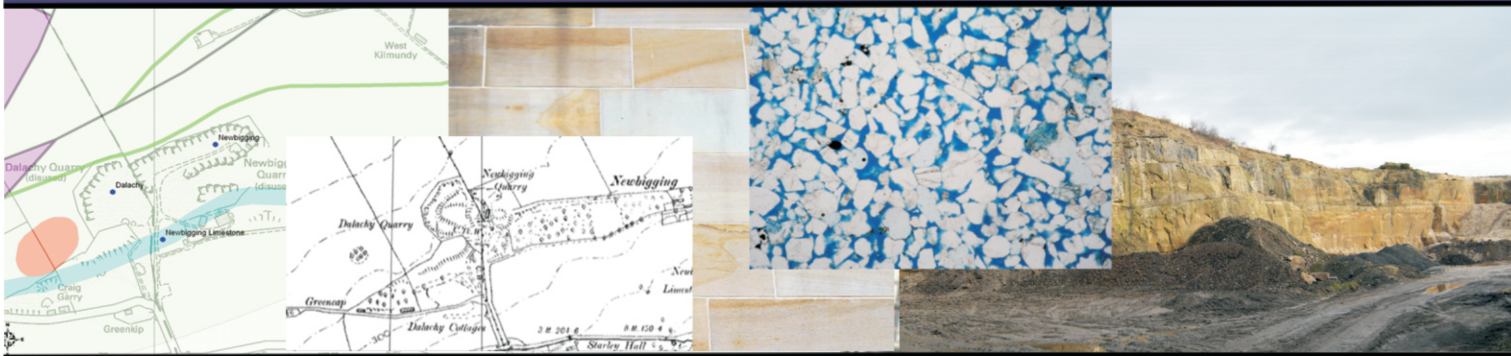
ASSESSING THE POTENTIAL FOR REOPENING A BUILDING STONE QUARRY:

NEWBIGGING SANDSTONE QUARRY, FIFE



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Assessing the potential for reopening a building stone quarry: Newbigging Sandstone Quarry, Fife

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Keywords

Newbigging, sandstone, quarry, building stone, resources, minerals, petrology.

Front cover

Main Image: National Library of Scotland, Edinburgh, constructed mid-1980s using Newbigging sandstone. Smaller images (left to right): Geology map of Newbigging area; Detail of 1856 map of Newbigging; Masonry panel from National Library of Scotland; Microscopic thin section of Newbigging sandstone; Newbigging sandstone quarry 2008.

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ABSTRACT

Newbigging Sandstone Quarry in Fife is one of a number of former quarries in the Burntisland-Aberdour district which exploited the pale-coloured Grange Sandstone from Lower Carboniferous rocks. The quarry supplied building stone from the late 19th century, working intermittently from 1914 until closure in 1937, and again when reopened in the 1970s to the 1990s. The stone was primarily used locally and to supply the nearby markets in the Scottish Central Belt.

Historical evidence indicates that prior to sandstone extraction, the area was dominated by large-scale quarrying and mining of limestone, and substantial sandstone quarrying is likely to have begun after the arrival of the main railway line in 1890. It is probable that removal of the sandstone was directly associated with limestone exploitation, and that the quarried sandstone was effectively a by-product of limestone production. Sandstone extraction was probably viable due to the existing limestone quarry infrastructure (workforce, equipment, transportation) and the high demand for building stone in Central Scotland in the late 19th century.

The geology within Newbigging Sandstone Quarry is dominated by thick-bedded uniform sandstone with a wide joint spacing, well-suited for obtaining large blocks. However, a mudstone (shale) band is likely to be present within a few metres of the principal (north) face of the quarry, around which the sandstone bed thickness and quality is likely to decrease. The mudstone bed forms a plane sloping at a shallow angle to the north, so that expansion of the quarry in this direction is likely to encounter a considerable volume of poor quality stone. Additionally, an east-west trending fault is present approximately 100 metres north of the quarry face, which is also likely to be associated with poor quality (fractured) stone.

Petrographic analysis of Newbigging sandstone from the BGS collections shows that the stone is relatively poorly compacted, and has a poorly developed mineral cement. Compared to other well-known building sandstones, Newbigging stone is weakly bonded and relatively friable. The results of mechanical testing of Newbigging sandstone show it has lower compressive strength compared to other building sandstones. These factors are likely to hamper the commercial viability of the material as a building stone.

The large size of Newbigging sandstone quarry and its use over a long period of time suggests that considerable quantities of stone were extracted, yet petrographic analysis and physical testing indicates that the stone is of relatively poor quality. This dilemma could be explained if the sandstone was originally quarried as a by-product of the existing limestone industry, rather than it being exploited primarily because it was a high quality sandstone.

It is concluded that the relatively poor quality of Newbigging sandstone, combined with the geological constraints which would limit expansion of the existing quarry, make it unlikely that the sandstone could compete with other stone types in the current market for building stone. Increasing requirements for testing and the need for consistency of supply demanded by modern construction methods make it unlikely that Newbigging sandstone would be commercially viable. The presence of other sandstone quarries in the district, in essentially the same geology, suggests that there are suitable deposits of sandstone locally, and further geological investigation may identify potential new sites for extraction of higher quality sandstone.

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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 specific sites in Scotland (Scottish Building Stone Resources Project). As part of this work BGS were asked to investigate the potential for reopening of the Newbigging Sandstone Quarry near Burntisland in Fife. This quarry is known to have a long history of operation, having been active at the end of the 19^{th} and early 20^{th} centuries and at times thereafter. Today there is a growing interest in the use of Scottish stone for a range of functions, including the repair of historic buildings, new construction, and stone for public realm and streetscape improvements, as well as infrastructure projects. An increasing awareness of Scottish stone and the importance of selecting appropriate stone for a particular job has led to an improving market for Scottish stone, in particular stone which has a proven historical reputation. The reopening of two historic sandstone quarries at Swinton in Berwickshire (2000) and Cullalo in Fife (2004) is taken as evidence of this potential resurgence of the Scottish stone industry.

The work described in this report followed a short visit to the quarry by Ewan Hyslop and Emily Tracey, and discussions with the owner and business manager Craig Mitchell and Michael Smith in August 2008. The report outlines the geological setting and documented history of sandstone production at Newbigging Quarry, based on archival records and survey maps held by BGS. A number of published sources were also consulted to provide background historical information. Stone samples collected during the quarry visit were compared with existing samples held in the BGS collections, and a number of samples underwent detailed analysis. The results were discussed alongside previously published test results on other samples from the quarry, and compared to test results from reputable sandstones from other quarries in Scotland and Northern England.

The purpose of the study is to collate existing technical and historical information available for Newbigging Sandstone Quarry, compare it to new data, and to present all the information in a form which can be used to give an estimation of the potential for Newbigging quarry to supply sandstone building stone in the future.

2. BACKGROUND AND HISTORICAL INFORMATION RELATING TO NEWBIGGING SANDSTONE QUARRY

Newbigging Sandstone Quarry is located c.2 km to the west of Burntisland in Fife [NT 211864], situated between the A909 and A92 roads. The quarry is relatively large for a building stone quarry and it is clear that a large amount of material has been extracted. The sandstone quarry is reputed to have been active in the late 19^{th} and early 20^{th} centuries, supplying building stone locally and to nearby Edinburgh, as well as overseas. The quarry was re-opened for a short period in the late 20^{th} century when stone was used for a number of new-build projects in Central Scotland.

An early reference to the stone is found in the list of UK building stones by Watson (1911):

Burntisland Newbiggen Freestone
Calciferous sandstone
Light yellow sandstone with brown ferruginous specks
Newbiggen Quarries, Fifeshire.
Wm. Chalmers, Esq., Burntisland.

A number of other sandstone quarries in Fife produced stone from the same geological strata, the Grange Sandstone. These are Grange Quarry, Burntisland [NT223867]; Dalachy Quarry, Burntisland [NT209863] (located immediately adjacent on the west side of Newbigging quarry); and Cullalo Quarry near Aberdour [NT184874] (the latter may be in sandstone slightly higher in the geological sequence –see McMillan et al. 1999).

Records suggest that early quarrying at Newbigging (historically known as Newbiggen) was for limestone. The Burdiehouse Limestone which crops out across the district in a roughly E-W band was exploited throughout the region for its good quality lime, quarried for both agricultural use and for building mortar. Lime is recorded as having been exploited in the district from as early as the 1300s. The value of the limestone was such that it was mined underground once the surface exposures became restricted. The limestone industry in the region expanded hugely in the 18th century, dominated by the Charlestown Lime Works which grew to an industrial scale operation (Haldane 1937). The Dalachy Quarry, located directly west of Newbigging Quarry (their borders touch) was operated from this time by the Earl of Morton.

On the 1856 map (Fig. 1), Dalachy Quarry is labelled as both limestone and freestone (i.e. sandstone), while Newbigging Quarry is marked only as limestone. It is likely that both quarries had been operated for some considerable time before this date. The map also shows a limekiln to the southwest of Dalachy Quarry, and the Newbigging Limestone Mine to the southeast.

The Carron Iron Company near Falkirk, founded in 1760, obtained limestone from Newbigging Quarry, and purchased the mine in 1808 (Marshall 2001). The iron company additionally purchased Newbigging Farm for its working horses and constructed limekilns along the shore to supply lime for local agricultural use. In 1817, a tram road wagon-way was constructed south of Newbigging Quarry to transport the limestone to Carron harbour which was built by the company at Ross Point immediately west of Burntisland (Marshall 2001). At this time limestone was being intensively excavated from this area, and there is no mention of sandstone being extracted.

In the 1845 New Statistical Account of Scotland “the western quarry” (probably referring to Dalachy Quarry) is described as extending for a hundred yards (i.e. c.90 metres). It records that as the limestone was extracted, a roof of sandstone was left supported by square legs of remaining limestone, creating rooms c.12 metres square. No mention of Newbigging Quarry or of sandstone extraction is made. It may be significant that the sandstone in Dalachy Quarry was not being exploited (at least on a large scale), and was largely left during the limestone extraction suggesting that the sandstone was not economically valuable. By July 1831 much of the Dalachy Quarry was flooded (Coupar 1845), and from this time it is likely that the majority of limestone was quarried from the Newbigging Limestone Mine to the south of the quarries.

The arrival of the North British Railway Line in 1890 heralded a significant change in Newbigging Quarry. The rail tracks ran only about 500 metres south of the quarry and it seems likely that the extraction of sandstone dates from this time (note however that samples dating 1889/90 in the BGS collections are only of limestone -Table 3). Comparison of the historic 1896 map (Fig. 2) with the map of 1921 (Fig. 3) shows the expansion of Newbigging Quarry following the arrival of the railway. At this time, building stone was being extracted from Newbigging quarry and traded under the operator William Chalmers (Watson 1911; Marshall 2001), with the number of workers recorded as having peaked in 1896 at 30 men (McMillan et al. 1999). By 1913 a new tramway was opened connecting the quarry to the limestone mine, providing a direct link to the main railway (Fig. 3) (Marshall 2001). From 1914 the quarry appears to have been worked intermittently, and eventually closed in 1937.

Newbigging Sandstone Quarry was reopened in 1979 by Scottish Natural Stones Ltd. to provide stone for the repairs to Gustavi Cathedral in Gothenburg, which was originally constructed from Newbigging sandstone in the 1870s. The quarry supplied stone for a number of projects in the late 1970s and though the 1980s (Table 1). The most significant use of the stone at this time was in 1984 for the National Library of Scotland in Edinburgh. It is recorded that only the bottom bed of the quarry was worked at this time as the top beds were discarded as not being to specification. The quarry was further worked for Phase II of the National Library in 1994. This is the last recorded building to have used this stone (McMillan et al. 1999). The list of buildings in Table 1 which are known to have used Newbigging sandstone is the only published information available, and it is accepted that many other buildings are likely to have been constructed using this sandstone type.

Published comments on the stone used for the National Library, describe Newbigging sandstone as being soft when first quarried, but mention it is said to harden after exposure to the air (McMillan et al. 1999). The stone in the building was claimed not yet to have a proven reputation as it had not stood long enough to have its weathering qualities assessed at the time of the book's publication. It is worth mentioning that Newbigging sandstone is likely to have been used in Burntisland and the local area since the 1850s with little evidence of poor performance or a bad reputation.

