Liddle's Quarry, Orkney: a resource evaluation and assessment of past and possible future uses of extracted stone

Minerals & Waste Programme

Open Report OR/12/070

BRITISH GEOLOGICAL SURVEY

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Keywords

Liddle's Quarry, Orkney Islands, resource evaluation, sandstone, building stone, dimension stone, Stromness, Kirkwall.

Front cover

Stockpiled sandstone blocks in Liddle's Quarry.

Bibliographical reference

GILLESPIE, M R AND TRACEY, E A. 2012. Liddle's Quarry, Orkney: a resource evaluation and assessment of past and possible future uses of extracted stone. *British Geological Survey Internal Report*, OR/12/070. 39pp.

Keyworth, Nottingham British Geological Survey 2012

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Acknowledgements

The authors would like to thank Peter Bevan (Engineering Manager, Development and Infrastructure, Orkney Islands Council) and Stuart Taylor (Orkney Aggregates Ltd).

Contents

FIGURES

1 Introduction

This report describes the outcomes of a project to evaluate the stone resource at Liddle's Quarry, near Stromness on Orkney (Mainland), and to assess past and possible future uses of the quarried stone in the Orkney Islands. The client, Historic Scotland, has been asked by Orkney Islands Council to support it in its research into the continued feasibility of Liddle's Quarry.

The main street and side streets of Stromness were originally paved using natural stone flags, setts and kerbs in the mid 19th century. The paving imparts considerable character and charm to the town, but its condition and aesthetic quality had suffered as a consequence of the physical impact of vehicles and piecemeal replacement over the years by natural stone from other sources and by concrete slabs. Sections of the paved carriageway in Stromness were identified for renewal as part of the Stromness Townscape Heritage Initiative. An investigation by the British Geological Survey in 2008-9 (Tracey et al., 2012) confirmed that Liddle's Quarry, some seven kilometres south-east of Stromness, was the source of the original paving stone, and concluded that the stone still exposed in the disused quarry would be suitable for the planned re-paving work. Orkney Islands Council subsequently granted planning permission to re-open the quarry, and in 2010 Orkney Aggregates Ltd began to extract new stone. Since then, newly extracted stone has been processed at Heddle Quarry, near Finstown in the centre of Mainland, and used in the ongoing project to repave parts of Stromness.

Orkney Islands Council now wishes to consider potential future uses of the stone from Liddle's Quarry, in Stromness and potentially in other places in the Orkney Islands. This project, which has been funded by Historic Scotland and conducted by the British Geological Survey (BGS), was designed with the following objectives:

- conduct a detailed resource assessment of Liddle's Quarry
- identify sites where stone from Liddle's Quarry, and if applicable stone with similar characteristics sourced from other Orkney quarries, has been used
- assess how to maximise the use of Liddle's Quarry stone, within the context of current and possible future natural stone use on Orkney Mainland.

BGS staff (Gillespie and Tracey) visited Orkney in March 2012 to gather field and archive information relevant to the project.

A description and resource assessment of Liddle's Quarry, as it was at the time of the field visit, is presented in section 2 of this report. Past uses of stone from Liddle's Quarry in Stromness, Kirkwall, and the area around Liddle's Quarry are described in section 3. Possible future uses of stone from Liddle's Quarry are considered in section 4.

The project has been conducted under the Memorandum of Agreement (2011-2016) between Historic Scotland and NERC (as represented by BGS).

2 Liddle’s Quarry

2.1 LOCATION

Liddle’s Quarry [HY 310 066] is cut into a gently sloping, south-west facing hillside on the west flank of Gruf Hill in the parish of Orphir in the south part of Mainland in the Orkney Islands. The quarry lies geographically between Kirkwall and Stromness, which are the two largest towns on Mainland, and less than 2 kilometres from the shore of Clestrain Sound (Figure 1).

