19th century. In the 1885/6 valuation rolls of Scotland the quarry was no longer operated by William Simpson, but by David Short and John Delvin (Builder and Contractor) of Glasgow. Short was the son of a Denny mason who moved to Glasgow, and Devlin was a sawyer whose son was a carpenter. The valuation rolls mention the same quarry, presumably Drumhead, unlet by 1886/7. Thorneydyke Quarry closed in 1903 after a brief re-opening in 1901 (Dinham, 1932).

Historic sites and buildings associated with Drumhead and Thorneydyke sandstone

Building	Architect	Date	Source
Craigs House, the Craigs, Stirling	Alexander Bowie	c.1817	Possibly Drumhead/Thorneydyke sandstone due to association with A. Bowie.
Larbert Church, Larbert, Falkirk	David Hamilton	1820	1819 Heritor Record (CH2/1326): “A decision was taken to build new Larbert Church with stones from Thorny-Dyke Quarry.”
Paving stone to Glasgow, 36 tonnes per week for 1 year	n/a	1822	CCL 60/55, 1/04/1822
Paving stone to Edinburgh, first shipment along Union Canal	n/a	1822—	CCL 60/55, 1/04/1822
Paving stone to Linlithgow, shipped along Union Canal	n/a	1822—	CCL 60/55, 1/04/1822
1-9 & 2-6 Allan Park (Wellington Place), Stirling	Alexander Bowie	c.1826	Possibly Drumhead/Thorneydyke sandstone due to A. Bowie association and visual analysis by E. Hyslop & E. Tracey.
35 & 37 Dumbarton Road, Stirling	Alexander Bowie	Late 1820s	Ibid.
Commercial Bank, Spittal Street, Stirling	Alexander Bowie	c.1827	Ibid.
Albert Hall, Stirling	William Simpson	c.1881	C.H. Dinham. Economic Geology of the Stirling and Clackmannan Coalfields, 1932.
Dunipace Parish Church	William Simpson	1888-90	Possibly Drumhead/Thorneydyke sandstone due to W. Simpson association.
North Parish Church	Unknown	1888-90	Gifford and Walker. Buildings of Scotland: Stirling and Central Scotland, 2002: 7.
Former Union Bank, Stirling	Unknown	Unknown	C.H. Dinham. Economic Geology of the Stirling and Clackmannan Coalfields, 1932.
Some houses on Pitt Terrace, Stirling	Unknown	Unknown	Ibid.
Some houses on the road to Cambusbarron	Unknown	Unknown	Ibid.

Table 1. List of buildings either reported to have used Drumhead or Thorneydyke sandstone, or known to have been associated with the historical quarry operators of Drumhead and Thorneydyke quarries, with dates of construction and source of the information. Buildings associated with both Drumhead and Thorneydyke quarries are listed together because the close proximity of the quarries suggests they exploit the same geological formation (see Section 3: Description of Geology of Drumhead). In several cases the information is very limited or details of the building are poor, and the date and exact use of the stone is not known (e.g. with the reference to ‘Paving stone in Glasgow’ the exact whereabouts of the use of Drumhead sandstone is not known). The reference to ‘Albert Hall’ is also controversial due to contradicting sources (discussed on p.9). It is likely that many other buildings in the Central Belt are constructed from Drumhead sandstone, but this information is not readily available.

Stirling site visit

Ewan Hyslop and Emily Tracey visited Stirling on 24 July 2009, in order to establish whether sandstone samples extracted recently from Drumhead Quarry share visual similarities with the stone used in buildings known to have been constructed by contemporary Drumhead and/or Thorneydyke quarry operators (i.e. A. Bowie and W. Simpson).

Two main sandstone types were identified during the site visit: 1) sandstone characterised by faint to strong lamination, and 2) sandstone characterised by disrupted bedding.

Lamination is a common characteristic of sandstone paving—the presence of lamination in sandstone is associated with lower porosity, hence it can yield a more durable material. The presence of lamination typically makes it easier to split a stone along its horizontal, thus yielding stone blocks with the geometric characteristics required of paving materials.

The bedding in a pile of unconsolidated (i.e. not yet hardened into rock) sediment can be disrupted by slumping and water escape structures. Such disruption is often localised; it can be restricted to just one of the sandstone beds exposed in a quarry, thus making it a distinctive feature. In this case, it is possible that the sandstone blocks originally appeared fairly uniform and the disturbed bedding only became evident through weathering of the block surfaces.

Typically, the strongly laminated sandstone was used in the Bowie buildings for the dressings and columns (Figure 13), while the sandstone with disturbed bedding was used for ashlar (Figures 9 & 12).

The bedding, grain size and colour of the laminated sandstone are all visually similar to the stone currently being extracted from Drumhead Quarry; however, further thin section analysis would need to be undertaken to confirm they are the same stone.

The sandstone with disturbed bedding may have come from Thorneydyke Quarry, which was also being operated by Bowie at this time. The two stone types are of a similar grain size and colour, although each is distinguished by either lamination or disturbed bedding. It is not uncommon for two quarries in close proximity and exploiting the same geological formation to be extracting broadly similar stone that nevertheless has distinctive characteristics. However, there are no Thorneydyke samples of good quality in the BGS collections to compare to either Drumhead or to the surveyed buildings. Further testing would be required to determine the source of each stone type unambiguously.

The site visit is documented in photographs on the following pages.

Figure 6: East (left) and south (right) elevations of Albert Hall, Stirling. Built c.1881 by William Simpson, architect. Contradicting evidence exists for the source of stone used in Albert Hall: in *Economic Geology of the Stirling and Clackmannan Coalfields* (1932) it is stated that Albert Hall is built from Thorneydyke Sandstone, whereas an article in the *Stirling Observer* from 27/09/1883 instead declares the building stone to be from Dunblane, Polmaise and Plean.

Figure 7: Front elevation of Craigs House, The Craigs, Stirling. Built c.1817 by Alexander Bowie, Stirling builder and operator of Thorneydyke Quarry. The sandstone may have been extracted from Thorneydyke Quarry, as Bowie was the builder and quarry operator. Further investigations would need to be undertaken to examine this possibility.

Figure 8: Commercial Bank, Spittal Street, Stirling. Built c.1827 by Alexander Bowie. Based on the valuation rolls of Scotland and the historical records contemporary with the construction of this building, A. Bowie was the operator of Thorneydyke Quarry. Bowie would probably have used the sandstone being extracted from his own quarry for the construction of this grand edifice.

Figure 9: Former Commercial Bank front entrance colonnade, Spittal Street, Stirling. Disturbed bedding is visible in the ashlar and weathered columns of this former bank building. The building stone may be Thorneydyke Sandstone; further analysis would need to be undertaken in order to determine this.

Figure 10: Allan Park, west (left) and east (right) side of road. Fourteen of the twenty-two houses on Allan Park were constructed by Bowie in the 1820s. It is highly likely that the tenements were constructed from Thorneydyke and Drumhead stone. Bowie's stone yard was located behind the west block of housing along Dumbarton Road. Stone from Thorneydyke Quarry (and possibly Drumhead Quarry) was stored and sold here.

Figure 11: Rear rubble walling of building on Allan Park. Notice the different characteristics of the lesser quality local whinstone rubble walling, most likely extracted from the quarry across Dumbarton Road, versus the high quality ashlar and dressings used for the front facades of the Allan Park tenements (Figure 10).

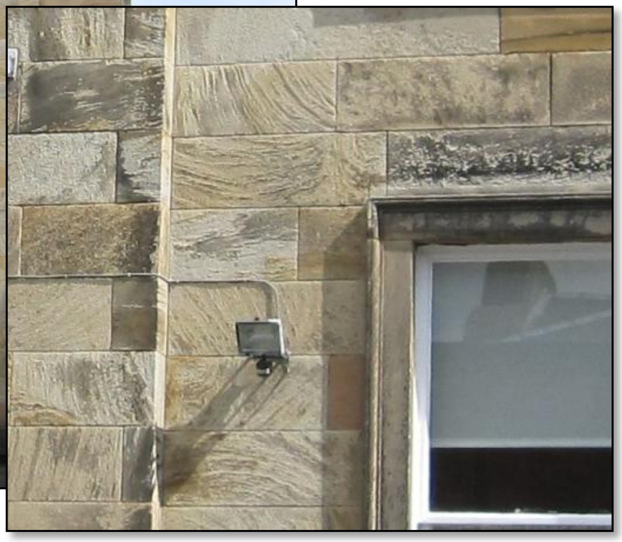


Figure 12: 19 Allan Park. The ashlar for this building displays the characteristics of disturbed bedding, which may be representative of Thorneydyke Sandstone (see insert image). The sandstone used for the columns and window surrounds is strongly laminated, which is a characteristic of some beds in Drumhead Quarry (see images below). This historic villa appears to be a good example of a building incorporating sandstone from both Thorneydyke and Drumhead quarries.

Figure 13: 19 Allan Park column (left) and window surround (right) alongside a sample taken from Drumhead Quarry. Laminated sandstone was very commonly used for paving and for columns and dressings. The sample of Drumhead Sandstone (right image) when compared to the sandstone dressings of 19 Allan Park has a very similar laminated appearance and colour.

3 Geological description of Drumhead Quarry

Drumhead Quarry lies within the Upper Limestone Formation of the Clackmannan Group, which is of late Carboniferous (Pendleian-Arnsbergian) age (Figures 14 & 15). The formation consists of a cyclic sequence of mainly sandstones and limestones, with some siltstones, mudstones, a few coals and seatrocks. The Thorneydyke, Blackcraig, Old Dunmore, Polmaise, Plean and Cowie quarries, amongst others, exploited the same geological formation, and all yield the well known “Cowie Rock”.

The sedimentary rocks are relatively flat lying, dipping c.10^{o} to the east, towards the north-south oriented Clackmannan and Falkirk-Stane synclines. The Upper Limestone Formation is overlain by the Passage Formation, a series of sandstones interspersed with thin layers of other sedimentary rocks, which crops out to the east of Drumhead. To the west there are some contemporaneous igneous intrusions, mainly quartz-microgabbro, belonging to the Midland Valley Sill-complex.

The area is covered by relatively thick superficial (glacial) deposits, which has hampered the geological interpretation of the area. The only exposed rocks are the two sandstone quarries at Drumhead and Thorneydyke (the latter now infilled). These factors make it difficult to establish details of the bedrock geology with certainty.