It seems likely that the proximity of the main railway line from 1890 was the main driver for the expansion of sandstone quarrying at Newbigging. Furthermore, the presence on site of a large and up to date limestone quarrying industry and the related infrastructure would have made both quarrying and transportation of the adjacent sandstone relatively easy and economic. The large size of the present Newbigging Sandstone Quarry is perhaps explained by the possible earlier extraction of limestone at the site, and that quarrying of sandstone was in effect a by-product of the limestone industry. At the end of the 19th century there was a large market of building stone in Central Scotland (linked to massive urban expansion), and it may be that the sandstone was quarried from the site largely because limestone was already being extracted.

Building	Address	Date	Source
Gustavi Cathedral	Gothenburg, Sweden	1870	McMillan et al. (1999)
Gustavi Cathedral (repairs)	Gothenburg, Sweden	1979	McMillan et al. (1999)
215-221 West George Street (construction of upper elevation)	Glasgow	Late 1970s	Leary (1986).
National Library of Scotland	33 Causewayside, Edinburgh	1984-87	McMillan et al. (1999)
National Library of Scotland (Phase II)	33 Causewayside, Edinburgh	1994	McMillan et al. (1999).
Cumbernauld House	Cumbernauld	Not given	Scottish Natural Stones. Newbigging Sandstone Pamphlet. Scottish Natural Stones Ltd., Springhill.
Craigie College	Ayr	1963-68	Leary (1986).
Kyle Shopping Centre	Ayr	Not given	Leary (1986).
County Buildings	Dumfries	Not given	Leary (1986).
Carlisle Cathedral (restoration)	Carlisle	Not given	Leary (1986).
Liberton Cemetery extension gates	Edinburgh	1926	Leary (1986).
Glasgow Art Gallery	Glasgow	Not given	Leary (1986).

Table 1. List of buildings reported to have used Newbigging sandstone, with dates of construction and source of the information. 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 (for example: the reference to 'Glasgow Art Gallery' could mean a number of buildings in the city). It is assumed that many other buildings are constructed from Newbigging sandstone, but this information is not readily available.

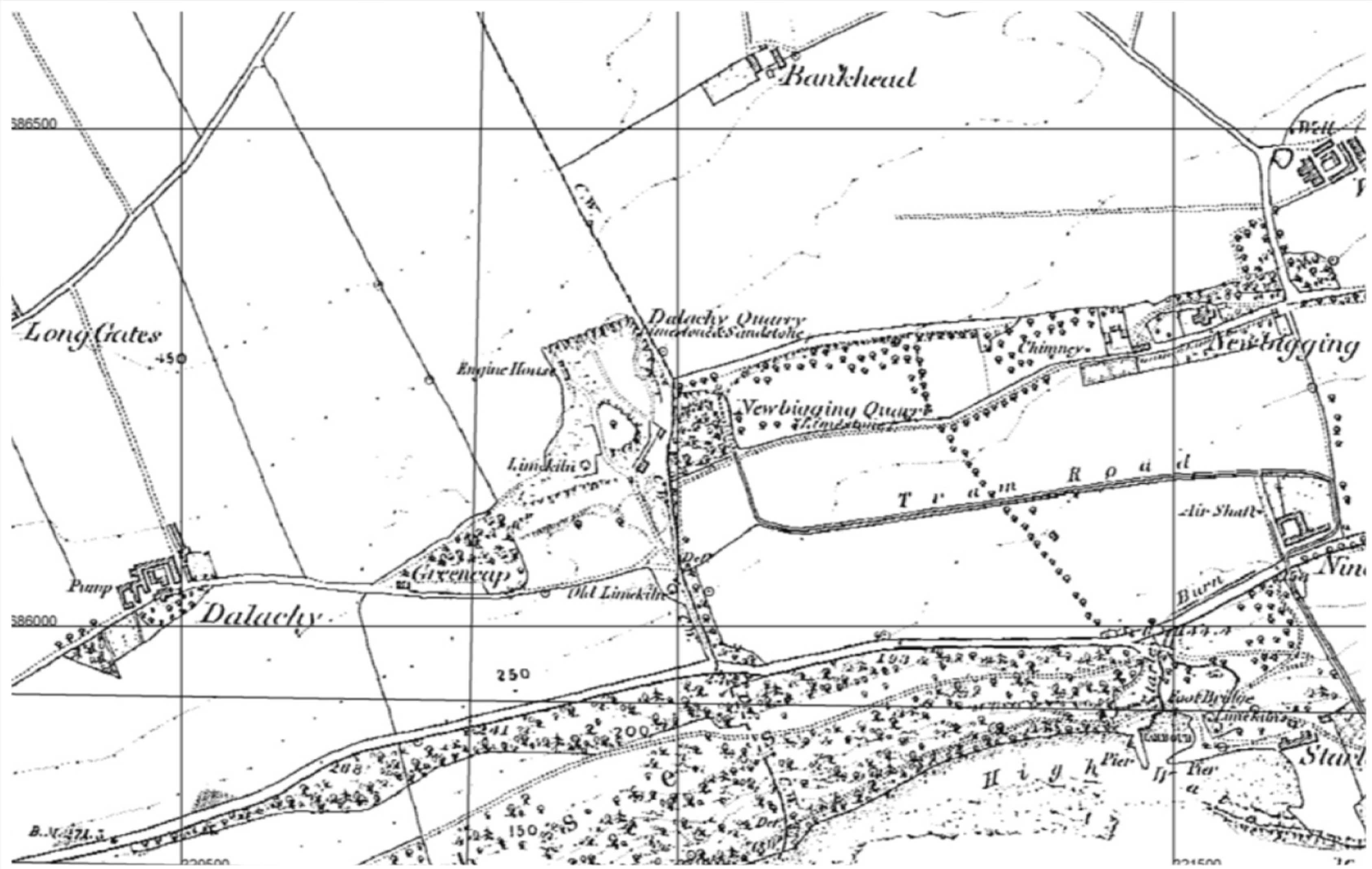
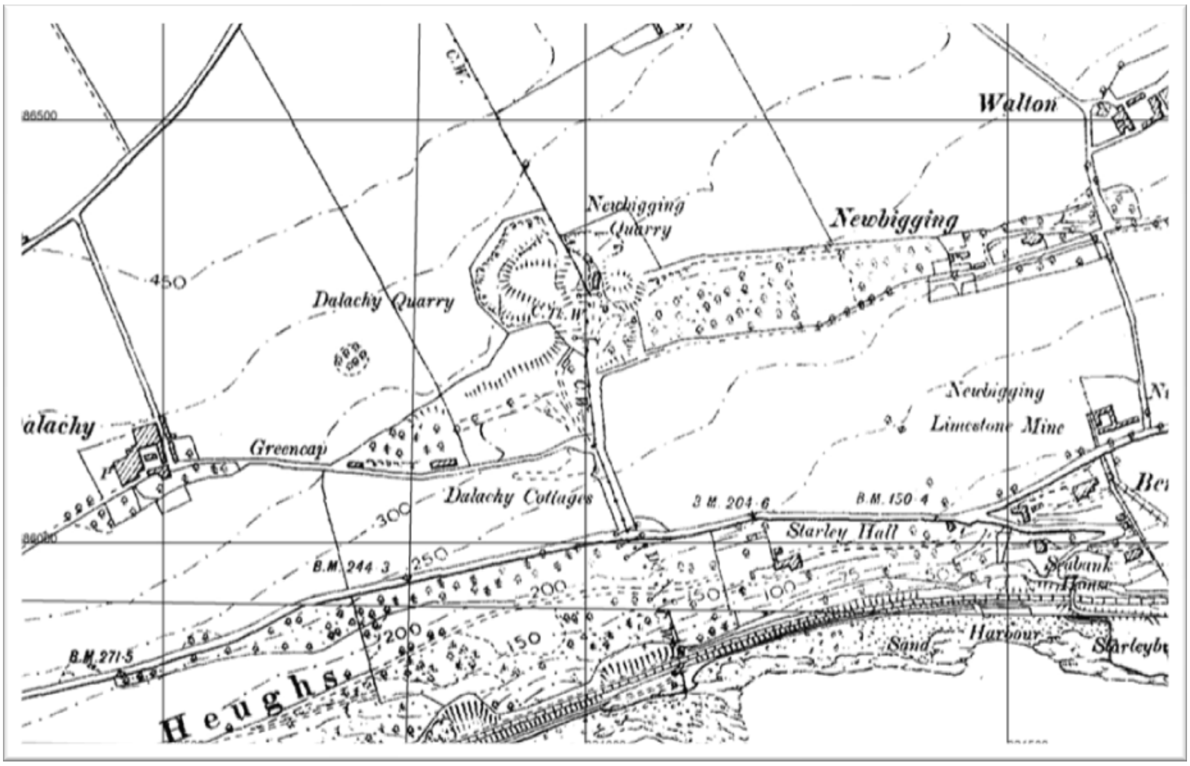
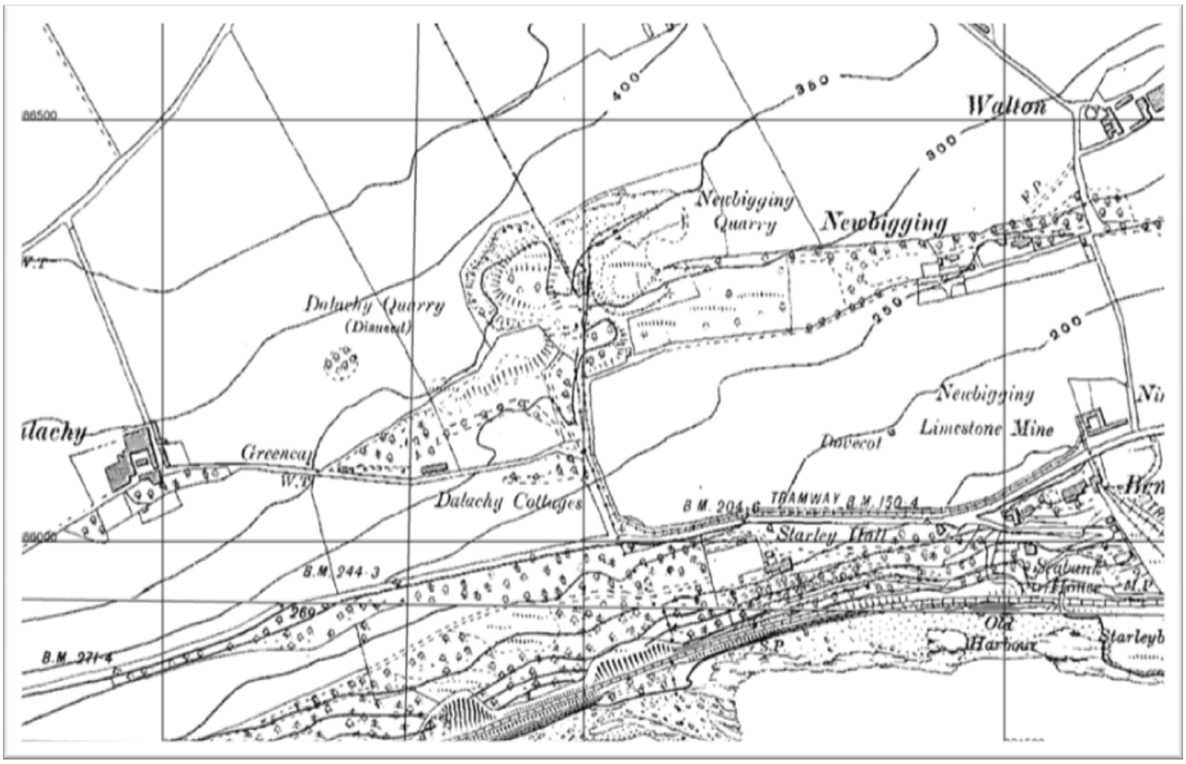


Figure 1. 1856 map of Newbigging, showing both Dalachy Quarry (marked as 'Limestone and Sandstone') and Newbigging Quarry ('Limestone'). Dalachy Quarry lies directly west of Newbigging Quarry. At this time Dalachy Quarry was much larger and extraction at Newbigging Quarry was smaller scale and only limestone. A limekiln is present to the southwest of Dalachy Quarry and an "Air Shaft" is located to the southeast (later referred to as Newbigging Limestone Mine) with Tram Road connecting the two. Lime kilns were scattered across the area, which was known as a major source of the material.