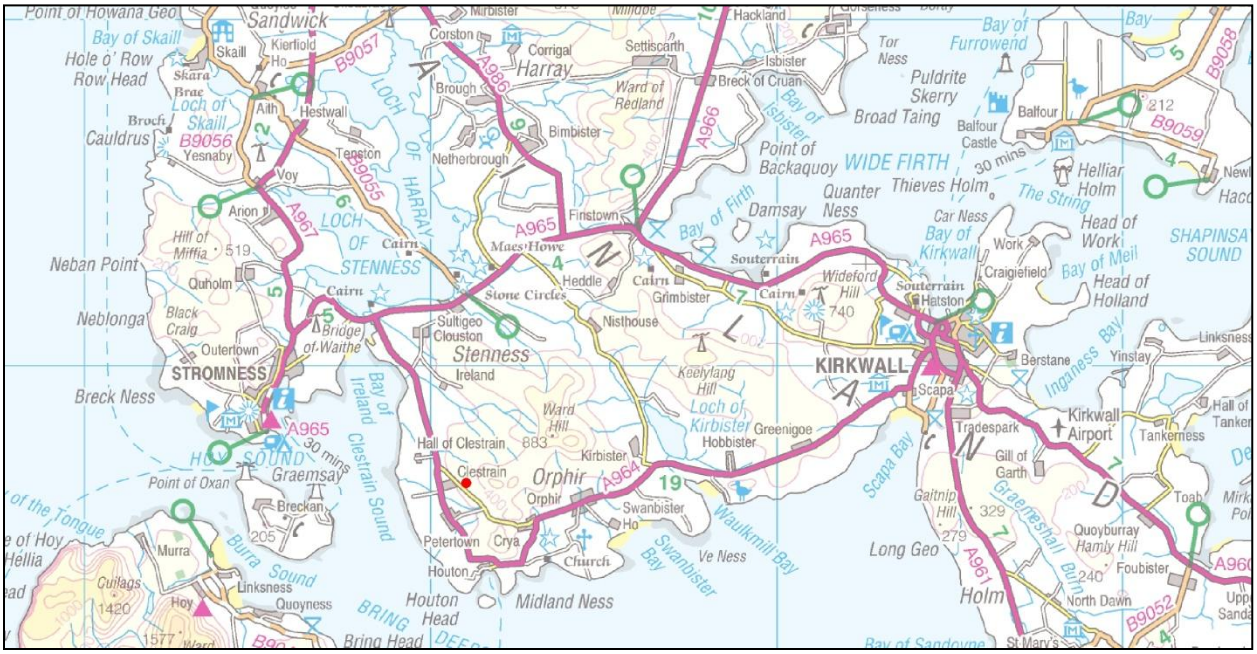

Figure 1 Ordnance Survey 1:250,000 scale topographical map of the southern part of Mainland (Orkney), showing most of the place names mentioned in this report.

Liddle’s Quarry position shown by red dot.

2.2 HISTORY

The first known record of quarrying activity in the parish of Orphir is in association with the construction of Balfour House, on Shapinsay, in 1847. Letters between David Balfour, the 4th Laird of Balfour and Trenaby, and Marcus Calder, his appointed factor, describe the difficulties of locating suitable building stone for the new construction. Letters in June 1847 describe a visit to the ‘Orphir quarries’ to locate suitable stone for Balfour House; the stone in Orphir was found to be too dark, so ‘Shapinsay Freestone’ together with stone from Tankerness and ‘the south’ were used instead (Record D2/15/7, Orkney Library and Archive, Kirkwall).

The ‘Plans of Clestrain’[1], which were surveyed by HR Sutherland in 1846 and are contemporary with the letters described above, do not show Liddle’s Quarry (Record D2/P1/1, Orkney Library and Archive, Kirkwall). Clestrain was surveyed again in 1873 by JD Miller of Kirkwall. The resulting ‘Plan of the lands of Clestrain and outfield pasture in Orphir and Stenness’ again does not show Liddle’s Quarry (Record D2/P1/16, Orkney Library and Archive, Kirkwall).

The first record of Liddle’s Quarry appears on the Ordnance Survey (OS) map of 1882 (Figure 2a); the quarry is represented as a poorly defined area with a working face and a crane on site. This first pit must therefore have been established sometime between the 1873 ‘Plan of the lands of Clestrain’ and the 1882 OS map.

[1] Clestrain is an area forming the part of the parish of Orphir that includes Liddle’s Quarry.