3.1 Interpretation of geology from maps and boreholes

Geological surveying took place over a number of years, with maps dated at 1860, 1899 and 1911 in the BGS archives. Due to poor exposure, different interpretations have been offered for the geology of the area, particularly regarding the locations of discrete limestone beds which have been used as ‘marker horizons’ to help constrain the geology throughout the district.

The Drumhead and Thorneydyke quarries are in close proximity (c.600m apart). Borehole logs (see Section 3.2 Drumhead Sandstone, the geology of the quarry in detail) show ‘Calmy’ Limestone positioned stratigraphically above the Drumhead Sandstone. Due to the thick overburden of superficial deposits and lack of exposures, it is not clear if the two quarries are separated stratigraphically by the Calmy Limestone, with Drumhead Quarry beneath and Thorneydyke Quarry above, or if both exploit the same geological horizon.

Although the Calmy Limestone is not exposed at the surface its presence is inferred immediately to the east of the quarry from borehole and mining records. The currently published geological survey map (Figure 15) shows it to be very close to the current east face of the quarry, curving around the north face of the quarry on the south limb of a fold. It would form a bed of limestone (probably mixed with impure sandstone, siltstone and mudstone) dipping as a shallow plane towards the east. The thickness of this unit is not specified, but it is likely to be in the order of 10 metres.

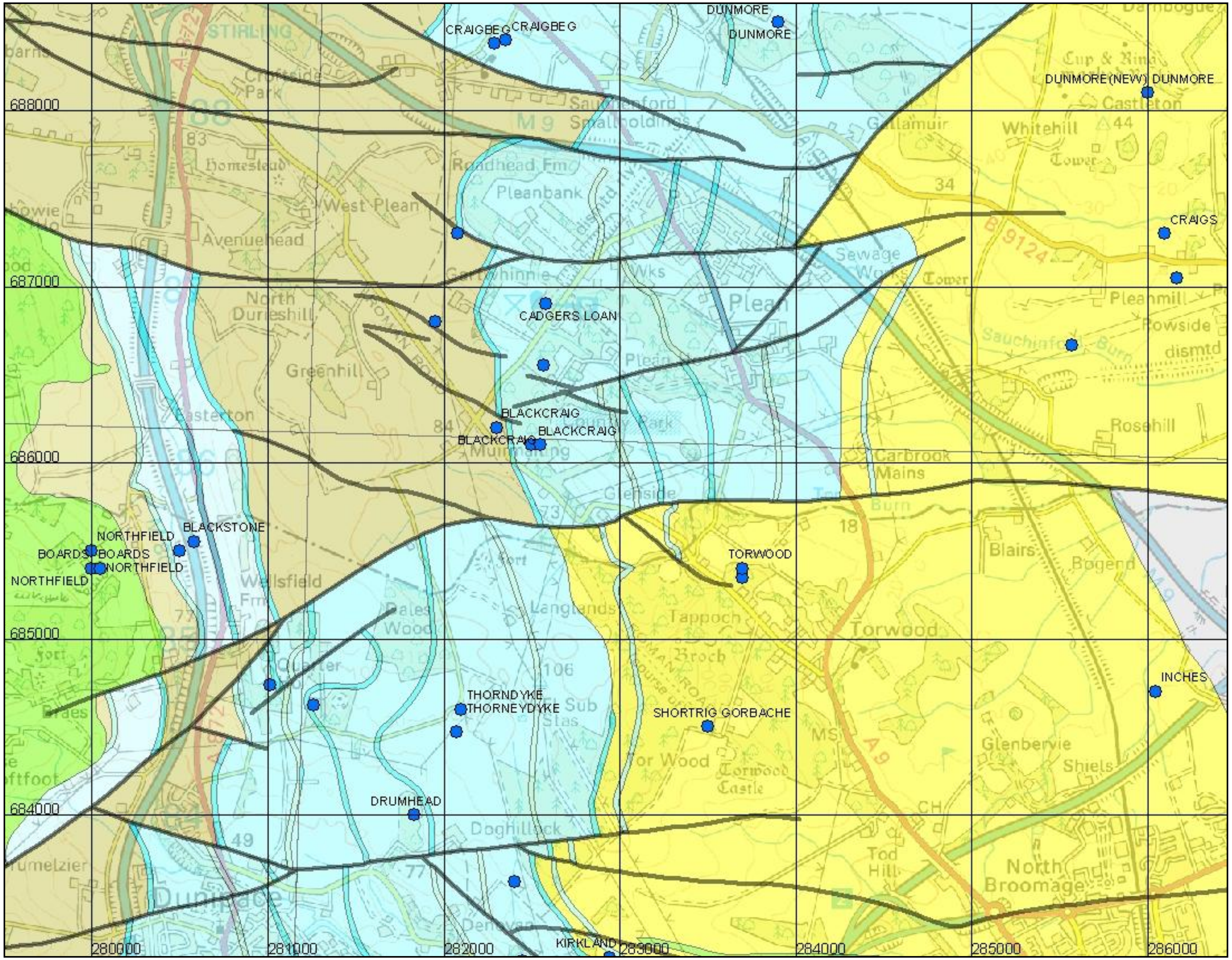


Figure 14: Current BGS geology map of the Drumhead Quarry area. Note the locations and names of the quarries in the area, represented by the blue dots, particularly for Drumhead Quarry towards the southwest corner of the map. Yellow: Passage Formation (Clackmannan Group sedimentary rock cycles (Carboniferous); blue: Upper Limestone Formation; brown: Limestone Coal Formation; green: Midland Valley Sill-complex (igneous rocks). The thin darker blue bands within the Upper Limestone Formation represent marker horizons, which have been used by geologists to map the bedrock geology of the area. Of particular importance to this study is the marker unit that crops out just NE of Drumhead Quarry. This band is known as the Calmy Limestone. Map is extracted from the current BGS geology map of the area (BGS, 1997).

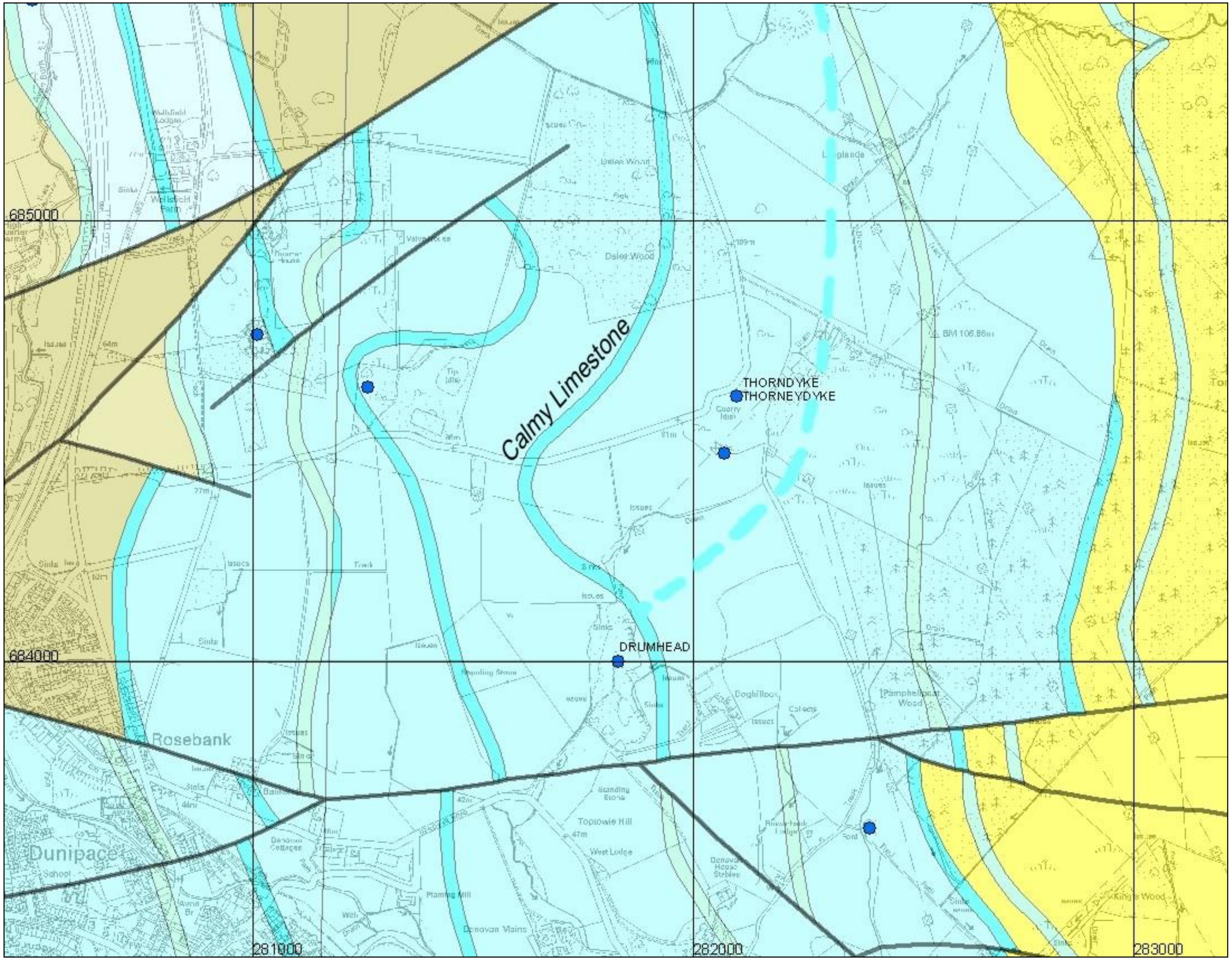


Figure 15: Current BGS geology map of the Drumhead Quarry area (BGS, 1997) showing the current interpretation of the Calmy Limestone location, and previous interpretation (blue dashed line) from the 1899 map. Note that the previous interpretation placed both Thorneydyke and Drumhead quarries to the west of the Calmy Limestone unit, and therefore both within the same geological horizon.

The problem of the Calmy Limestone

The location of the Calmy Limestone is an important consideration when assessing the potential for expanding Drumhead Quarry; a limestone bed near the quarry face could constrain the potential for expansion. Also, the nature of the sandstone may change near the limestone (e.g. the sandstone beds may become thinner -‘flaggier’-, and may contain impurities such as mud and/or carbonate). Thus, sandstone quality may be affected to some degree.