Figures 2 and 3. Maps from 1896 (above) and 1921 (below) showing that the tram road is no longer present, but the North British Railway (built c.1890) is located just south of Starley Hall. Dalachy Quarry is still in operation in 1896, but by 1921 it is marked as disused. Newbigging Quarry shows significant expansion over this time period, probably enhanced by the construction of a tramway in 1913, directly linking the quarry to the main railway line via the limestone mine. The growth of the sandstone quarry at this time suggests that improved transportation is likely to have been a significant factor in the viability of sandstone extraction from Newbigging Quarry.

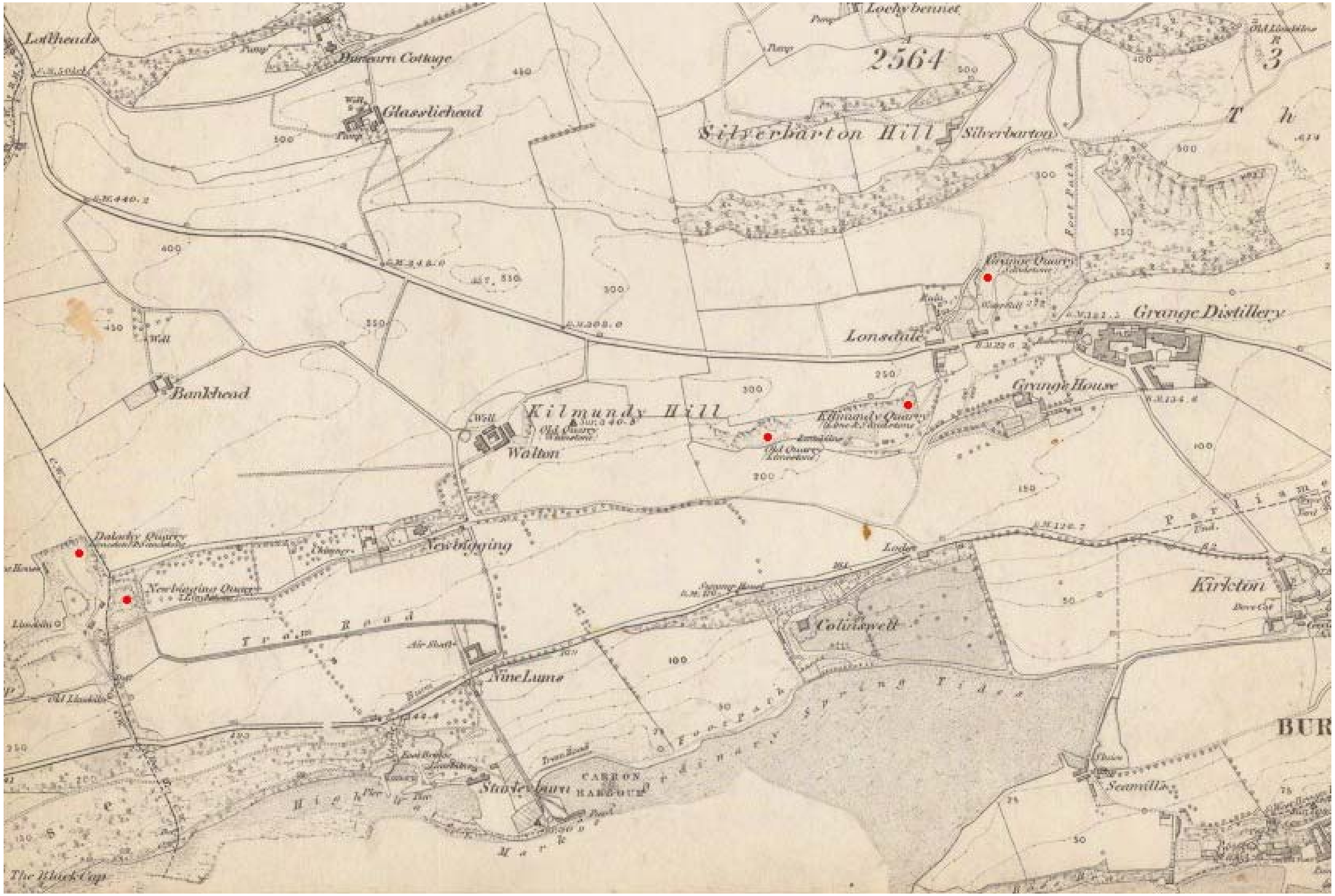


Figure 4. 1856 map showing the presence of several other quarries in the surrounding area. An old whinstone quarry is marked on Kilmundy Hill, and limestone and sandstone have been extracted from quarries at Kilmundy and Grange. These sandstones are likely to be from the same (or similar) beds as the Newbigging sandstone.

3. DESCRIPTION OF THE GEOLOGY OF NEWBIGGING

The geology of the area is relatively complex with mixed sedimentary rocks of the Lower Carboniferous and common intrusions of igneous rocks (Fig. 5; Browne and Woodhall 2000). Newbigging Quarry lies in the Grange Sandstone, forming part of the Sandy Craig Formation within the Strathclyde Group (Fig. 6). The formation consists of a range of sedimentary rock types, typically occurring as repeated 'cycles' of mudstone, siltstone and sandstone with limestone and dolostone. The sedimentary rocks are overlain to the north by the Kinghorn Volcanic Formation (Bathgate Group), consisting of basaltic tuff and lavas.

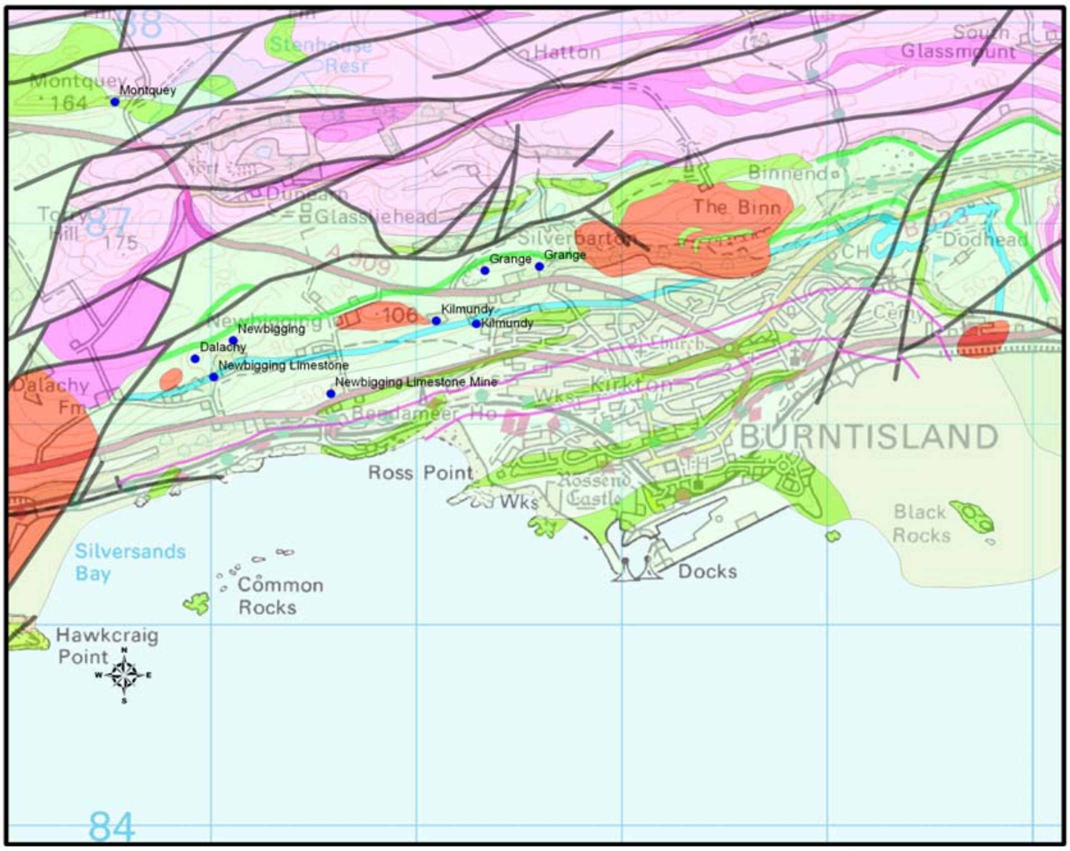
The Burdiehouse Limestone crops out immediately south of the sandstone quarry. It has been exploited at this locality and underground at various places nearby. The associated sandstone beds have been quarried at several locations around Newbigging. The large Grange Quarry less than 1 km to the east probably exploited sandstone from the same bed horizon as that at Newbigging.

There are two small outcrops of basaltic rock in the area around Newbigging, one forming Kilmundy Hill to the east of the quarry and the other smaller outcrop lying close to the southwest of Dalachy quarry. A few micrograbbro sills are also present to the southeast. It is possible that smaller igneous intrusions (dykes and sills) could be present nearer the quarry, although none is shown on the map. The quality of the sandstone is likely to be detrimentally affected close to these igneous intrusions, particularly the larger masses.

A number of mostly north-east to south-west trending faults are shown on the geology map of the area. None are shown to intersect the quarry, although one fault is present approximately a hundred metres to the north of the northern face of the quarry. As this fault is approached it is likely that the joint spacing in the sandstone will become reduced (thus reducing the average block size) and the stone may become highly fractured close to the fault.

The sandstone beds in the quarry dip gently to the north at 6 – 8 degrees. The detailed geology map shows a thin horizon of mudstone running just beyond the northern edge of the quarry. Part of this mudstone is exposed in the uppermost beds at Dalachy Quarry (Fig. 7). It is likely that the quality of the sandstone will diminish as this mudstone is approached, both in terms of reducing bed thickness and increasing mudstone content. This suggests that expansion of the existing quarry face to the north may lead to relatively poor quality sandstone, with the better stone found below the mudstone (at increasing depth). Further north and above the mudstone the sequence changes to mixed sandstone, siltstone and mudstone, and the potential for the sandstone to provide good quality building stone is likely to be reduced (Fig. 6). In addition, the BGS boreholes referred to in Fig. 6 indicate that the depth of overburden increases north of the quarry site, making extraction of bedrock more difficult in this area.

The sandstone beds exposed in Newbigging Sandstone Quarry are of unusually high and consistent bed height (several metres in places) (Fig. 8). In addition, the exposed quarry faces show vertical joint spacing is wide (frequently several metres). Both these factors are crucial in terms of determining block size and directly influencing the economic viability of the stone. In the case of the observed faces at Newbigging Quarry the predicted block size is large. Despite this, the presence of a mudstone band and a fault to the north of the current quarry face may have a significant impact on the potential of the stone, and the microscopic (petrographic) examination and mechanical testing (described below) are also important factors.