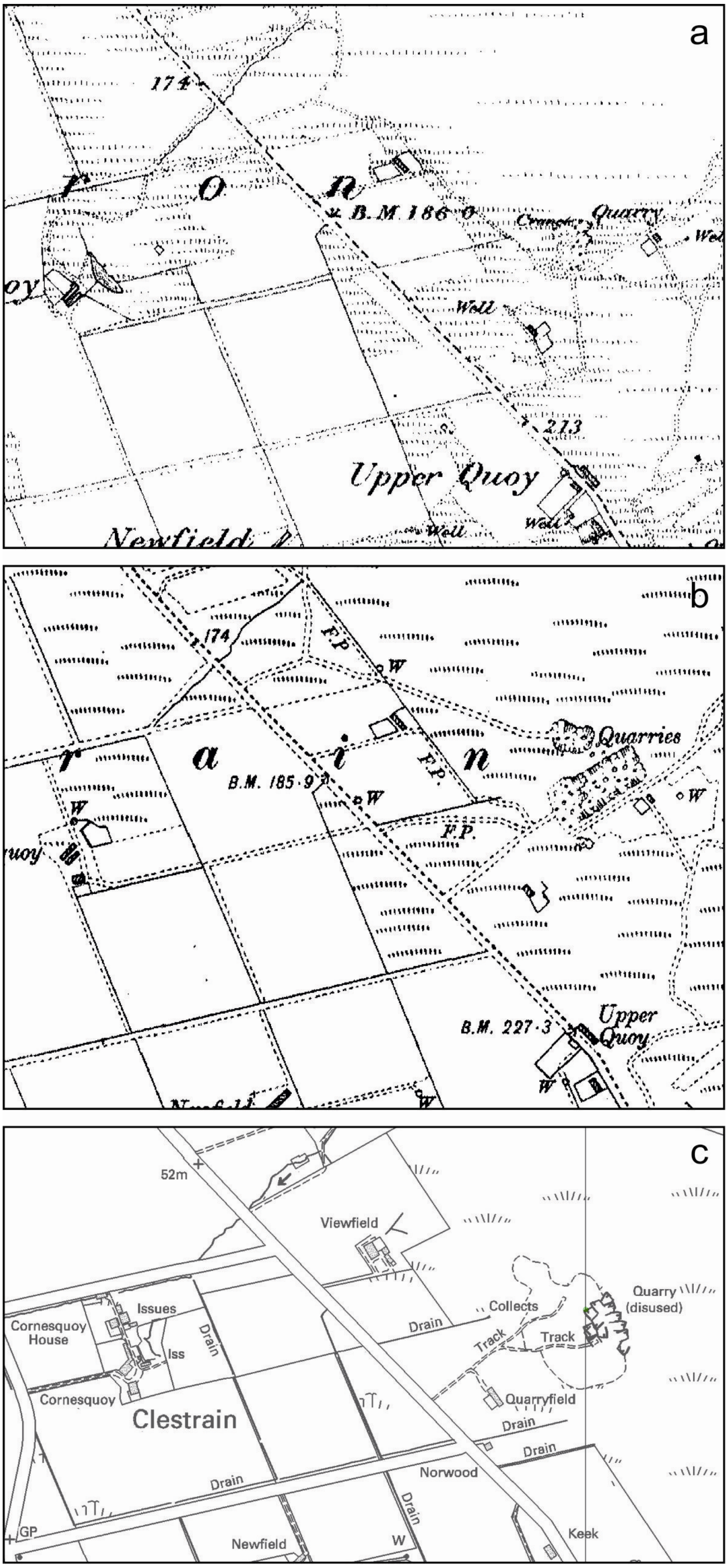

Figure 2 Historical Ordnance Survey maps of Liddle's Quarry surveyed at 1:10,000 scale. (a) 1882, (b) 1903, (c) current release. See text for details.

Comparison of the 1882 and 1903 OS maps (Figure 2) indicates that the original pit underwent significant expansion to the north-east between these dates, more than doubling in size. A second smaller pit also appeared during this period to the north of the original pit, at the end of a new track from the north-west. Both of these early OS maps show a track, building and well on the south-east side of the original pit within what appears to be a marked perimeter.

Liddle's Quarry is named after Marcus Liddle. Marcus Liddle is first mentioned in the 1891 Orkney Census as a farmer in Orphir. His father, Andrew was born in 1824 in Shapinsay. The Orkney Valuation Rolls show Marcus Liddle as occupier of 'Quarryfield' (see Figure 2c) from 1905 until 1926/7, and a published 'Contract between the Town Council of Stromness and Marcus Liddle' indicates that Liddle was operating the quarry in 1915. Given that Liddle lived in the area as far back as at least 1891 he may have operated Liddle's Quarry for a significant period at the turn of the century.