According to the most recently published geological maps, Drumhead Quarry appears to be partially bounded at its northern end by the Calmy Limestone and at its southern end by the intersection of two faults (Figure 15). No significant faults intersect the quarry; however, small faults and other fractures associated with the larger mapped faults may partially affect the quality of stone for extraction.

Hand annotated geological field slips superimposed on the Ordnance Survey map of 1899 (Figure 16) show the conjectural outcrop of the Calmy Limestone running north-south immediately east of Drumhead Quarry and bending northeast to pass east of Thorneydyke Quarry. This would place both Drumhead Quarry and Thorneydyke Quarry stratigraphically below the Calmy Limestone and probably in the same geological horizon, between the Orchard and Calmy limestone bands. This interpretation has changed in the current geological map, which shows the outcrop of the Calmy Limestone immediately east of Drumhead Quarry, just clipping the northern end of the quarry and trending northwest. This map puts the Drumhead Sandstone stratigraphically below the Calmy Limestone, and the Thorneydyke Sandstone above it, hence placing them in different geological horizons.

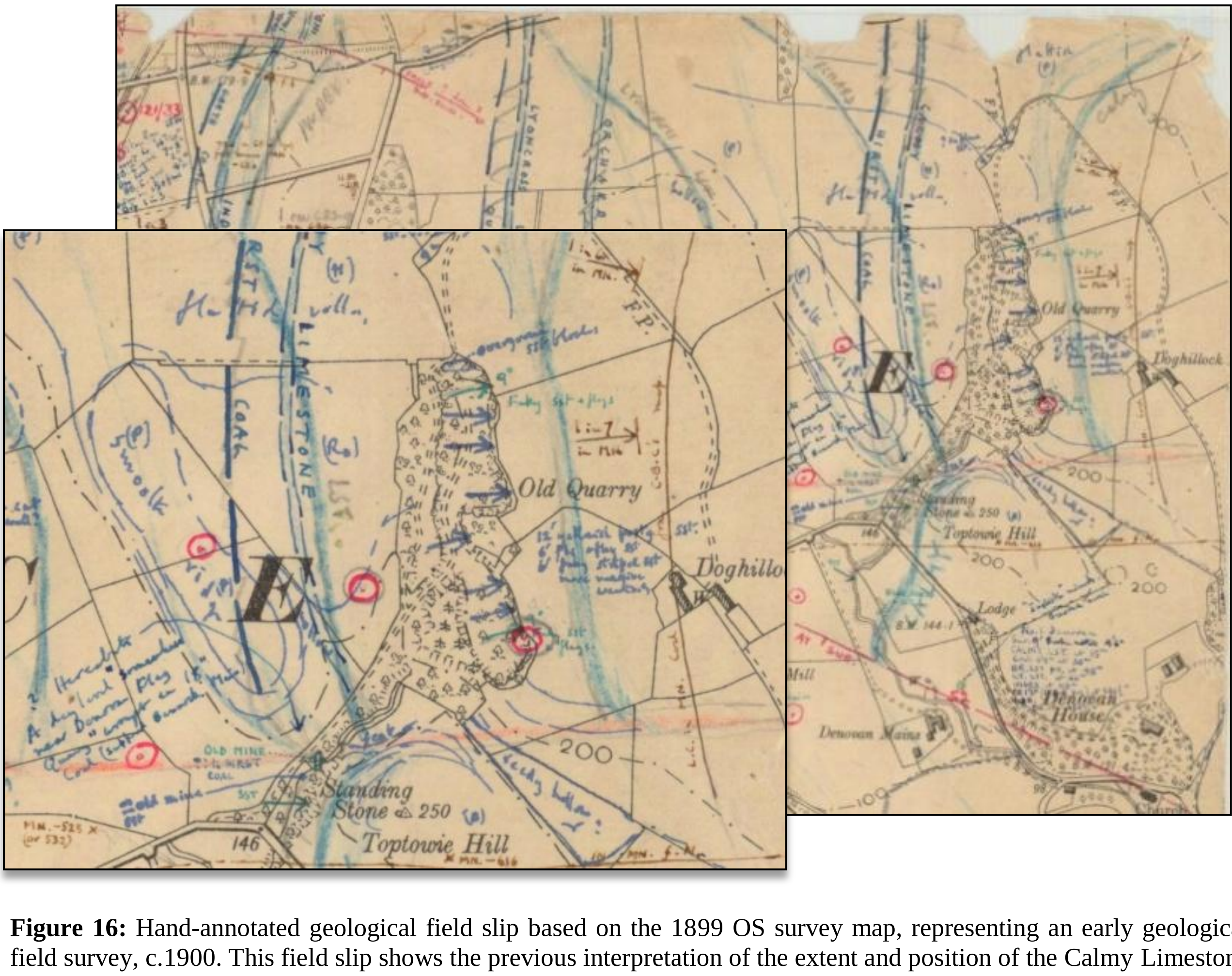


Figure 16: Hand-annotated geological field slip based on the 1899 OS survey map, representing an early geological field survey, c.1900. This field slip shows the previous interpretation of the extent and position of the Calmy Limestone (blue line to the right of the quarry).

Recent borehole data from the geotechnical report *Site Investigation into the Geology of Drumhead Quarry, Denny* (APS GeoServices Ltd., 2009) have shown that the Calmy Limestone is not present in the area immediately to the north of the quarry face (Figure 17). The geotechnical report also noted that "boreholes 09DH01P, 09DH02P and 09DH03 [to the east of the quarry] encountered predominantly mudstones with minor sandstones… It is envisaged that these are part of the overlying limestone sequence." These two observations support the interpretation presented on the 1899 geological fieldslips (Figure 16), which illustrate the Calmy Limestone cropping out to the east of both Drumhead and Thorneydyke quarries, rather than swinging round the north end of Drumhead Quarry (as shown on the current geological map). This in turn supports the possibility that Drumhead and Thorneydyke quarries were extracting sandstone from the same geological horizon; however, there is still no conclusive evidence for this assertion. Further borehole testing would provide additional constraints.

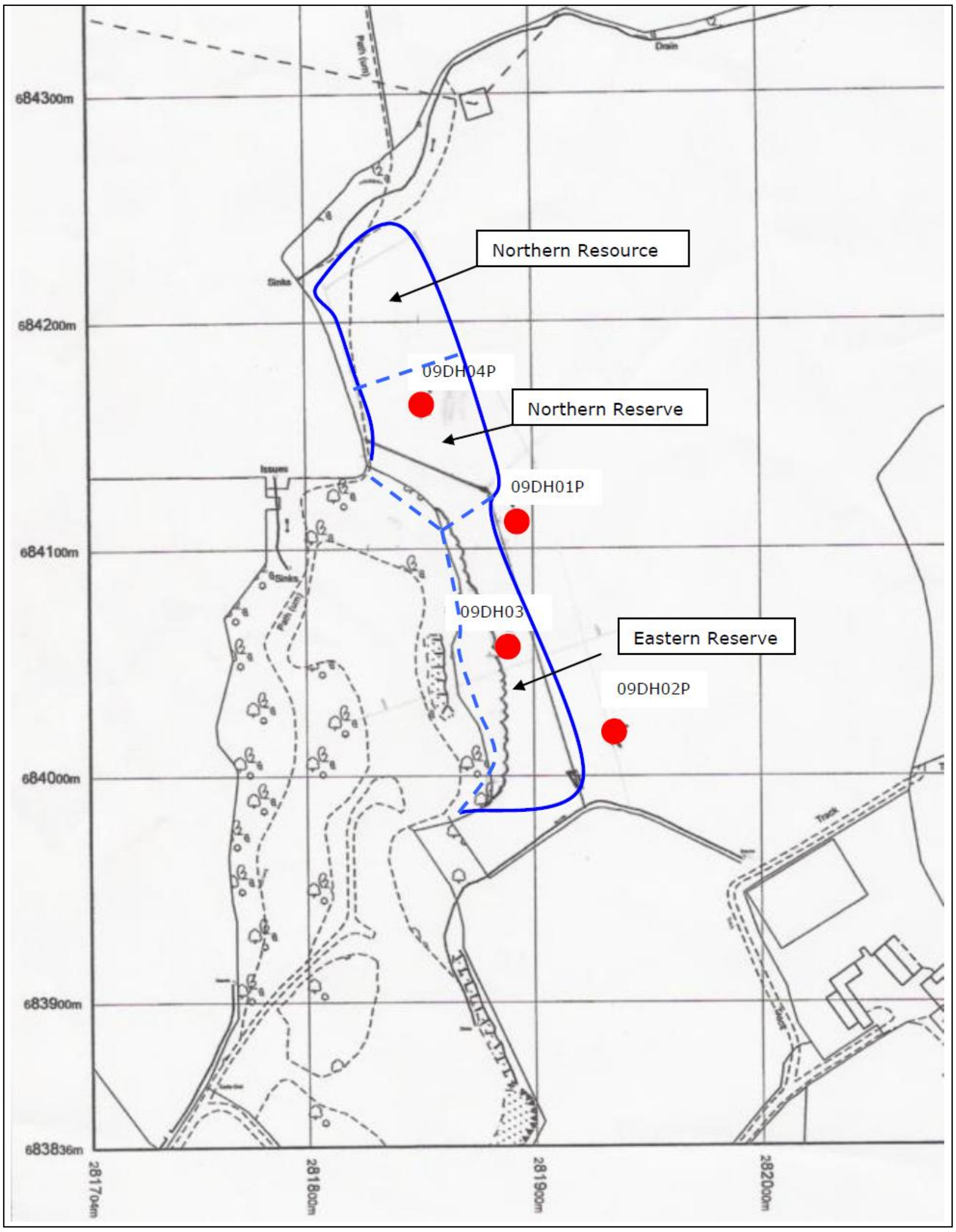


Figure 17: Map showing Drumhead Quarry and the locations of the boreholes drilled by APS GeoServices Ltd. (red dots). Blue lines indicate possible areas for future expansion of the quarry as described in the geotechnical report from which this map has been extracted (APS GeoServices Ltd., 2009).