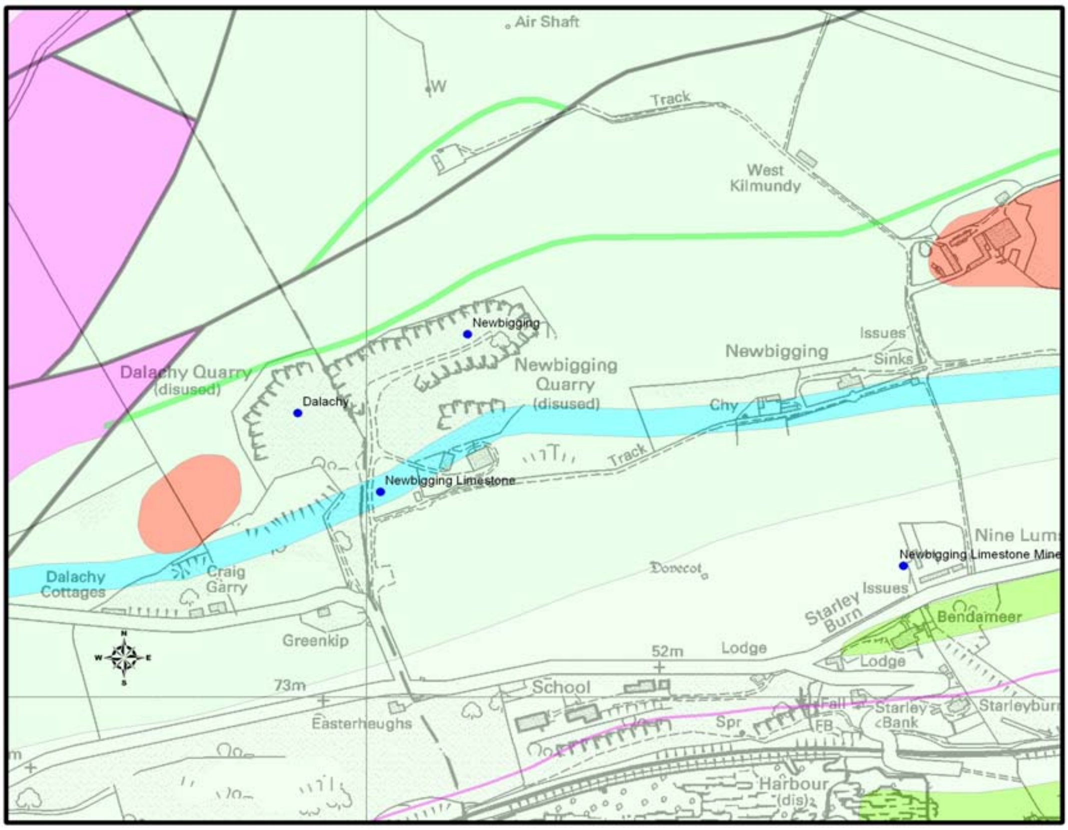


Fig.5. Geology map of the Burntisland area (above) and detailed area around Newbigging (below). The Carboniferous sequence of mixed sandstones, siltstones, mudstones and limestone are shown in a pale grey-blue colour. The light blue band is the Burdiehouse Limestone. Green and red areas are igneous intrusions, and thin green bands are mudstone (shales). Purple and lilac colours represent volcanic rocks. Black lines are faults. The main sites of quarries and mining are shown as blue dots.

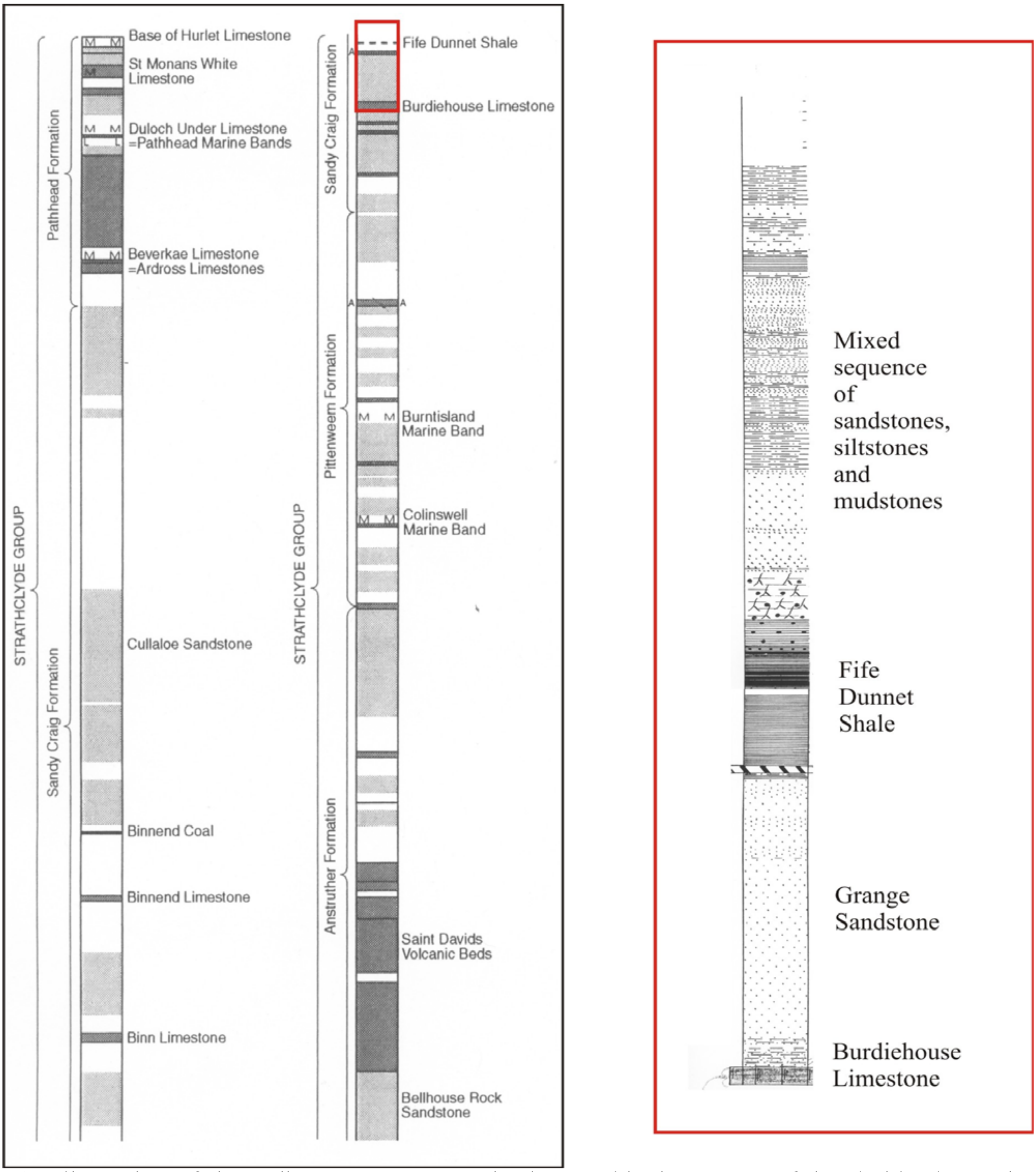


Fig. 6. Illustration of the sedimentary sequence in the Newbigging area. Left-hand side shows the Sandy Craig Formation within the Strathclyde Group sequence, containing the Cullaloe Sandstone in the upper part (left side). The small red box area shows the sequence at Newbigging Quarry, between the Burdiehouse Limestone and the Fife Dunnet Shale (adapted from Browne and Woodhall 2000). Right-hand side (large red box): Sketch (not to scale) of the detailed sedimentary sequence at Newbigging inferred from borehole logs, showing the Burdiehouse Limestone at the base, overlain by the Grange Sandstone (exploited in Newbigging Sandstone Quarry), itself overlain by the Fife Dunnet Shale. Above the shale is a mixture of sandstone, siltstone and mudstone, suggesting that significant high quality sandstones suitable for building stone may not be present immediately north of the quarry. Adapted from borehole logs NT28NW/90 (Whinnyhall No.4 W Bore) & NT28NW/11 (Newbigging No.8 Bore 1894).

Fig. 7. View of upper parts of the sedimentary rock sequence above the underground mine at the adjacent Dalachy Quarry, showing thinning of the sandstone beds towards the top where a dark rubbly mudstone bed is present. Note the orange staining in the sandstone near the mudstone. The presence of this mudstone in the rocks immediately to the north of the Newbigging Sandstone Quarry may influence the quality of the sandstone if the quarry were to be extended in this direction (Photo: Mike Browne, BGS).

Fig. 8. General view of western end of Newbigging sandstone quarry (north face), showing the large and consistent bed heights of the sandstone and the wide vertical joint spacing (Photo: Mike Browne, BGS).

4. SAMPLES

A large number of samples of both sandstone and limestone from Newbigging are present in the BGS rock collections, dating from the late 19th century and recording several periods in the 20th century when the quarry was active (the 1930s and 1990s), and from material collected more recently since the quarry closed. These are listed in Tables 2 and 3, with a brief description and showing the analyses carried out in this study. A number of the sandstone samples are shown in Figs 9 to 11 below.

Fig. 9. Three cut block samples of Newbigging sandstone supplied to BGS in the 1990s following the reopening of the quarry by Stewart McGlashen Ltd. The samples show a range of colours, from off-white (MC5709 bottom-left) to yellowish-buff with orange iron oxide speckles (MC4397 top-left). The large sample to the right (MC4397) shows some dark bedding laminae near the base. Further details given in Table 2.

Fig. 10. Examples of samples of Newbigging sandstone from the BGS collections, both modern and historical, showing the typical off-white to pale yellow colours. These samples are all relatively easy to disaggregate under finger pressure (ED10425 top-left; ED10434 top-right; MC1341 bottom left; MC10777 bottom-right). Further details given in Table 2.

Fig. 11. Samples of Newbigging sandstone from the BGS collections, both modern and historical, showing disaggregation of stone which is friable under finger pressure. Sample ED10434 (top left), from Newbigging Farm, has disintegrated in the laboratory after it was sawn to produce the thin sections for microscopic analysis. (ED10436 top-right; ED10435 bottom-left; ED10425 bottom-centre; ED10433B bottom-right). Further details given in Table 2.

Sample Number	Date Collected	Description	Macroscopic analysis	Microscopic analysis	Compressive Strength
MC5709	1996	Cut quarry sample, white/very pale grey. Moderately compact.	●	●	●
ED10433B	2008	Pale buff, slightly speckled. Friable	●	●	
ED10434	2008	From Newbigging Farm. Whitish, extremely friable, completely disaggregated.	●	●	
MC5782	1996	Cut quarry sample of buff coloured, softly speckled appearance. Compact.	●		
MC1341	1939	White, with a soft speckled aspect. Slightly friable.	●		
MC1340/ED10345	1939	White with a soft speckled aspect. Slightly friable.	●		
MC10777	2005	White/very pale grey. Friable	●		
ED10425	2005	White/very pale grey. Friable.	●		
ED10434	2008	White/very pale grey. Friable.	●		
MC5840/ED10436	2000	Pale buff, slightly speckled appearance. Slightly friable.	●		
MC4397A	1979	Cut quarry slab sample of greyish buff, laminated stone. Partly parallel lamination, with some ripple lamination.	●		

Table 2. Samples of Newbigging sandstone held in the BGS collections. The different analytical tests carried out in this study are shown.

Sample Number	Source	Date Collected	Description
S1098	Newbigging Quarry	18??	Limestone
S5795	Newbigging Mine	1889/90	Limestone
S11255	Newbigging Quarry	1904	Dolerite
S33765	Newbigging Quarry	1940/1	Sandstone
S34855	Newbigging Limestone Works	1942	Limestone/Dolomite
S35896-9	Newbigging Limestone Mine	1943	Limestone

Table 3. Samples of various stone types collected from Newbigging prior to 1945.

5. PETROGRAPHIC ANALYSIS OF NEWBIGGING SANDSTONE

5.1 Methodology

All the samples of Newbigging sandstone in the BGS collections (Table 2) were examined visually (macroscopic description below). Three samples then underwent detailed microscopic analysis, selected as being representative of the range of characteristics shown by all the samples of Newbigging sandstone (microscopic description below). Macroscopic analysis was carried out using a binocular microscope. Colour was determined using a standard Munsell® Colour Rock Chart (Geological Society of America). Thin sectioning was carried out at the British Geological Survey thin section laboratory, each sample impregnated with blue dye resin in order to highlight porosity. The section is 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 Macroscopic Description

Fine to medium grained sandstone, mostly off-white to light grey in colour. Some samples have a pale creamy yellow colour, sometimes with a softly speckled appearance given by pale orange coloured ferruginous grains. Munsell colour code ranges from 2.5Y 8/1; *light grey* in the palest of the stones to 2.5Y 8/2; *light grey* to 2.5Y 8/3; *pale yellow* in the stronger coloured variety. The orange colour may vary, appearing as broad irregular bands.

In all samples but one, the sandstone has a uniform texture (freestone) with no apparent bedding. In one cut slab bedding is defined by black laminae (probably carbonaceous) showing cross-lamination, giving a 'wispy' texture (illustrated in Fig. 9).

None of the samples show any reaction to 10% HCl indicating absence of carbonates. After this test all the samples tested showed an unsightly yellowing staining indicating some mobilisation of iron oxides. A water bead test indicates very high permeability. Minor powdery clays are visible partially infilling the porosity.