Descendants of Liddle have provided oral accounts in which they describe cart loads of stone being taken from the quarry in the early part of the 20th century to the nearby shore of Hoy Sound at Upper Sower [HY 293 061], from where it was transported by boat to Stromness. No records appear after 1927 to indicate that Liddle's Quarry was still in operation (see section 4 in Tracey et al., 2012 for additional historical references); it can therefore be assumed that quarrying ceased around this time.

The latest OS map (Figure 2c), which pre-dates the most recent quarrying, presumably shows the features of the site as they were when the quarry ceased operating (possibly late 1920s/early 1930s). The historical quarry faces (as represented in the 1903 map) are partially covered or obscured and a new pit has appeared to the south-east of the original pit, at the end of a track. The mapped outline of the worked area encompasses the ground formerly occupied by the building and well, which are no longer represented.

A recent aerial photograph (taken c.2007) shows Liddle's Quarry prior to re-opening in 2010 (Figure 3). Since 2010 the quarry has been worked intermittently by Orkney Aggregates Ltd.

Figure 3 Aerial photograph of Liddle's Quarry before quarry activity began in 2010.

The road at left is Scorradale Road. Quarryfield house sits just off the track connecting the road and the quarry. The quarry is substantially overgrown by heather (brown) and grass (green).

2.3 GEOGRAPHY

Liddle's Quarry today is dominated by a large pit (the most recently developed of the three pits described in section 2.2), and two smaller long-disused pits a short distance to the north-west. All three pits are contained within a broadly rectilinear boundary fence.

A map of the area within the boundary fence was prepared as part of this study (Figure 4). The following description, and the line work on the map, were correct at the time the quarry was examined for this study (March 2012). Subsequent activity in the quarry may have changed some aspects of the geography described below.

Around 40 metres north of the present access gate, two steep grassy banks around 5 metres high and at roughly 90 degrees to each other define two sides of a former pit (Pit 1 on Figure 4). This is likely to be the original pit that first appears on the OS map of 1882 (Figure 2a) and appears in expanded form on the 1903 OS map. The sides and floor of the pit are entirely vegetated, with no rock now exposed, and the pit has clearly been long disused.

To the north, a second pit (Pit 2 on Figure 4) takes the form of a rectangle of approximately 60 x 40 metres cut into the hillside. This is likely to be the second pit at Liddle's Quarry, which first appears on the 1903 OS map to the north of the original pit (Figure 2b). Bedrock is currently exposed in only two or three small sections of the back wall (Plate 1a). The highest rock face is 2 to 3 metres high, but the pit floor is occupied by mounds of old spoil and the real (bedrock) floor may be a metre or two deeper. Much of the spoil is concealed beneath heather, but some visible heaps of piled blocks suggest at least some of the mounds are size-graded (Plate 1b). Mounds of vegetated spoil flank the pit on its north-west and south-east sides, but heather and thin peat sit directly on soil and glacial till along much of the back wall. Old maps show a road accessing this pit from the north-west, but there is no sign of the road at ground-level today.

The youngest and largest of the three pits forming Liddle's Quarry (Pit 3 on Figure 4) has a less regular form than the two older pits. The pit is broadly circular in plan, and a worked rock-face can be traced for approximately three-quarters of the circumference (Figure 4). The height of the rock face ranges from essentially nothing at either end to a maximum of nearly 6 metres along its back wall. In the centre of the pit is an upstanding 'island' of unquarried, peat- and spoil-covered rock (Plate 1c). The island is bounded by two roadways: an old, overgrown track bounds its north-west side, while the south and east sides are bounded by the roadway that is currently used to access the quarry (Plate 1c). A small hut housing a well sits on the island, near its east side. The bedrock on which the hut sits (and the top surface of the island generally) is approximately 3.5 metres above the adjacent roadways. The well appears on the oldest OS map of the area (Figure 2a), sitting in unquarried ground east of the original (oldest) pit. The well therefore pre-dates Pit 3, which currently surrounds it; the island of rock on which the well now sits may therefore have been preserved in order to protect the well. Vegetated mounds of old spoil lie within and around the edges of the pit (Plate 1d), and cover parts of the island (Figure 4).