3.2 The character of exposed Drumhead Sandstone

The sandstone beds in the quarry dip gently (5-7 degrees) to the east. Vertical joints are relatively widely spaced, typically several metres apart. The quarry appears to yield two clearly differentiated types of sandstone, which will produce two different varieties of building stone:

- The sandstone exposed in the top beds of the quarry has a pale creamy buff colour. It is faintly to strongly laminated, and occasionally flaggy towards the top beds. The large blocks already extracted are generally of a height of 80cm to over 1m, and of a relatively consistent bed height. Occasionally this sandstone may be stained by limonitic iron oxides.
- The other type of sandstone is exposed in the lower beds of the quarry. On the basis of a restricted inspection (due to the limited view of the quarry face), there appears to be a relatively thick bed (exact bed thickness is unknown at this time, but possibly up to 2m) of off-white, uniform sandstone.

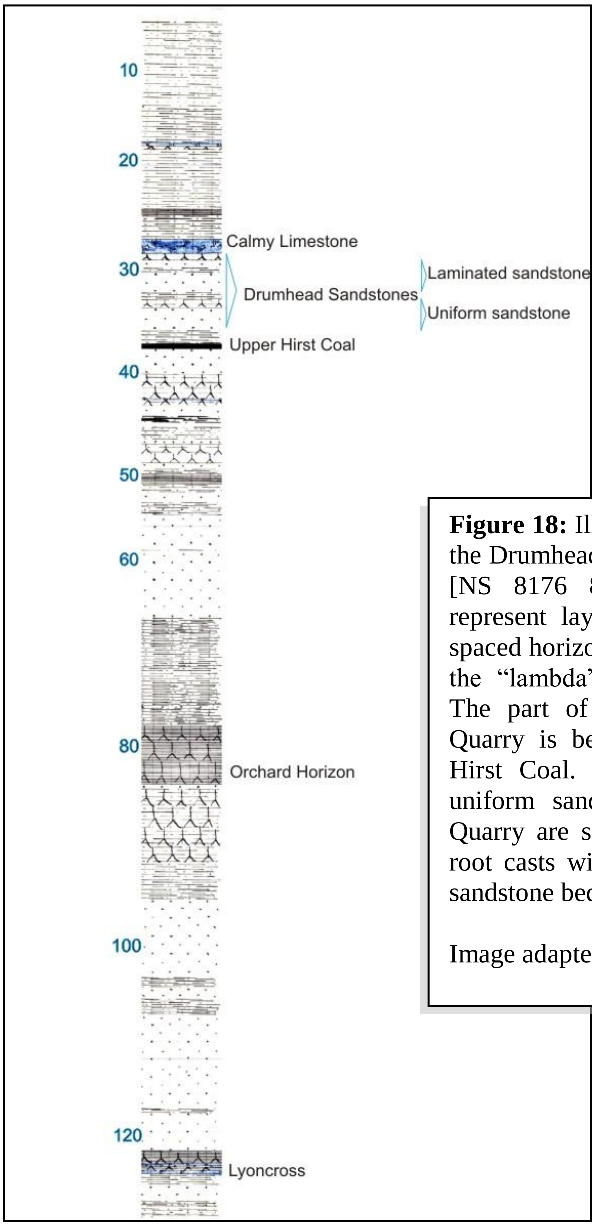


Figure 18: Illustration of the sedimentary sequence near the Drumhead area, from a borehole core extracted from [NS 8176 8344] (No.1 Denovan borehole). Dots represent layers of relatively pure sandstone; closely spaced horizontal lines indicate shale and mud horizons; the "lambda" shaped symbols represent fossil roots. The part of the sequence intersected by Drumhead Quarry is between the Calmy Limestone and Upper Hirst Coal. The laminated sandstone bed and the uniform sandstone bed that crop out at Drumhead Quarry are separated by some thin beds of shale and root casts within a paleosol at the top of the uniform sandstone bed. Depths are in metres.

Image adapted from BGS Borehole Log NS88SW/21.

Figure 19: Drumhead Quarry (looking east), 7 April 2009. A thick layer of superficial deposits overlying the bedrock is visible behind large blocks of sandstone recently extracted from the quarry site. These laminated and pale buff to orange coloured blocks have been extracted from the topmost beds of the quarry. The blocks illustrate the relatively thick nature of this bed. The effects of the plug and feather method of extraction are visible in the block of sandstone to the right.

Figure 20: Drumhead Quarry (looking east) with several large blocks of sandstone and the wall of overburden in the background, September 2009. This photograph was taken during the drilling programme by APS GeoServices Ltd to determine the rock type present to the east and north of the quarry; the drill rig is just visible along the horizon.

Figure 21: Drilling at borehole 09DH03P directly east of the currently exposed quarry face.

Figure 22: Drilling into grey/white sandstone, borehole 09DH03P, Drumhead Quarry. Drilling to the north of the current quarry face (borehole 09DH04P) encountered iron stained sandstone (probably the buff sandstone observed in the quarry) immediately below the superficial deposits.

4 Samples of Drumhead Sandstone

Samples of sandstone from Drumhead Quarry (some already held in the BGS collections and some collected as part of this investigation) are listed in Table 3, with a brief description and indication of the analyses carried out in this study. Photographs of some of the samples are shown in Figures 23-25.

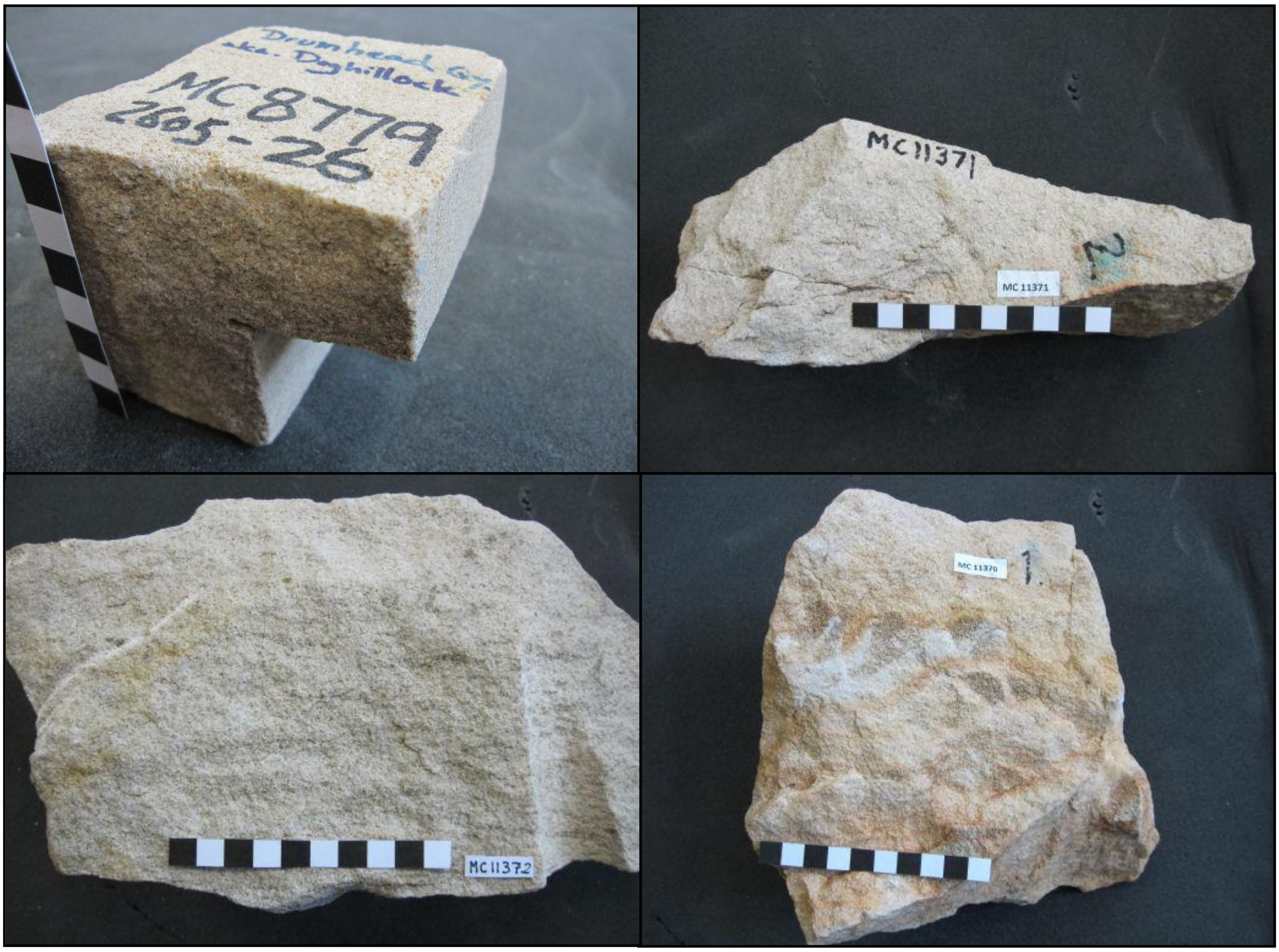


Figure 23: Composite image of four rough block samples of the laminated variety of Drumhead Sandstone. The samples show a range of colours, from pale greyish buff (MC11371, MC11372) to buff (MC8779) to pale greyish buff with orange iron oxide staining (MC11370 bottom-right). All show a moderately marked lamination (not obvious in these photos). Further details provided in Table 3.

Figure 24: Samples of pale creamy buff, laminated Drumhead Sandstone from the BGS collections. Most of the cut blocks and slabs show the typical slightly irregular lamination caused by accumulations of iron oxides and muscovite mica. Sample MC8569 shows well developed parallel bedding lamination.