Most of the samples appear soft and friable, being easily disaggregated by finger pressure or scratching by fingernail (see Figs. 10 and 11). The two more strongly coloured samples (MC5782 with iron speckling; MC4397A with lamination) appear to be more compact and less friable than the rest (Fig. 9). The palest and most white coloured samples appear to be the weakest. A number of these samples which had been sent as one piece to the thin section laboratory completely disaggregated into loose sand as the samples were sawn for thin sectioning (Fig. 11).

5.3 Microscopic Description

The microscopic description is based on detailed examination of thin sections from three samples which cover the range of sandstone quality observed in the quarry:
MC5709: reasonably competent stone;
ED10433B: friable stone;
ED10434: very friable stone.
Microscopic images of each of these samples are shown in Fig. 12.

Fine to medium grained, moderately to poorly sorted sandstone, containing minor clay minerals. Framework grains are generally subangular to subrounded, with occasional rounded grains, ranging from 0.04 to 0.8mm, mostly within the 0.20-0.4mm size. Dominated by quartz (c.90%), generally monocrystalline with a small percentage of polycrystalline grains. Some have undulating extinction indicating a metamorphic provenance. A variety of feldspar grains (both K-feldspar and plagioclase) appear mostly well preserved and constitute c.3-4%, with occasional relict (skeletal) grains replaced by clay minerals. Minor lithic grains (rock fragments) appear often in small sizes mostly of various metamorphic origins (slate, quartzite, schist and occasional chert), constituting c.2-3% of the total of the stone. Minor randomly oriented small white mica (muscovite) is present (<1%). Large zircon appears as an accessory mineral. In samples MC5709 and ED10434 iron oxides appear as very small discrete grains, some with rounded shapes and in amounts <1%. In sample ED10433B, iron oxides are more abundant, c.3% appearing as large mobilized grains encompassing quartz grains, infilling the porosity locally as well defined spots with a maximum diameter of c.2mm.

Matrix minerals comprise c.2-3% of the stone, comprising mostly secondary clay minerals, and locally infilling the porosity.

The samples all have a high porosity (visually estimated at c.20-22%) which is very well communicated, with a range of micro and macropores and conduits. Porosity is mostly primary, (original) with some secondary due to weathering of feldspars and to the breakage of contacts between grains. This latter microporosity highly increases the permeability of the samples and reduces the strength of the stone. The sandstones have very little authigenic silica cement, and where present the silica overgrowth often does not appear to be cementing grains but produces idiomorphic grains and partially infills pore spaces. When grains are occasionally cemented, the silica overgrowth appears as a 'meniscus' cement. Grains are mainly bound by their contacts, but these are rather poor, mostly point-contact with some longer contacts showing pressure solution. In the thin sections there are common 'floating' grains, with minimal or no contacts between them. The rock type is classified as a quartz arenite, close to a subarkose sandstone.

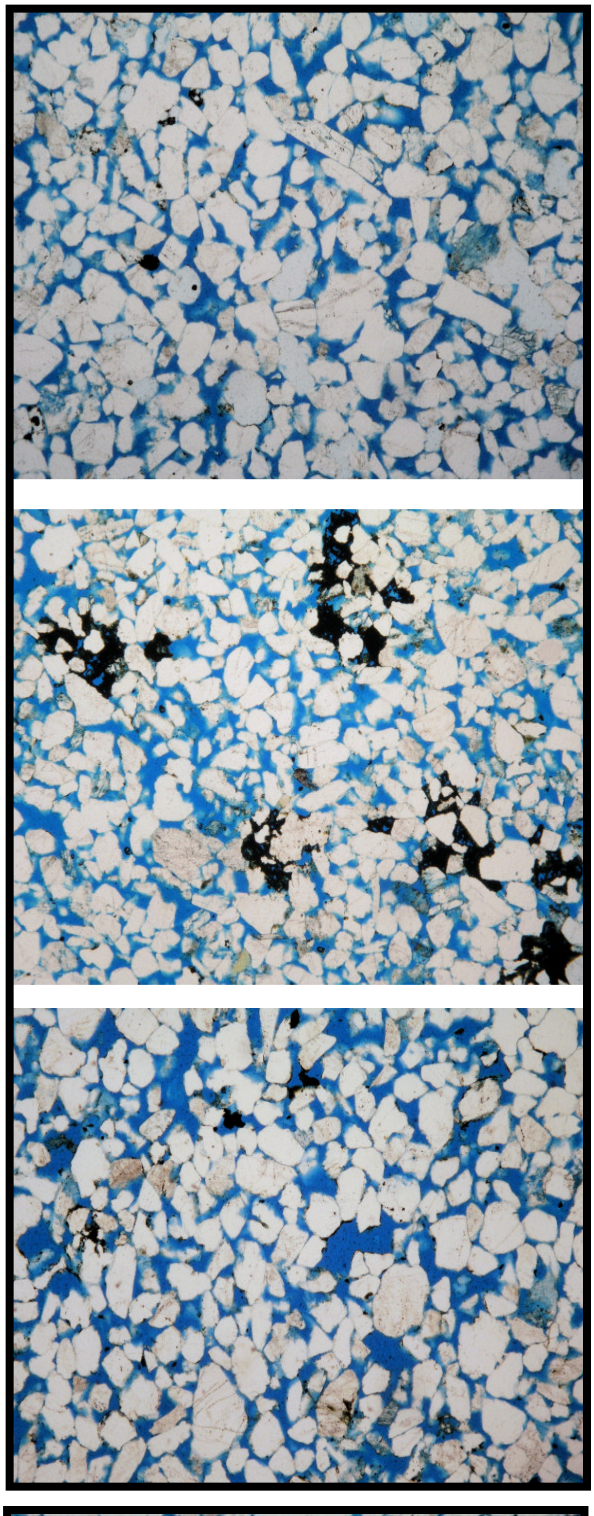


Fig. 12. Microscope images of Newbigging sandstone in thin section; from top to bottom MC5709 (reasonably competent stone), ED10433B (friable stone), ED10434 (very friable stone). Images are c.3mm wide, taken under plane polarised light. Porosity is highlighted by blue dye resin.

The sandstone is dominated by quartz (white sandstone grains) with very few other minerals present. Black grains are iron oxides, more abundant and better developed in sample ED10433B.

The amount of blue dye is unusually high for a building sandstone and indicates the high porosity for Newbigging sandstone. Note also the poor contacts between grains, many of which appear to be ‘floating’ or only just touching. This is due to poor compaction and lack of natural mineral cement bonding the grains. These factors suggest that the sandstone is likely to be relatively weak and easily disaggregated.

Sample MC5709 (upper image) is a more competent sandstone than samples ED10433B (middle image) and ED10434 (lower image) which show decreasing strength. This can be seen by the subtle decrease in compaction (increasing pore space) seen from top to bottom. This variation is likely to be a natural variation possibly reflecting slight differences in compaction between different beds in the quarry. Despite this it should be noted that even the upper images (sample MC5709) has relatively high porosity and low compaction compared to most sandstones used as building stone.

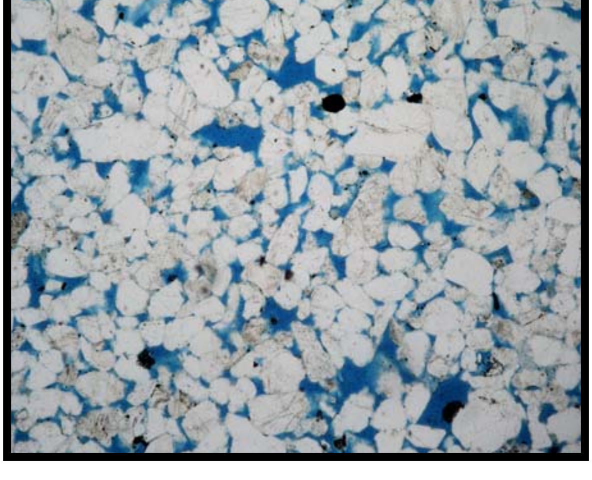


Fig. 13. Microscopic thin section image of sandstone from the recently reopened Cullalo Quarry (Fife). Note the increased compaction of this sandstone as seen by less blue resin (lower porosity) and stronger contacts between grains. Cullalo sandstone is much more competent (difficult to disaggregate) compared to Newbigging sandstone. Image c.3mm wide, taken under plane polarised light. Porosity is highlighted by blue dye resin.

6. PETROGRAPHIC COMPARISON OF NEWBIGGING SANDSTONE WITH OTHER SANDSTONE TYPES

The samples of Newbigging sandstone which underwent petrographical analysis were compared to other well-known building sandstones which have a good reputation, both historically and from currently active quarries use. These are:

Sandstone	Quarry Source	Use and current status/availability
Craigleith	Craigleith Quarry, Edinburgh	Quarry closed and infilled. Small quantities of reclaimed stone available.
Cullalo(e)	Burntisland, Fife	Used in Edinburgh from early 19^{th} century. Quarry reopened 2004
Clashach	Moray	Quarry active. Used locally and further afield throughout 20^{th} century.
Darney	Northumberland	Quarry active. Used in Central Scotland from early 20^{th} century.

The above stone types have been selected for comparison since they are similar sandstones in visual and textural terms to the Newbigging sandstone. They are all generally quartz-rich sandstones with a uniform texture and pale colour, with an open texture and moderate porosity. They are considered representative of stone types with which Newbigging sandstone would have to compete if it were in the marketplace today.

Microscopic comparison shows that the main difference between these stone types and Newbigging sandstone is related to the contacts between the grains and in the distribution and amount of the silica mineral cement (Figs. 12 and 13). In Newbigging sandstone, the contacts between sand grains are poorly developed, with many grains appearing to 'float' in the thin section where the grains appear not to be touching (Fig. 14). In the other sandstone types the grains have much more contact, with both long and point (pressure solution) contacts commonly developed (Fig. 13).

The natural mineral cement in these rocks is a silica cement, formed by the dissolution of quartz following grain impaction (during compaction) where pressure solution has resulted in mobilisation of silica into open pore spaces where it reprecipitate and grows 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 durability of a sandstone. In the Newbigging sandstone the silica cement is poorly developed and is rather scarce and patchy (Fig. 15). Where present it commonly fails to cement the grains. In the other sandstones the silica cement is well developed and commonly forms a strong mineral cement (Fig. 16). Detailed comparison of microscopic characteristics of samples of Newbigging sandstone with other sandstone types is illustrated in Fig. 17.

These observations show that Newbigging sandstone has lower compaction and is considerably less well cemented than the other stone types. This is highly likely to be reflected in the performance of Newbigging sandstone as a building stone, suggesting that it will be relatively easy to disaggregate and lacking in strength.

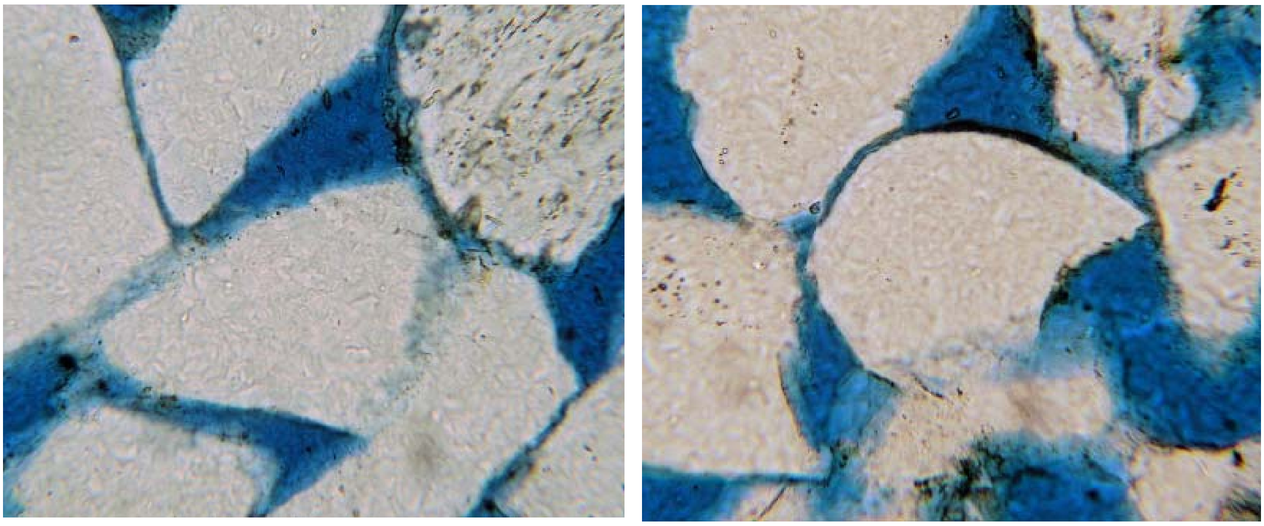


Fig. 14: Detailed images of grain contacts in Newbigging sandstone sample ED10434, showing examples of 'floating grains' and poorly developed mineral cement, leading to lack of bonding between grains. Plane polarised light; porosity highlighted by blue dye resin. Magnification x25.