Recent quarrying activity at Liddle's Quarry (since 2010) has produced a number of changes in Pit 3 (Plate 2a-c), which include the following:

- the previously grass-covered access route has been re-established and is now a broad, level dirt track;
- a 2 to 3 metres high 'bench' of bedrock which previously connected what is now the island and the back wall of the pit has been quarried ;
- large mounds of fresh, new spoil fill the northern-most part of Pit 3, where the 'bench' previously existed (Plate 2d), and occupy ground to the south and east of the access roadway (Plate 3a); mounds of new spoil also cover much of the east side of the island, including ground around the well;
- the old rock faces have been re-worked in three areas on both sides of the access roadway (Figure 4);

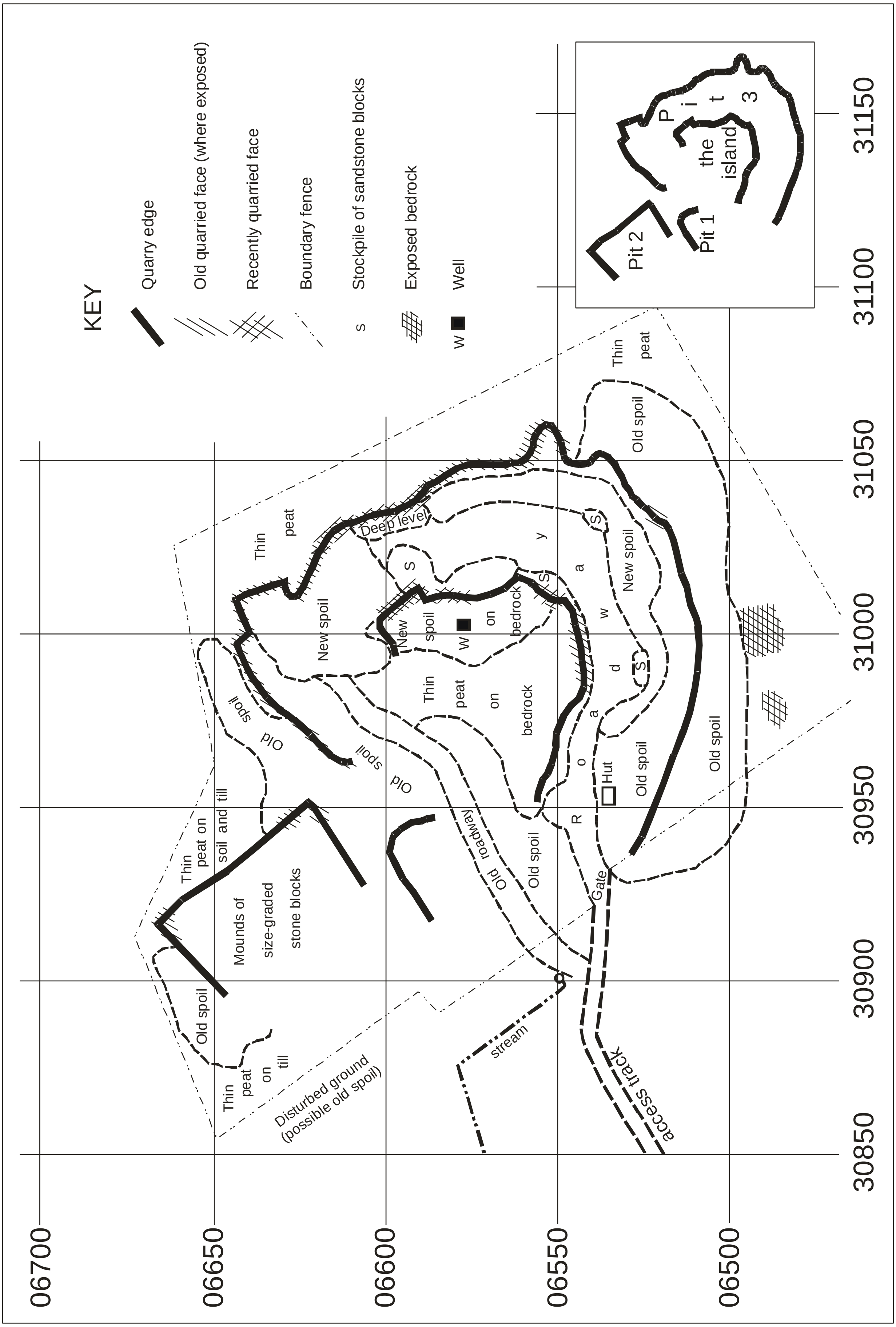

Figure 4 Map of Liddle's Quarry, March 2012.