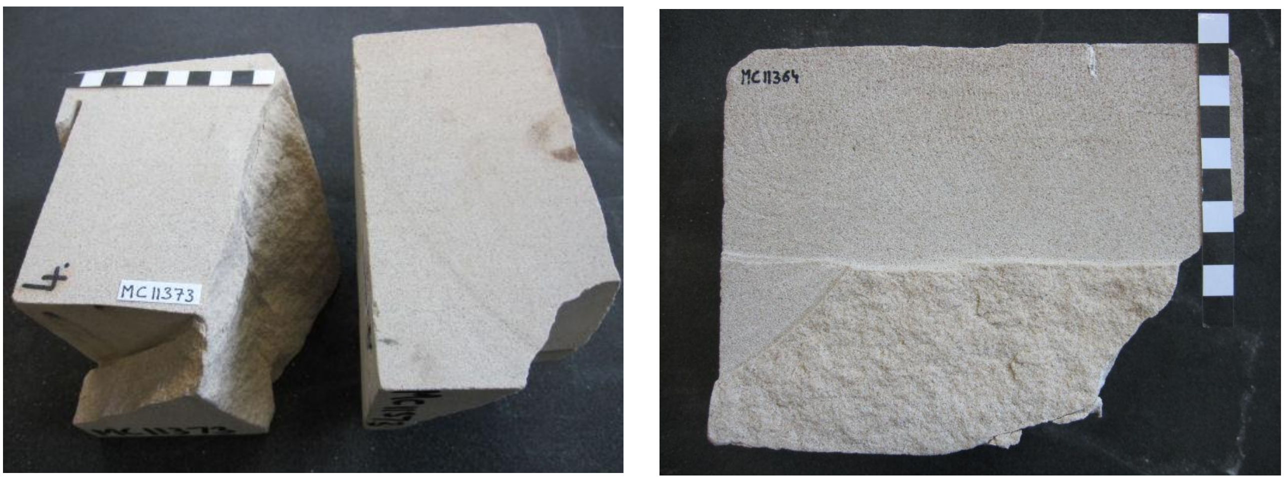


Figure 25: Samples of white to off-white, uniform Drumhead Sandstone from the BGS collections: cut blocks. Sample MC11373 (left) has been split in two parts; one of them (leftmost) was subjected to a compressive strength test (Section 7).

Sample Number	Description	Macroscopic analysis	Microscopic analysis	Compressive Strength
MC8569	Pale greyish buff, speckled with well developed parallel bedding lamination, cut slab.	●	●	
MC8779	Pale greyish buff, speckled, laminated, roughly squared sample.	●	●	
MC11364	White, uniform, competent; roughly saw cut sample.	●	●	
MC11365	Pale greyish buff, speckled, laminated, roughly squared sample.	●	●	
MC11370	Pale greyish buff, speckled, laminated, with irregular staining by iron oxides. Rough block.	●		
MC11371	Pale greyish buff, speckled, laminated. Rough block.	●		
MC11372	Pale greyish buff, speckled, laminated. Rough block.	●		
MC11373	White, uniform; roughly saw cut sample.	●		●
MC11374	Pale greyish buff, speckled, partially developed bedding lamination.	●		●
MC11375A	Pale greyish buff, speckled, partially developed bedding lamination, cut quarry sample.	●		
MC11375B	Pale greyish buff, speckled, partially developed bedding lamination, cut quarry sample.	●		
ED10432A	Pale greyish buff, speckled with uniform to weakly laminated texture.	●	●	
ED10432B	Pale greyish buff, speckled, laminated, cut quarry sample.	●	●	
ED10432C	Pale greyish buff, speckled, laminated, cut quarry sample.	●		

Table 3. Samples of Drumhead Sandstone held in the BGS collections. The different analytical tests carried out in this study are shown.

5 Petrographic analysis of Drumhead Sandstone

5.1 Methodology

All the samples of Drumhead Sandstone in the BGS collections (Table 3) were examined visually and using a binocular microscope. Separate macroscopic descriptions are provided below for the two main varieties of Drumhead stone—'buff, laminated' and 'white, uniform'. Colour was determined using a standard Munsell® Colour Rock Chart (Geological Society of America). Several samples selected as being representative of the two main varieties then underwent detailed microscopic analysis using thin sections. Thin section preparation was carried out at the British Geological Survey Thin Section Laboratory; each sample was impregnated with blue dye resin in order to highlight porosity, and each thin section was supplied on a glass slide measuring 75 by 25mm. Thin sections were cut perpendicular to any bedding orientation. They were examined using a petrological microscope (Zeiss Standard WL polarizing microscope) following the procedures given in BS EN 12407:2000 'Natural Stone Test Methods – Petrographic Examination'. Stone type is defined in accordance with European Standard prEN 12670:1997.

5.2 Hand specimen description: <u>buff, laminated variety</u>

The macroscopic description is based on a detailed examination of all the samples listed in Table 3, with the exception of MC11364 and MC11373. The samples encompass the range of character displayed by the irregularly laminated sandstone observed in the quarry.

The stone is fine- to coarse-grained, poorly sorted, strongly to faintly laminated and generally pale greyish buff to pale creamy buff sandstone, with a faint speckled appearance. Occasionally may present stronger colours and may show some irregular bands of orange/ochre limonitic iron oxides. Munsell colour code covers a range from 10YR 7/2; *light grey* to 10YR 8/2; *white* to 10YR 8/3; *very pale brown*. The strength and distribution of orange colouration varies: it typically appears as broad irregular bands, tinting the stone locally to approximately 10YR 6/6; *brownish yellow*.

The samples show a faint bedding lamination. This bedding is defined by irregular dark brown to black laminae (accumulations of iron oxides and muscovite mica), which are commonly parallel but sometimes appear as small ripple lamination (Figure 24). Bedding is not uniformly present throughout the samples; some parts are strongly laminated while others display fewer bedding laminae.

None of the laminated samples show any reaction to 10% HCl, indicating the stone contains no carbonate minerals. All of the samples subjected to this test developed yellowish staining, indicating some mobilisation of iron oxides. Powdery clays or weathered feldspars are visible in hand specimens, and often these are the minerals that change colour following the acid test. A water bead test indicates relatively high permeability in all samples. All samples are well compacted and strongly cohesive.

5.3 Thin section (microscopic) description: <u>buff, laminated variety</u>

The microscopic description is based on detailed examination of thin sections from the following six samples: MC8569, MC8779, MC11364, MC11365, ED10432A, ED10432B. These samples encompass the range of character displayed by the irregularly laminated sandstones observed in the quarry. All the samples are very similar, except ED10432A which has less lamination.

Fine- to occasionally coarse grained (mostly medium grained), moderately sorted sandstone, containing minor clay minerals. <u>Framework</u> grains are generally subangular to rounded, ranging from 0.05 to 0.8mm in the coarsest of the samples, mostly within the 0.18-0.35mm size in all samples. The range and relative proportions of detrital grains is broadly similar in all samples. They are dominated by quartz (c.65%), which is generally monocrystalline with undulating extinction (indicating a metamorphic provenance). Feldspar grains (both K-feldspar and plagioclase) of all sizes appear moderately preserved and constitute c.7%, with occasional relict (skeletal) grains replaced by clay minerals. Minor lithic grains (rock fragments), often in small sizes, are mostly of metamorphic origin (quartzite, occasional schist and chert) and constitute c.2% of the stone. Moderately oriented white mica flakes (muscovite) constitute <1% of the stone. Zircon appears as an accessory mineral. Iron oxides form medium and large, occasionally corroded, grains comprising c.3% of the stone. Accumulations of these ‘opaque’ grains form the macroscopic lamination. Matrix minerals comprise well developed coatings of authigenic silica (c.4%) developed on detrital quartz grains and a small proportion (c.2%) of clay. The rock type is classified as **subfeldspathic-arenite**.

The samples all have relatively high porosity (c.17%). Pore spaces are well communicated, making this a rather permeable stone. Porosity is mostly intergranular with some due to weathering of feldspar grains. Grains are also bound by point and long contacts with a relatively large proportion showing pressure-solution indenting; these types of grain boundary are typical of strong, durable sandstone.

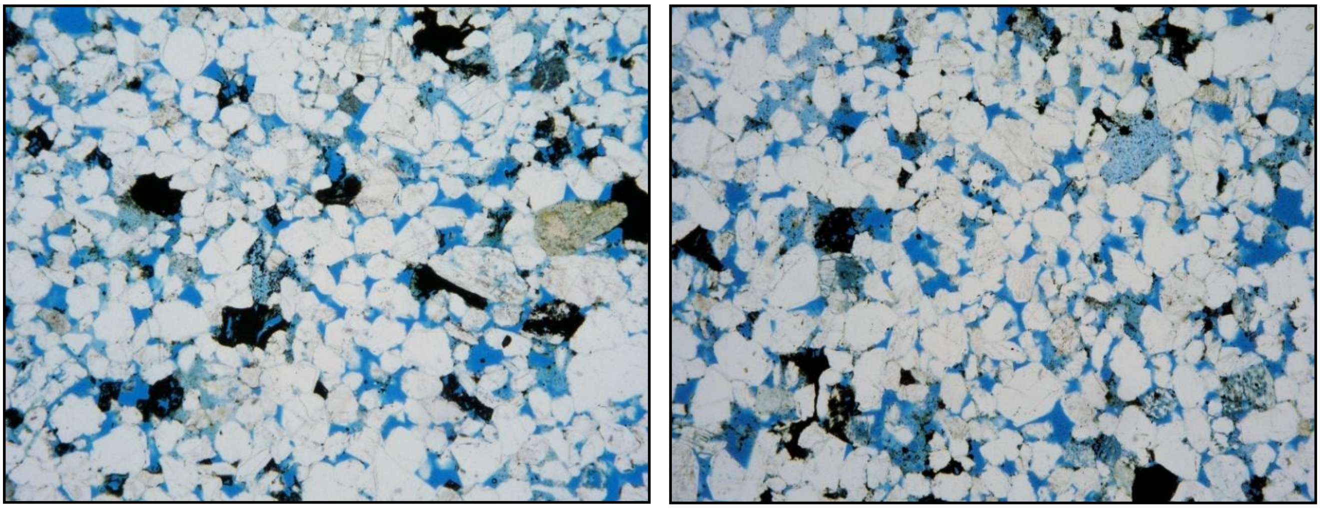


Figure 26: Drumhead Sandstone (laminated variety) in thin sections. Both images are sample MC11365. The poor sorting and common iron oxides (black grains) are characteristic. Images are c.3.3mm wide, taken under plane polarised light. Porosity is highlighted by blue dye resin.