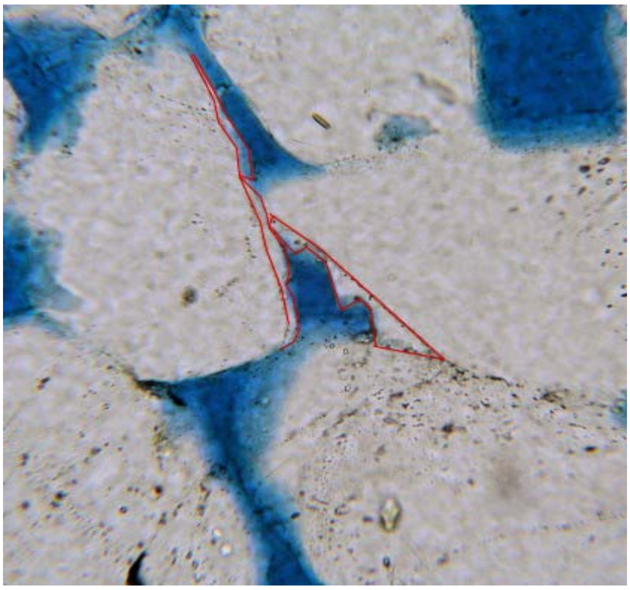


Fig. 15. Detail of grain contacts in Newbigging sandstone (MC5909). The stone shows poor compaction with grains only just touching. The red lines enclose growths of natural silica cement which are too poorly developed to significantly bond the grains together. Plane polarised light; porosity highlighted by blue dye resin. Magnification x25.

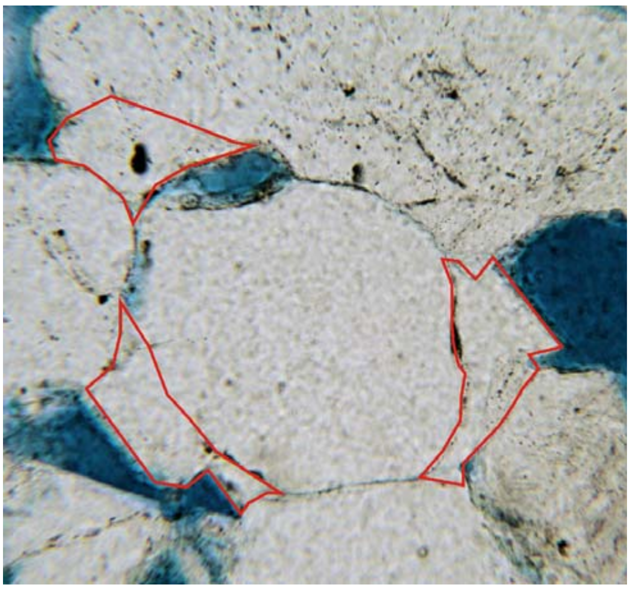
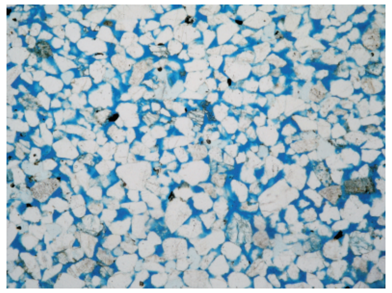
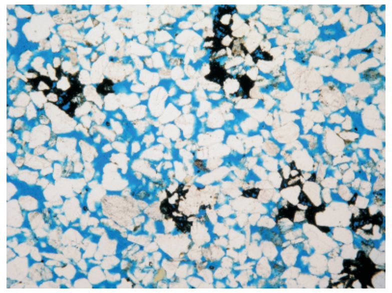
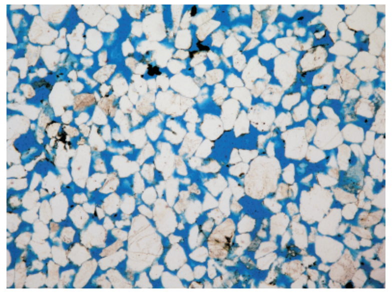
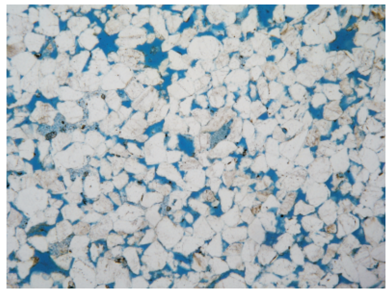
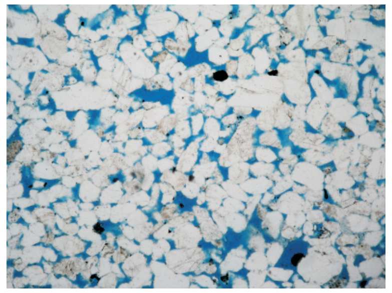
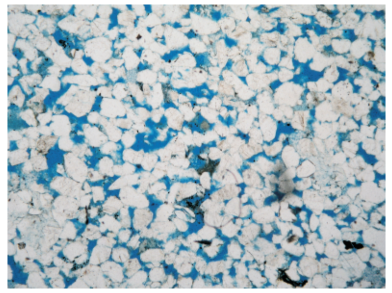
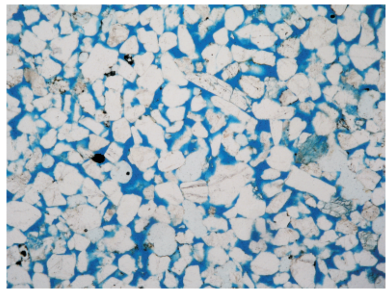
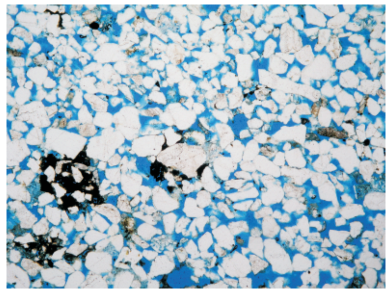
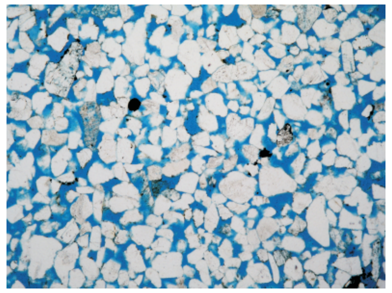
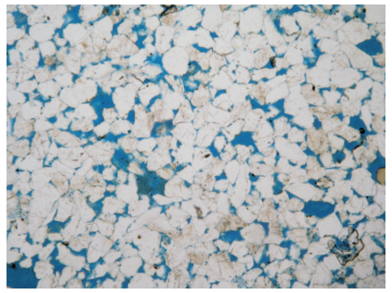
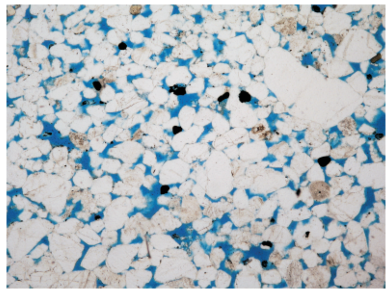
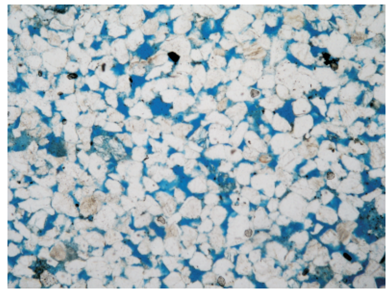
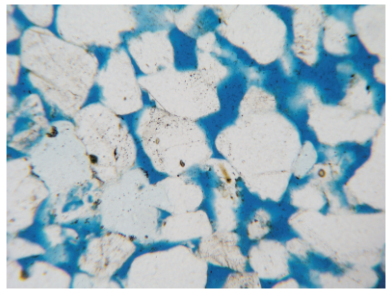
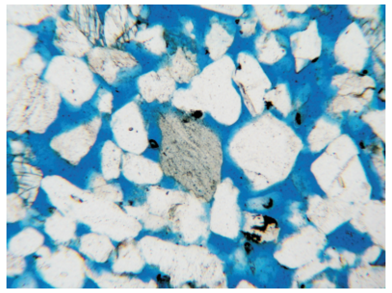
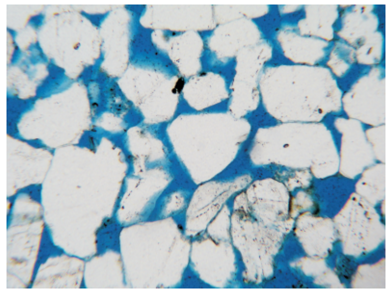
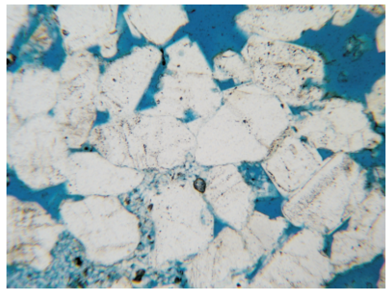
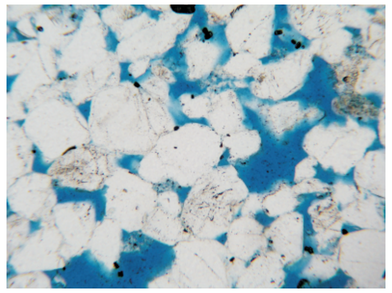
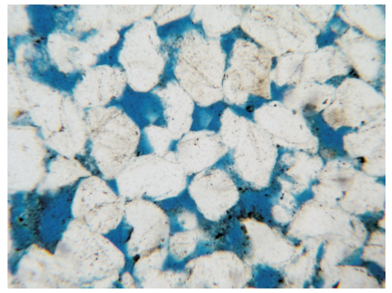
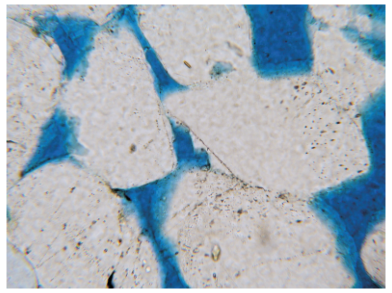
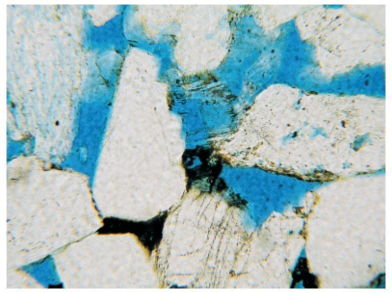
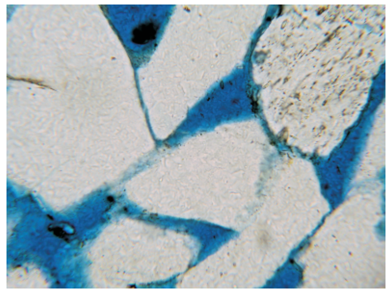
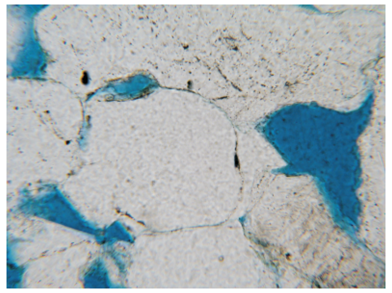
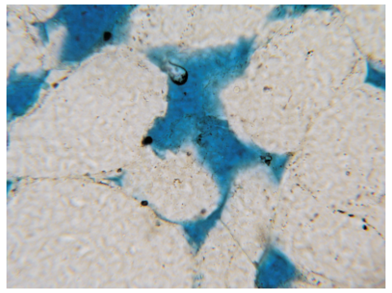
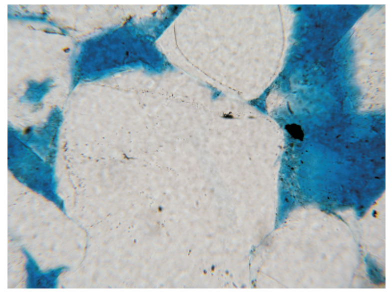


Fig. 16. Detail of grain contacts in sample of Craigleith sandstone. The stone shows high compaction giving good (long) contacts between the grains. The red lines enclose growths of natural silica cement which bond the grains together. These features result in a strong and highly durable sandstone. Plane polarised light; porosity highlighted by blue dye resin. Magnification x25.