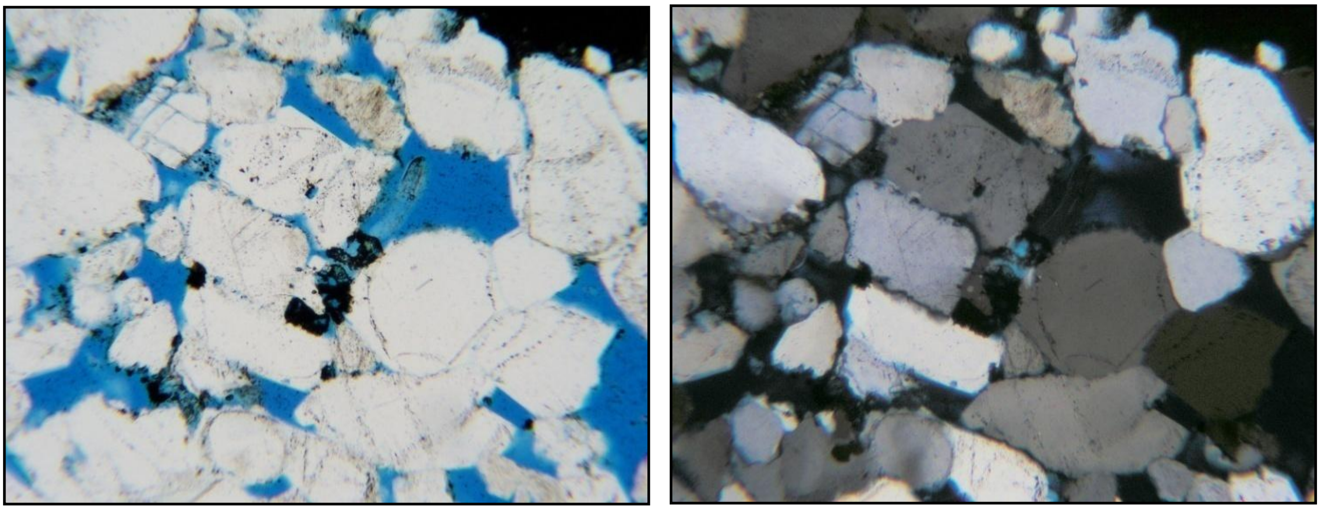


Figure 27: Detailed thin sections of Drumhead Sandstone. Note the impact contacts (pressure-solution) and the well developed authigenic silica cement layer (clear overgrowths) around some of the grains, which together yield a cohesive (difficult to disaggregate) sandstone. Left image: plane polarised light. Right image: cross polarised light. Images are c.2mm wide. Porosity is highlighted by blue dye resin.

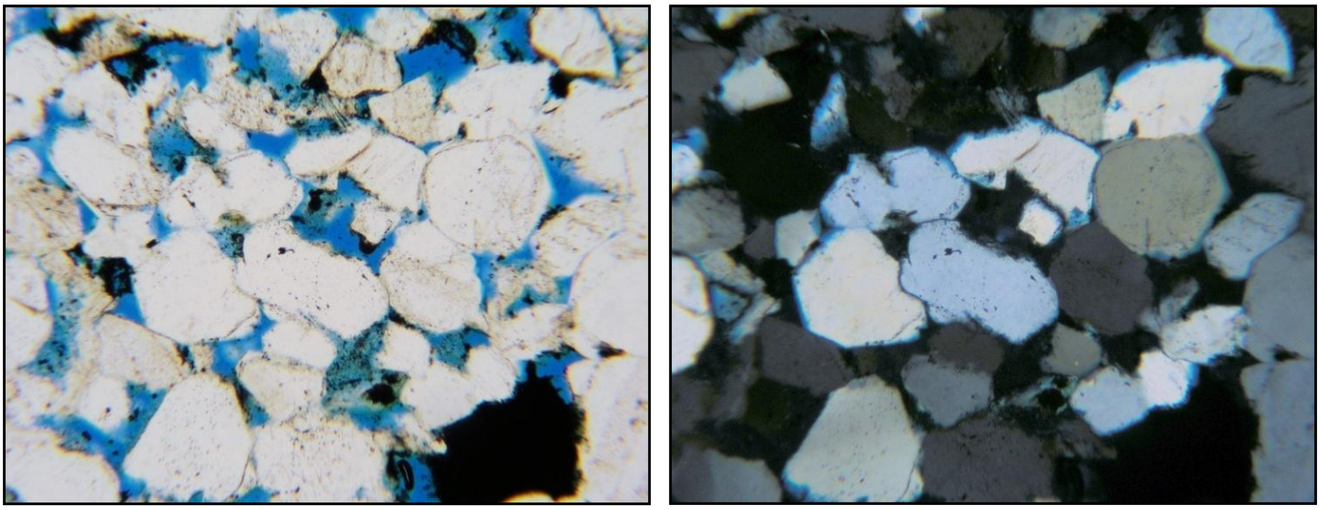


Figure 28: High magnification thin sections of the Drumhead Sandstone. The pressure-solution contacts and good silica cementation of the grains are well displayed. Despite the moderately open porosity, the well-developed authigenic silica cement binds the grains tightly. LHS: plane polarised light. RHS: cross polarised light. Images are c.1mm wide. Porosity is highlighted by blue dye resin.

5.4 Hand specimen description: white, uniform variety

The macroscopic description of this variety is based on samples MC11364 and MC11373 (Table 3).

Fine- to medium grained sandstone, with a uniform off-white colour; the, Munsell colour code is 2.5Y 8/1; *white*. Both samples have a uniform texture (freestone) with no apparent bedding. Both samples show a weak to moderate reaction to 10% HCl indicating the presence of carbonate minerals. After this test the samples showed yellow discolouration indicating that some of the mineral constituents are prone to acid attack. A water bead test indicates moderate to high permeability. Minor powdery clays/altered feldspars are visible partially infilling the porosity. All samples are strongly cohesive and well compacted.

5.5 Thin section (microscopic) description: white, uniform variety

The microscopic description is based on detailed examination of one thin section from sample MC11364, which is representative of this type of the Drumhead stone.

Fine- to medium grained, well sorted sandstone, containing minor clay minerals and some carbonate mineral. The stone is uniform in texture and composition even at microscopic scale. Framework grains are generally sub-angular to rounded, ranging from 0.05 to 0.45mm, and mostly within the 0.20-0.30mm size. The stone is dominated by quartz (c.68%), which is generally monocrystalline. Some grains have undulating extinction indicating a metamorphic provenance. A small proportion (c.2%) of feldspar grains (both K-feldspar and plagioclase) appears mostly well preserved, with occasional relict (skeletal) grains replaced by clay minerals. A small proportion (c.2%) of lithic grains (rock fragments) is mostly of metamorphic origin (quartzite). Small flakes of randomly oriented white mica (muscovite) comprise <1% of the stone. Large oval-shaped zircon crystals are distinctive but comprise a negligible proportion of the stone (<<1%). Iron oxides comprise 1% of the stone, occurring both as discrete detrital grains and in association with altered carbonate minerals. The matrix comprises silica overgrowths on quartz grains (c. 6%), carbonate minerals (probably calcite; c.3%), forming anhedral sparry crystals, and c.4% clay, which is at least partly derived from the weathering of feldspar. The stone is classified as **quartz-arenite**.

The sample has moderate porosity (visually estimated at c.14%), with moderately to well communicated pores and conduits in a range of sizes. Grains are bound by good contacts, ranging from ‘long’ to ‘pressure-solution’ type, and the sandstone is well cemented by the silica overgrowths. These factors yield a strong, cohesive, well compacted and well cemented sandstone.

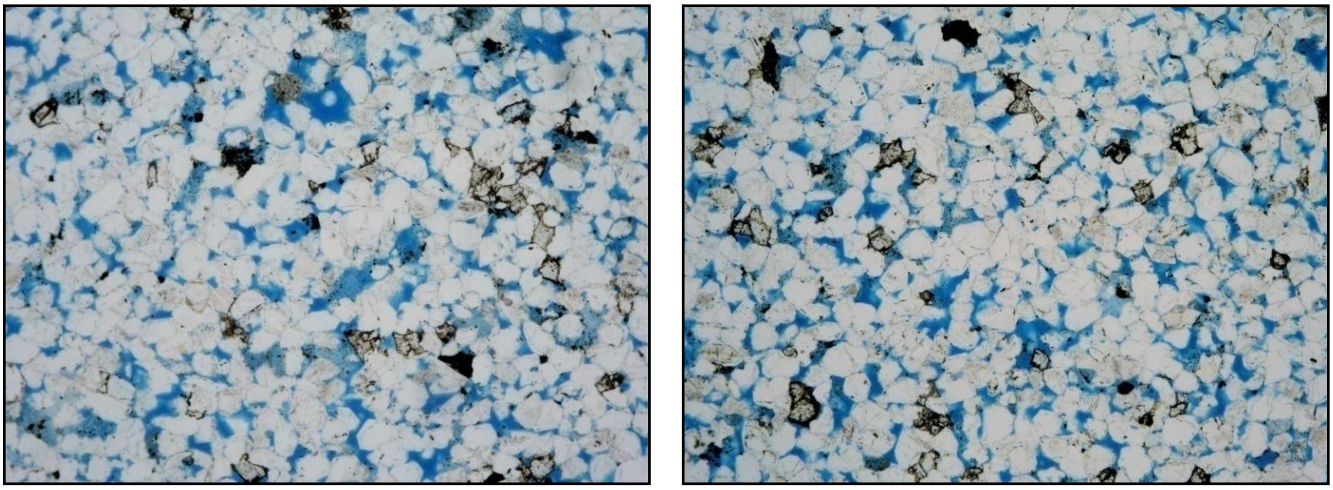


Figure 29: Thin section images of Drumhead Sandstone (uniform, white variety). Both images are of sample MC11364. The images demonstrate the well sorted character of the sandstone, and the presence of scattered carbonate crystals (dark-rimmed with grey centres). Images are c.3.3mm wide, taken under plane polarised light. Porosity is highlighted by blue dye resin.

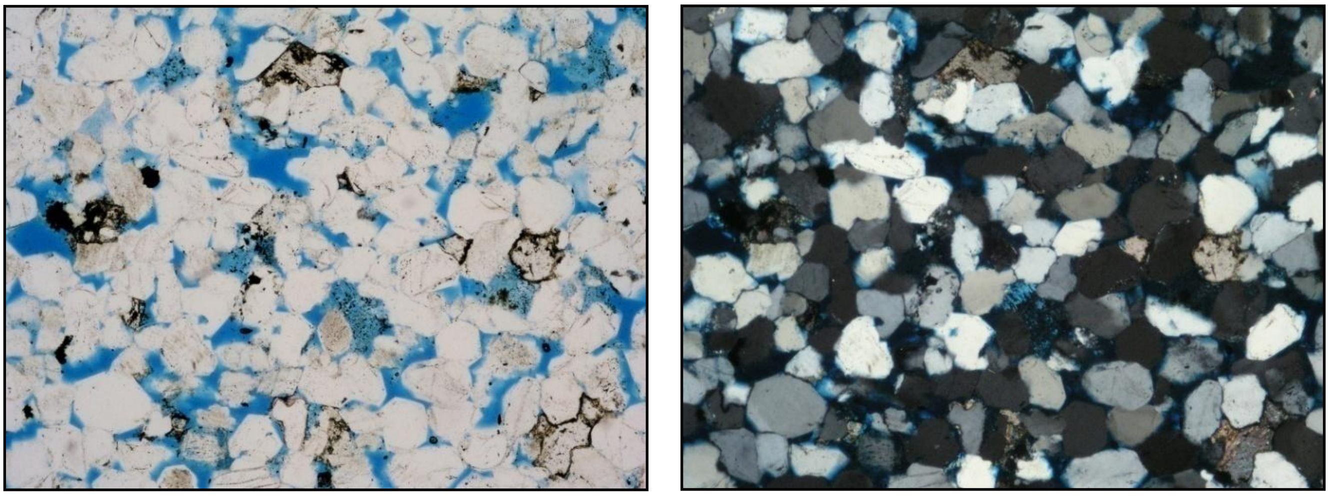


Figure 30: Detailed thin section images of Drumhead Sandstone. Note the 'long' and 'pressure-solution' contacts between detrital grains, and the well developed overgrowths of silica (translucent white, commonly with perfect crystal faces) on detrital quartz grains. LHS: plane polarised light. RHS: cross polarised light. Images are c.2mm wide. Porosity is highlighted by blue dye resin.

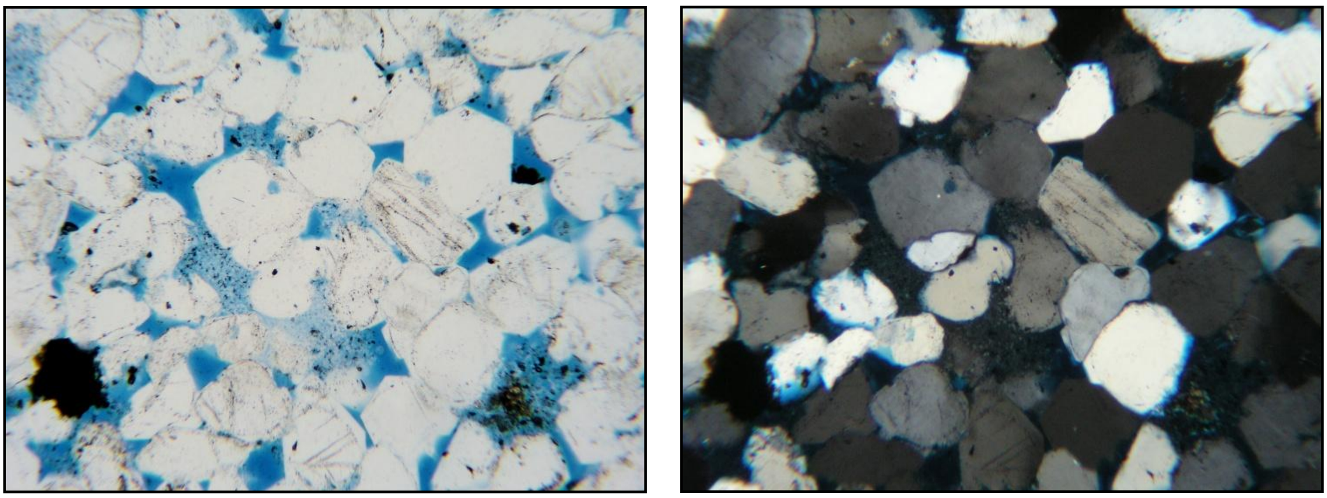


Figure 31: High magnification thin section image of the white, uniform variety of Drumhead Sandstone. The perfect crystal faces formed by overgrowths of silica on some detrital quartz grains are clearly visible. There is minor clay infill (light blue) and the pore system is less open than in the laminated sandstone. LHS: plane polarised light. RHS: cross polarised light. Images are c.1mm wide. Porosity is highlighted by blue dye resin.

5.6 Concluding notes

Both varieties of Drumhead Sandstone have well developed contacts between sand grains, and many grains display long, pressure-solution contacts (Figures 28 and 31). The dominant natural mineral cement in these rocks is silica, formed by the dissolution of quartz when detrital grains were pressed into each other as the sediment layers were buried and the detrital grains underwent compaction. The dissolved silica re-precipitated on the quartz grains, effectively bonding them together. The presence of a well developed silica cement is one of the most important factors in determining the strength and durability of a sandstone. In both varieties of Drumhead Sandstone the silica cement is very well developed and well distributed (Figures 27, 28 and 30, 31). In the white variety, a small proportion of sparry carbonate cement in the intergranular spaces provides an extra source of grain bonding in the stone.

6 Comparison of Drumhead Sandstone with other sandstones

Thin section images of Drumhead Sandstone and several other well-known building stone sandstones are presented in Tables 4 and 5. The sandstones selected for comparison are broadly similar in character to the two varieties of Drumhead Sandstone and have a good historic reputation. They have been widely used throughout the central part of Scotland (Falkirk, Stirlingshire, Clackmannanshire, part of West Lothian), in Glasgow and parts of Ayrshire, but are currently unavailable. All the thin section images are at the same scale (c.3.3mm wide) and were taken in plane polarized light. Porosity is highlighted by blue dye resin.

A brief comparison of the thin section images reveals some notable differences (e.g. a significant proportion of a pale brown carbonate mineral in the Dullatur sandstone, and variations in the proportions of opaque [black] material). In general, however, the sandstones are broadly similar in many important respects, including the type and relative proportions of detrital grains, the grain-size, degree of compaction and silica overgrowth development, the proportion of pore space, and permeability.

Drumhead Sandstone should therefore provide a good substitute for several currently unavailable sandstones that were once extracted and used as building stone in Central Scotland. These include the well reputed pale buff sandstones quarried in East Ayrshire (e.g. Dean Quarry, Kilmarnock), Falkirk, Stirlingshire, Clackmannanshire, and parts of West Lothian (e.g. Kingscavil Quarry, Linlithgow). The white Drumhead Sandstone, which is essentially uniform, well sorted, and has a high proportion of quartz, should be a good match for the highest quality ‘blonde’ sandstones from reputable quarries such as Giffnock and Bishopbriggs.

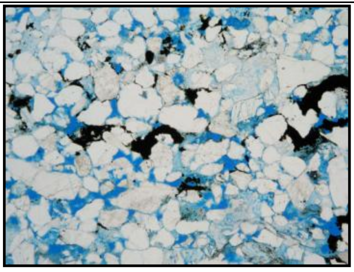
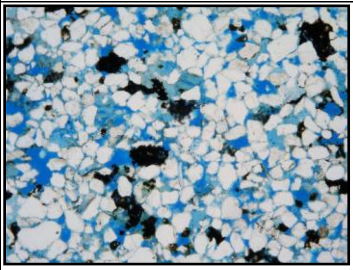
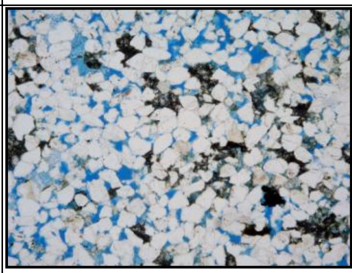
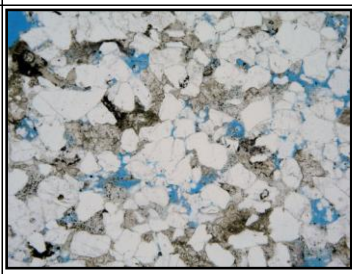
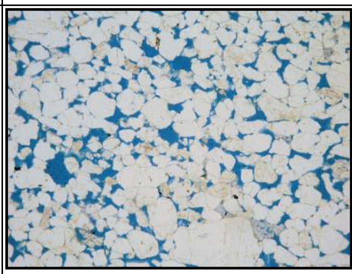
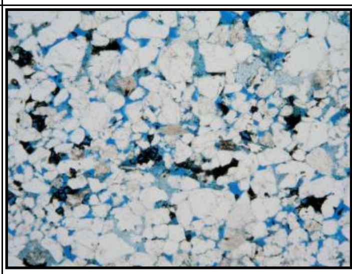
Sample details	Image
Dean Quarry Pale greyish buff and laminated. Kilmarnock. Quarry closed and infilled. Sample ED10480.	
Dean Quarry Pale greyish buff and laminated. Mason Murphy Building – Kilmarnock (Records state source is Dean Quarry). Sample ED10496	
Plean Pale grey with a buff tinge, faintly laminated. Sample MC8570	
Dullatur Dense, grey to grey-buff sandstone. Sample S13726	
Dunmore 'old' Off-white sandstone, uniform (part of the 'Cowie Rock'). Quarry closed/infilled. Sample S22831.	
Drumhead Quarry Laminated variety. Sample MC8779.	

Table 4. Thin section images of laminated sandstones from the Central Belt. Note that the laminated character, while obvious in the hand specimens, is commonly not clear in these thin section images.