Fig. 17. A3-size comparison of microscopic thin section images of Newbigging sandstone with sandstones from Craigleith, Cullalo and Darney quarries, showing different characteristics at different magnification levels. Note at lower magnifications the difference in compaction between the samples (much more open porosity in Newbigging sandstone). At higher magnifications the poor grain contacts seen in the Newbigging samples contrast with the strong grain bonds in the other samples.

MAGNIFICATION	NEWBIGGING MC 5709	NEWBIGGING ED10433B	NEWBIGGING ED10434	CRAIGLEITH	CULLALO	DARNEY
x4.5						
x4.5						
x10						
x25						
NOTES	**Poorly compacted:** · Minimal contacts between grains. · Many grains appear 'floating'. **Poorly developed mineral cement:** · Lack of silica overgrowth cementing grains.			**Moderate to well compacted:** · Good (long) contacts between grains. **Well developed mineral cement (Craigleith and Cullalo):** · Abundant silica cement bonding the grains.		

7. MECHANICAL TESTS AND PHYSICAL PROPERTIES OF NEWBIGGING SANDSTONE

Together with the petrographic analysis, the physical properties of a stone (including the results of mechanical tests) can provide an indication of the potential performance and the quality (strength, durability etc.) of a particular stone type. In this section test values for Newbigging sandstone are presented and compared to other sandstone types.

The Compressive Strength Test (also known as Crushing Strength Test) is defined as the maximum load per surface unit that a core cylinder of the stone can support until it breaks, when put into a standard press (REF). This value is particularly important where the stone has to carry loads, in dressed stones, rubble or functional elements as mullions, cornices, etc., but it is also a very useful indication as to the performance and quality of a stone. Poor bonds between the constituent mineral grains will give a low strength value, providing an indication of susceptibility to disaggregation and stone decay from weathering.

One of the more competent samples from the Newbigging sandstone from the BGS collections (sample MC5709) was selected for Compressive Strength testing as being representative of the Newbigging sandstone. The details and results of the test are given in Appendix 1. The test result is shown in Table 4 alongside other published results for Newbigging sandstone compiled from a number of sources and compared to other well known sandstone types.

For compressive strength the Newbigging sandstone shows a range of values from 10.9 to 33.5 MN/m^2. Craigleith and Clashach sandstones are both >80 MN/m^2 and Cullalo and Darney sandstones are 35.7 and 32 MN/m^2 respectively. The uppermost compressive strength value for Newbigging is therefore similar to Cullalo and Darney. The point load strength test for Newbigging is very weak compared to the other sandstone types. Both Newbigging and Darney stone show relatively poor results for the salt crystallisation test.

In terms of the tests indicating strength and durability, the Newbigging samples are consistently low compared to the other stone types. The results published in McMillan et al. (1999) are accompanied by a note stating that the Newbigging stone shows unusually high variability in the tests, suggesting that the stone is inconsistent. In overall terms the mechanical tests show that Newbigging stone does not compare well with the other stone types currently on the market.

Name (source of data)	**Bulk Density Kg/m^3**	**Crushing Strength MN/m^2**	**Point Load Strength MN/m^2**	**Water Absorption %**	**Apparent porosity %**	**Salt crystallization test**
Newbigging (This study; Appendix 1).	-	24.8	-	-	-	-
Newbigging (Scottish Natural Stones data 1987)	2643	33.5	-	7.44	-	-
Newbigging * (McMillan et al. 1999). *Variable, the values are averages.*	2309	10.9	0.6	12.6	18.9	Disintegrated after 10 cycles.
Craigleith (McMillan et al. 1999).	2220	93.9 94.3	-	6.8	13.5	30% mass loss after 15 cycles.
Cullalo (McMillan et al. 1999).	2160	35.7	2.6	11.2	18.4	15 % mass loss after 15 cycles.
Darney (McMillan et al. 1999).	2180	32	2	10.3	17.6	Disintegrated after 10 cycles.
Clashach (McMillan et al. 1999).	2346	85.8	9	5.2	9.2	Unaffected.

Table 4: Physical test results for Newbigging sandstone compiled from a number of sources, and compared to tests of other well-known sandstones (Craigleith, Cullalo, Darney and Clashach).
*The source of the data states: “the mean values stated obscure an unusually wide range of test results on samples from this source”.

8. DISCUSSION

8.1 Quality of the stone

The test results presented in this study show that Newbigging sandstone has relatively low values of strength and durability indicators compared to other reputed sandstone types. Petrographic analysis shows that this is caused by a lack of compaction and a poorly developed natural mineral grain cement, leading to relatively easy disaggregation of the sandstone grains. The results suggest that Newbigging sandstone would not perform as well as other reputable stone types. It is considered unlikely that the stone would be able to compete in today's marketplace where testing is required, and specifications for high value/high volume contracts require consistent high quality stone with high strength values (e.g. for thin cladding panels).

8.2 Resources in Newbigging Quarry

There are a number of concerns regarding the potential for expansion of the quarry. Immediately beyond the current north face of the quarry a mudstone band is present which is likely to continue northwards as a shallow dipping sheet, making it likely that any northwards expansion of the quarry would encounter a large volume of mudstone and associated poor quality sandstone. In addition, the presence of a fault some 100 metres to the north of the quarry may present problems in terms of fractured rock, although the width of any affected zone is not known. In summary, the geological constraints at the current quarry site mean that there may be difficulties extracting good quality sandstone if the quarry is expanded to the north.

8.3 How has Newbigging sandstone performed in buildings?

A number of published records exist naming buildings which have used Newbigging sandstone, although much of the information is scant (Table 1). It is beyond the scope of this study to investigate further sources of information regarding the use of the stone, and it has not been possible to sample stone from buildings for detailed examination (with the exception of Newbigging Farm). Visual examination of some of the known examples of Newbigging sandstone have been undertaken (National Library Building in Edinburgh; 215-221 West George Street, Glasgow; Newbigging Farm) and are described below. Attempts to identify Newbigging sandstone at other recorded sites (e.g. Liberton Cemetery Gates; Glasgow Art Gallery, and a reported use at the 'colony buildings' in Leith) could not verify the specific presence of this stone type at these locations.

Visual examination of the Causewayside building (built 1984-1994) shows that the sandstone appears to be performing reasonably well (Figs 18 and 19). The greening of parts of the masonry by organic growth is likely to be due to the lack of rainwater dispersal features in the design of the building rather than a problem with the stone. A few (relatively minor) problems were noted where the stone has suffered physical damage and where fixings had failed but these may not necessarily be a specific fault of the stone. An interview with a stone mason who worked on the construction of the building reported that a high proportion of the sandstone blocks had to be rejected on the site due to failure during transportation or during handling on site immediately prior to fixing. The stone was reported to be difficult to use and unreliable in this respect.

At 215-221 West George Street, Glasgow the late 1970s upper story extension is reported to be constructed from Newbigging sandstone, whilst the lower part of the building is a local Glasgow sandstone. Visual inspection from street level indicates that the condition of the extension is good, with the masonry appearing to retain its sharp edges with normal weathering for a sandstone construction of this age (Fig. 20). No detailed examination of this building was undertaken.

The masonry in Newbigging Farm (dated 1825) is reported to be Newbigging sandstone. The condition of the masonry appears to be good, with blocks still retaining original tooling details. However, sampling of a dressed stone from a window (removed due to a fracture) shows that despite the good condition of the external surfaces, the sandstone internally is highly friable. This specific sample (ED10434) completely disintegrated during handling and sawing for the preparation of a thin section.

It is concluded that the Newbigging sandstone used on the visited buildings appears to be performing satisfactorily. This is despite the fact that the stone internally is likely to be relatively soft and friable (as examined at Newbigging Farm). This concurs with verbal evidence from a mason involved in the construction of the Causewayside Library that the stone was easily damaged when being transported and handled, but has performed well once placed in the building. It would seem that the relatively friable nature of Newbigging sandstone is an issue, although once the stone is placed in a building it can perform as expected for a sandstone of this type.

Further verbal evidence has been obtained from a former director of Scottish Natural Stones (the last operator of the Newbigging quarry in the 1990s). This person (who made the decision to close the operation) stated that the quality of the stone was too poor in terms of durability and that the sandstone was too friable to use. It was regarded that the frequent occurrence of damage and failure of blocks when handling the stone and the consequent large wastage, made the processing of Newbigging sandstone uneconomic.

8.4 Why was Newbigging sandstone ever quarried?

The large size of the current Newbigging quarry suggests that a significant amount of sandstone has been extracted, and documentation shows that the stone was used for building construction over a long period of time (including a number of significant buildings). However, it is difficult to reconcile this with the issues of poor quality identified above. It is perhaps possible that the quality of the stone previously quarried was of better quality than that seen in the quarry today, although such variation would be unusual within a quarry. The samples in the BGS collections were obtained over a long period of time, and although some are more competent than others, they are all generally weak and there is no indication that the older samples are better. The test results suggest that whilst the best Newbigging sandstone is similar to Darney sandstone, most is likely to be of lesser quality.

The historical evidence suggests that the exploitation of Newbigging sandstone may have been related to the existing limestone quarries, where it was removed in order to allow quarrying of the underlying limestone. It therefore seems likely that it was commercially exploited essentially as a by-product of the limestone industry, and at a time when there was a massive demand for building stone in Central Scotland (unlike today). It is worth noting that in the adjacent Dalachy Quarry (which operated before the Newbigging Quarry; Figs. 2 and 3) the limestone was extracted by underground mining and much of the sandstone was left in situ. The later Newbigging Quarry in adjacent (and probably identical) geology exploited the sandstone overburden, possibly because by that time it was commercially viable due to (i) the existing quarry infrastructure, equipment and workforce; (ii) the presence of the railway network allowing efficient transport of the stone; and (iii) increasing demand for building stone in Central Scotland in the late 19th century.

Fig. 18. National Library of Scotland, Causewayside, Edinburgh, built in the mid-1980s using Newbigging sandstone. The soiling on the masonry is likely to be largely due to the lack of rainwater dispersal detailing on the building, rather than a problem with the stone itself.

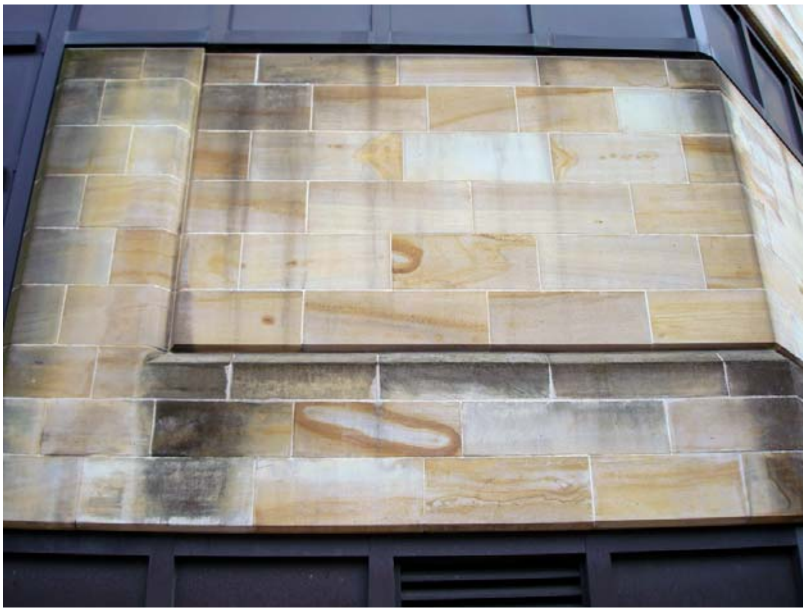


Fig. 19. Detail of Newbigging sandstone masonry on National Library of Scotland, Causewayside, Edinburgh. The masonry blocks appear to be in generally good condition with sharp edges and smooth outer face. There is no obvious indication of stone decay. The variable colours are due to natural iron oxides present in the quarry which are likely to be stable.