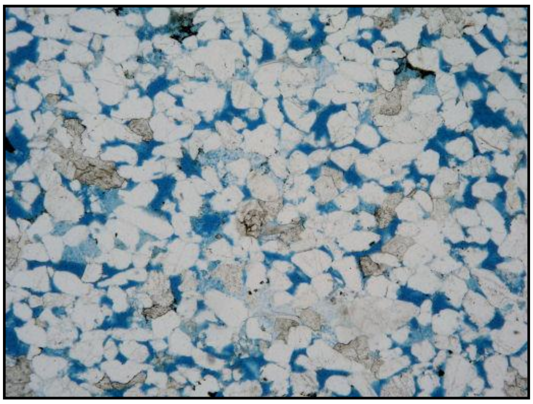
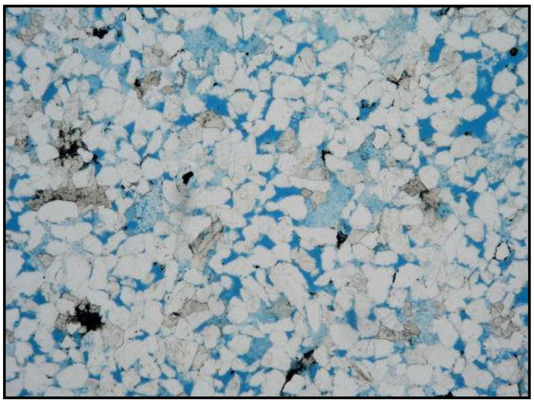
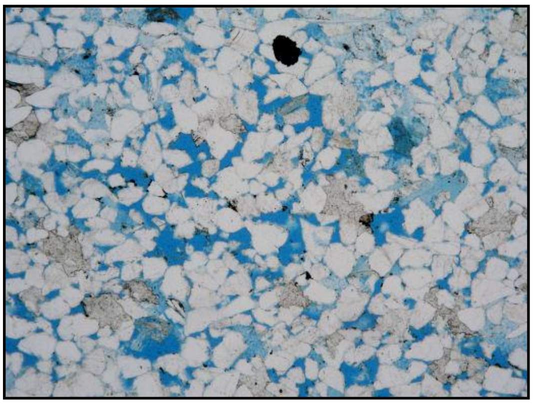
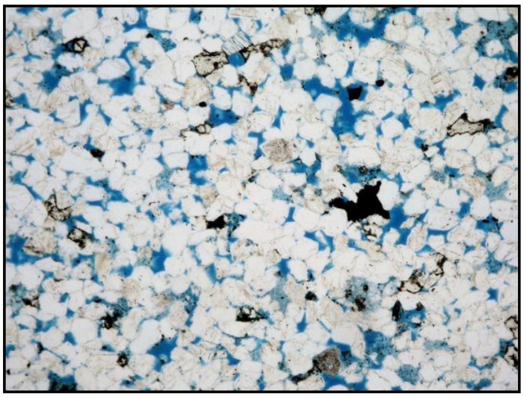
Sample details	Image
Giffnock Quarry, Glasgow (South). Homogeneous and uniform, white. Quarry closed and infilled. Sample S13727	
Giffnock Quarry, Glasgow (South). Homogeneous and uniform, white. Quarry closed and infilled. Sample S13505	
Huntershill Quarry-Bishopbriggs Glasgow (North). Homogeneous and uniform, white. Quarry closed and infilled. Sample S13828	
Drumhead Quarry White, uniform variety. Sample MC11364	

Table 5. Thin section images of uniform sandstones from the Central Belt.

7 Mechanical tests and physical properties of Drumhead Sandstone

The Compressive Strength Test (also known as Crushing Strength Test) yields a value for the maximum load per surface unit that a core cylinder of stone can support until it breaks, measured in Mega Newtons per square meter (MN/m^2). This value is particularly important where the stone has to perform a load-bearing function, for example in dressed stones, rubble or functional elements such as mullions and cornices. It is also a useful indication of the likely durability and weathering performance of a stone. Poor bonds between the constituent mineral grains will typically result in a low compressive strength value, providing an indication of susceptibility to disaggregation and stone decay from weathering.

Two samples of Drumhead Sandstone from the BGS collections were selected for Compressive Strength testing. The samples are representative of the two types of Drumhead Sandstone: MC11373 (white, uniform), and MC11374 (buff, laminated). The details and results of the test are given in Appendix 1. The test results, and those of several other well known sandstone types, are shown in Table 4.

No physical properties data are available for most of the historically quarried stone types described in Section 6 (i.e. any of the other 'Cowie Rock' sandstones, and those from Dean, Giffnock, and Bishopbriggs). Hence, the Drumhead Sandstone data have generally been compared to currently available sandstones. The historically important Craigleith sandstone (Edinburgh), which is no longer available, has been included as the 'benchmark' due to its reputation as one of the highest quality building stones in the UK.

The sample of buff, laminated Drumhead sandstone yielded a compressive strength value of 74.2 MN/m^2, while the white, uniform variety yielded a significantly higher value of 89.0 MN/m^2. The significance of, and reason for, the difference in these two values is not easy to judge on the basis of just two samples. Both values compare favourably with those for several currently available sandstones, they are broadly comparable with some reputable white and buff sandstones such as Clashach (85.8 MN/m^2) and Dunhouse Buff (84.1 MN/m^2), and they are a little lower than Craigleith sandstone (93.9 MN/m^2).

Name (source of data)	**Bulk Density Kg/m^3**	**Compressive Strength MN/m^2**
Drumhead (This study; Appendix 1; MC11373-white)	2200	89.0
Drumhead (This study; Appendix 1; MC11374-buff)	2150	74.2
Craigleith (McMillan et al. 1999).	2220	93.9 94.3
Cullalo (McMillan et al. 1999).	2160	35.7
Clashach (McMillan et al. 1999).	2346	85.8
Cragg (McMillan et al. 1999).	2170	61.5
Blaxter (McMillan et al. 1999).	2173	55.1
Dunhouse Buff (Building Research Establishment)	2202	84.1
Stanton Moor (Building Research Establishment)	2259	79.0
Peakmoor (Building Research Establishment)	2210	72.5

Table 4. Physical test results for Drumhead Sandstone and for a selection of well-known unavailable and currently available sandstones.

8 Conclusions

Drumhead Quarry contains two varieties of quartz-rich sandstone: a white, texturally uniform variety, and a buff, laminated variety. Bedding (when present) is clearly defined by thin irregular dark laminae, containing variable amounts of iron oxides and mica. Detrital grains are well cemented by natural silica cement overgrowths. Both varieties are strongly cohesive, yielding moderately high to high compressive strength values that are comparable to those of good quality sandstone building stones. Both varieties display moderately high permeability. These characteristics suggest that Drumhead Quarry could provide good quality building stone that is strong, durable, not prone to significant weathering discolouration, and likely to be suited to a range of uses, including rubble walling and ashlar. Widely spaced joints in exposed sandstone beds, and bed thicknesses of typically around one metre, suggest the sandstone could be extracted as large (metre-scale) blocks.

Recent borehole investigations suggest the Calmy Limestone crops out to the east of Drumhead Quarry, and probably swings north-eastwards rather than to the west as shown on the current geological map. The greatest potential for extracting high quality sandstone therefore may lie in extending the quarry northwards. On the current geological map for the Drumhead area, geological faults are shown to intersect ground just south of the quarry. Fractures and other features associated with these faults may adversely affect the quality of stone locally in and around this part of the quarry.

Sandstone from Drumhead Quarry (and from the nearby Thorneydyke Quarry, which may exploit the same geological unit) has been used in the construction of many civic and residential buildings in the Falkirk and Stirling districts, and as paving in Edinburgh and other parts of the Central Belt of Scotland. Many other quarries in the Central Belt have in the past produced sandstone of broadly similar appearance to Drumhead sandstone. These stones have been used in paving and numerous buildings throughout the region. However, these quarries are no longer active, and there are no quarries in the region currently supplying sandstone of this type.

Drumhead sandstone could meet a potentially significant demand for building repairs, new-build construction, and paving throughout the Central Belt of Scotland. Drumhead-type sandstone is in particularly high demand in the Stirling, Glasgow and Linlithgow areas. The reopening of Drumhead Quarry could provide the industry with an important new source of high quality sandstone for new build and repair work.

References

British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: http://geolib.bgs.ac.uk.

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Appendix 1 Recent stone matching recommendations of Drumhead Sandstone

Below is a list of structures for which Drumhead Sandstone has been recommended for building stone repairs through the BGS GeoReports stone matching enquiry service over the past year. The BGS Edinburgh office receives over 100 building stone enquiries every year; this list represents nearly one fifth of all enquiries in the last year.

Tenements/Buildings/Houses:
19 Lynedoch Street, Glasgow
31 Lacrosse Terrace, Glasgow
75 Waterloo Street, Glasgow
87-91 St. Vincent Street, Glasgow
270 Woodlands Rd, Glasgow
Castle Campbell, Dollar
Cumbernauld House, Cumbernauld, North Lanarkshire
Lanarkshire House, 191 Ingram Street, Glasgow
Liberal Club, Bo'ness
Linlithgow Burgh Halls
RWF House, Renfrew Street, Glasgow
University of Glasgow—West Medical Building
55-59 Buchanan Street, Glasgow
98 Buchanan Street, Glasgow

Monuments/Structures/Churches:
Burns Statue, Camperdown, Australia
Former Church, Providence Brae, Bo'ness
Glasgow Central Station, rear archway
Greenock West Kirk, George Square, Greenock
Sculptures at University of East London, London
St. Michael's Well, Linlithgow
The Merchants Steeple, The Briggait, Bridgegate, Glasgow

Appendix 2 Compressive strength test

British Geological Survey Laboratories Test Services
Engineering Geology Laboratories

LABORATORY REPORT

Compressive strength of sandstone from Drumhead Quarry, Denny for the BGS

By D C Entwisle

British Geological Survey, Keyworth, Nottingham NG12 5GG,
August 2009

Compressive strength determination for Drumhead Quarry

Method

The test technique was based on that described in ASTM (1995), test C170-90. A cylindrical core sample, of nominal diameter of 50 mm, was drilled from the block sample so the axis of the cylinder was perpendicular to the bedding. The test specimen was cut and the ends surface-ground so they were flat and parallel to within 20 μm. The test sample length was nominally the same as the diameter. The specimens were weighed and measured and then allowed to dry in the laboratory. A 2000-kN compression machine was set up for the size of the specimen used. Both platens had a Rockwell hardness of not less than HRC58. The lower platen included a spherical seat. The spherical seat was lubricated with oil. The specimen, platens and spherical seating were accurately centred. The loading rate during the test did not exceed 690 kPa/sec. The load was measured using a 330 kN RDP load cell S/N 470876 with RDP E525 digital indicator.

Results

Compressive strength $\sigma_C = W/(1000 \times A)$ MN/m^2

where W is the maximum load (kN).
A is the area of the load bearing surface of the sample (m^2).

The results are presented in the table below with units of MN/m^2.

Sample	BGS Collection No.	Weight g	Dimensions, mm Length	Dimensions, mm Diameter	Nominal Density Mg/m^3	Load at failure kN	Time to failure secs	Compressive Strength MN/m^2
EGLLJ157/4	MC11374	209.35	50.16	49.76	2.15	144.4	140	74.2
EGLLJ157/3	MC11373	215.13	50.19	49.76	2.20	173.1	179	89.0

Test performed by David Entwisle on 05/08/2009, samples were tested air dried.

Reference

Anon. 1995. Annual Book of ASTM Standards, section 4: Construction, volume 04.08 Soil and Rock; Building Stones. American Society for Testing and Material, Philadelphia, USA.