Fig. 20. Part of 215-221 West George Street, Glasgow where the upper story extension is constructed from Newbigging sandstone (over a typical grey bedded Glasgow Sandstone). The Newbigging stone appears to be in good condition with no indications of unusual weathering or decay.

9. SUMMARY, CONCLUSIONS AND FURTHER COMMENTS

9.1 Summary

The historical evidence shows that major production of sandstone quarrying at Newbigging Quarry did not begin until the late 19th century, possibly coinciding with the connection to the national railway network in c.1890. Up to this time the area was a major producer of limestone from both surface quarrying and underground mining. The sandstone beds at Newbigging Quarry geologically overlie the limestone, and once the surface outcrops of limestone had been quarried it would have been necessary to extract the limestone either by underground mining or by removal of the sandstone overburden. The early maps of the area (1856 and 1896; Figs. 1 and 2) suggest that the Newbigging Quarry began as a surface limestone extraction to the south of the present quarry site, and was driven northwards over time (1921; Fig. 3), requiring removal of the sandstone to access the underlying limestone. It is therefore possible that the quarrying of sandstone was effectively a by-product of limestone production. The economic viability of sandstone extraction at this time was probably greatly assisted by the existing limestone quarry infrastructure and workforce, and significantly enhanced by the arrival of the railway after 1890. At the end of the 19th century the demand for building stone was high, and a quarry situated close to the main markets (Edinburgh and Central Scotland) with good transport links was likely to be economic.

The geology of the site shows that the Newbigging Sandstone Quarry exploited the Grange Sandstone, a particular sandstone formation that was quarried as a building stone at a number of localities nearby (e.g. Kilmundy, Grange and Cullalo quarries). At Newbigging Quarry itself there are a number of geological features that probably influenced the current shape of the quarry, and which could today limit the future expansion of the quarry and the quality of stone. A band of mudstone (shale) is present running along the northern boundary of the quarry (Fig. 5), today exposed in the upper part of the Dalachy quarry (Fig. 7). Although the mudstone bed is likely to be less than 10 metres thick, the quality of the adjacent sandstone is likely to be diminished in terms of both composition (i.e. the presence of mudstone material in the sandstone) and bed thickness. Expansion of the quarry northwards from its current face would have to take this mudstone bed into account; and its continuation as a plane gently dipping towards the north means it would be encountered over a considerable distance northwards. Fig 5 also shows the presence of a significant fault trending SW-NE approximately a hundred metres north of the quarry. The stone adjacent to the fault is likely to be fractured, and this could affect the quality of the sandstone in terms of block size; although the width of the zone of rock affected by shattering or groundwater flow around the fault is not known.

Petrographic analysis of samples of Newbigging sandstone shows that although it has a favourable uniform grainsize and relatively quartz-rich composition, it is relatively poorly compacted and has a poorly developed silica mineral cement. The last two factors mean that the sandstone grains are poorly bonded, making the stone weak and prone to disaggregation. Compared to other reputable building stone types which are similar in terms of composition, texture and appearance, the Newbigging sandstone shows significantly lower compaction and a less developed silica cement. These factors are likely to effect the performance of Newbigging sandstone as a building stone, making it less suitable than other stone types. Mechanical test results for Newbigging sandstone show that, in terms of tests indicating strength and durability, the values for Newbigging sandstone come out consistently low compared to other well-known sandstones.

It is difficult to reconcile the results from petrographic and mechanical testing which indicate the poor quality of Newbigging sandstone with the large size of the quarry and the (presumed) extensive use of the stone over a long period of time. It appears that although the stone is friable and subject to disaggregation when handled, it is 'stable' when in place in a building and appears to perform relatively well. It is possible that the main reason for quarrying the sandstone from this site in the first place was because of the pre-existing limestone quarries, rather than the exploitation of a top quality sandstone building stone.

9.2 Conclusions

Examination of samples and testing of Newbigging sandstone shows that the stone is relatively friable and has poor strength. This is due to a fundamental lack of compaction and poorly developed silica mineral cement. Other well-known building sandstone types are more compacted and/or have better developed mineral cement, making them stronger and more suitable as a building stone.

The geology of site indicates that expansion of the current Newbigging quarry is constrained to the north by the presence of a mudstone (shale) band and a fault to the north of the present main quarry face. The presence of these features and the likelihood of associated poor quality sandstone (smaller bed heights, increased fracturing etc.) may limit the presence of good quality sandstone in the ground immediately north of the quarry.

Historical evidence suggests that the sandstone at Newbigging is likely to have been quarried as a by-product of limestone mining. The quality of the sandstone may never have been high, but the prior existence of infrastructure (equipment, workforce, transport links etc.) and the expanding market for building stone at the end of the 19^{th} century, as well as the proximity to the markets in Edinburgh and Central Scotland, may have made quarrying of the sandstone commercially viable.

The combination of fundamentally poor-quality stone and the geological constraints in the current quarry mean that it is unlikely that Newbigging sandstone would be commercially viable as a building stone today. The current market is highly competitive and dominated by large scale operators in the north of England. Successful quarries need to able to produce stone that is versatile in order to supply a range of uses, and the high value products (e.g. large volumes of thin-cut cladding) are particularly demanding in terms of testing and consistency. It is felt that the potential market for Newbigging sandstone would be limited to the lower-value end of the market (e.g. rubble block), making extraction less cost-effective.

9.3 Further Comments

It is recognised that this study is based on analysis of relatively few samples and uses only a limited number of analytical and testing techniques. Despite this, based on the evidence available, it is considered unlikely the extraction of Newbigging sandstone as a building stone today would be profitable. This does not rule out other uses for the stone, particularly as it is a relatively pure high silica sandstone with a uniform fine sand grainsize. In these respects it differs from most other sandstones which could, for example, make it a suitable source of silica. Alternative uses for the sandstone have not been investigated in this report.

It is a possibility that sandstone previously quarried from Newbigging quarry was more durable and better quality than that seen today. An intensive survey of the quarry site was not carried out as part of this study, although detailed examination of a range of samples obtained over a long time period has shown that all the sandstone samples have similar characteristics. In general terms it is unusual for large differences in performance to be seen in stone from the same quarry. Even if high quality stone was present in certain beds it may still be uneconomic if the remaining stone cannot be marketed.

It is clear that a number of building stone quarries in the district exploited the Grange Sandstone. Although these have not been investigated in this study, it is logical to assume that the sandstone was of good quality. This suggests that other parts of the sandstone outcrop may be of better quality. It would be possible to undertake a geological investigation to identify adjacent areas where the sandstone is present, and by drilling (or examination of any surface exposures) determine the quality of the sandstone and the potential for opening a new quarry in good quality stone.

10. TERMS AND CONDITIONS

Geological observations and interpretations are made according to the prevailing understanding of the subject at the time. The quality of such observations and interpretations may be affected by the availability of new data, by subsequent advances in knowledge, improved methods of interpretation, and better access to sampling locations.

Raw data may have been transcribed from analogue to digital format, or may have been acquired by means of automated measuring techniques. Although such processes are subjected to quality control to ensure reliability where possible, some raw data may have been processed without human intervention and may in consequence contain undetected errors.

Detail which is clearly defined and accurately depicted on large-scale maps may be lost when small-scale maps are derived from them. The most appropriate techniques for copying original records are used, but there may be some loss of detail and dimensional distortion when such records are copied.

Although samples and records are maintained with all reasonable care, there may be some deterioration in the long term.

Data may be compiled from the disparate sources of information at BGS's disposal, including material donated to BGS by third parties, and may not originally have been subject to any verification or other quality control process.

Data, information and related records which have been donated to BGS have been produced for a specific purpose, and that may affect the type and completeness of the data recorded and any interpretation. The nature and purpose of data collection, and the age of the resultant material may render it unsuitable for certain applications/uses. You must verify the suitability of the material for your intended usage.

If a report or other output is produced for you on the basis of data you have provided to BGS, or your own data input into a BGS system, please do not rely on it as a source of information about other areas or geological features, as the report may omit important details.

The data, information and related records supplied in this report by BGS can only be indicative and should not be taken as a substitute for detailed site investigations and/or specialist interpretations, and other professional advice. You must seek professional advice before making technical interpretations on the basis of the materials provided.

REFERENCES

ASTM. 1995. Annual Book of ASTM Standards, section 4: Construction, volume 04.07 Building Seals and Sealants; Fire Standards; Building Constructions; Dimension Stone. American Society for Testing and Material, Philadelphia, USA.

British Standard 2000. BS EN 12407:2000 'Natural Stone Test Methods – Petrographic Examination'. British Standards Institution, London.

Browne, M.A.E. and Woodhall, D.G. 2000. Geology of the Kirkcaldy district. Sheet description of the British Geological Survey, 1:50,000 Series Sheet 40E Kirkcaldy (Scotland). 50pp.

Coupar, Rev. David. 1845. The New Statistical Account of Scotland: The Parish of Burntisland, vol. IX. William Blackwood and Sons, Edinburgh.

Forsyth, Robert. 1806. The Beauties of Scotland: containing a clear and full account of the agriculture, commerce, mines, and manufactures of the population, cities, towns, villages of each county. John Brown, Edinburgh.

Haldane, D. and Allan, J.K. 1931. The Economic Geology of the Fife Coalfields Area 1: Dunfermline and West Fife. H.M.S.O., Edinburgh.

Marshall, Peter. 2001. Burntisland: Fife's Railway Port. Oakwood Press, Usk, Gwent.

McMillan, A.A., Gillanders, R.J., and Fairhurst, J.A. 1999. Building Stones of Edinburgh, 2nd edition. Edinburgh Geological Society, Edinburgh.

Watson, J. 1911. British and foreign building stones. Cambridge University Press.

British Geological Survey Laboratories Test Services
Engineering Geology Laboratories

LABORATORY REPORT No. LJ 148

Compressive strength of a sandstone the Newbigging Quarry, Burntisland, Fife for the BGS.

By D C Entwisle

This report was
prepared for Ewan Hyslop,

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

1. Introduction

This is a factual report on the method and result of a compressive strength test carried for Ewan Hyslop, BGS Edinburgh. The sample, from the Newbigging Quarry, Burntisland, Fife, Scotland (NT 211 864) was supplied by L Albornoz, BGS, Edinburgh. The sample was received on the 19th January, prepared on the 20th and tested on the 21 January 2008. The summary of results is in Table 1.

2. Method

2.1 Compressive Strength

Method

The test technique was based on that described in ASTM (1995), test C170. A cylindrical core sample, nominal diameter of 50 mm, was cored from sample supplied. A sub-sample was cut and the ends surface ground so they were flat and parallel to within 20 µm. The test sample length was equal to or slightly greater than the diameter. The sample was air dry after preparation then weighed and measured. A 2000-kN compression machine was set up for the size of the specimen used and the load measured using a 330 kN load cell. Both platens had a Rockwell hardness of not less than HRC58 and 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.

Results

Uniaxial Compressive strength $\sigma_C = W/(1000 \times A)$ MPa (7)

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 Table 1.

Table 1. Uniaxial compressive strength results.

Sample	BGS collection number	Weight g	Dimensions, mm Length	Diameter	Nominal Density Mg/m^3	Load at failure kN	Time to failure secs	Compressive Strength MPa
EGLLJ148/A	MC5709	185.99	49.36	48.72	2.02	46.2	40	24.8

Air dried sample

Operator: David Entwisle
Date: 21/01/09