Numbers are eastings (bottom) and northings (left). Squares are 50 x 50 metres.

- along a short section of the back wall, the pit has been excavated downwards as well as backwards into the rock-face; the resulting ‘deep level’ is approximately 2 metres below the level of the roadway, and contains standing water (Plate 3b).

The deep level is currently the deepest part of the entire Liddle’s Quarry site, and the newly worked back wall above it is currently the highest quarry face, at nearly 6 metres. The standing water is on bedrock; this is the only part of Liddle’s Quarry in which bedrock is currently exposed on the quarry floor.

The new spoil is not vegetated and is typically comprised of much larger stone blocks (up to 2 metres longest dimension) than most of the old spoil. The top surface of the large area of new spoil in the northern-most part of Pit 3 is 3 to 4 metres above the level of the access roadway. Limited space within the pit means a lot of spoil has to be moved in order to excavate, store and remove new stone.

Four separate piles of worked stone blocks (referred to below as ‘stockpiles’) sit on either side of the roadway in Pit 3 (Figure 4). The largest has a dog-leg shape and is around 40 metres long and 2.5 metres high (Plate 3c). The three others are significantly smaller. Each consists of piled blocks of fresh sandstone with maximum dimensions of around 3 metres long, 2 metres wide and 0.5 metre thick.

The exposed rock faces in Pit 3 display the different effects of historic and modern quarrying techniques. The old quarried faces are quite irregular and contain zones of radiating fractures which formed when explosive charges were used to detach new stone from the quarry wall. Recent quarrying has employed heavy machinery to prise blocks of rock from the quarry face, and this has produced large, regular, clean faces (Plate 2d).

2.4 DRAINAGE

The most obvious surface drainage in Liddle’s Quarry is a small stream, which issues from a culvert at [HY 30900 06548], around 10 metres west of the boundary fence and 20 metres north-west of the main entrance gate (Plate 3d; Figure 4). The stream dog-legs down-slope immediately below the quarry, cut in straight lines to form a ditch around 1 metre deep through thin peat and glacial till. A ditch cut parallel to, and a few metres from, the boundary fence marking the south-east limit of the site may have been dug to divert hillside run-off around the quarry. No other visible streams or ditches drain the quarry, but wet ground just within the boundary fence to the west of Pit 2 and Pit 1 highlights a zone of surface run-off from the quarry into the field below. Subsurface drainage through concealed spoil may be happening more generally beneath the south-western part of the boundary fence. The recent history of the well sited at the east end of the island is not known – it may have supplied water to the quarry in years gone past and may never have been a public water supply.

2.5 GEOLOGY

2.5.1 Rock character

All of the stone exposed in Liddle’s Quarry is sandstone. The stone is typically of mid grey colour (when dry and fresh), and it has in general a relatively homogeneous character. In detail, however, the stone commonly has a bedding lamination revealed by weakly coloured, closely spaced, bedding-parallel bands (Plate 4a). A description and photograph of the stone as viewed under the microscope is presented in Tracey et al. (2012). It is well sorted, quartz-rich, fine-grained sandstone (‘fine-grained’ denotes sand grains mainly between 0.125 and 0.25 mm diameter). The quartz sand grains have overgrowths of quartz, which bind the grains together making the fresh stone hard and cohesive. Carbonate minerals (probably mainly calcite [$CaCO_3$] and dolomite [$CaMg(CO_3)_2$]) and some clay form a mineral cement between the sand grains, and this means the fresh stone has very low porosity and permeability.

Very rarely, bedding-parallel zones up to around 10 cm thick of chemically altered, very pale yellowish-green 'bleached' stone are encountered (Plate 4b). These zones are likely to have formed where oxygen-rich water has moved through the rock at some time in the geological (not recent) past.

The sandstone was deposited in beds up to around 1.5 metres thick. Each bed represents a unit of sand that was deposited during broadly consistent conditions, and the boundary between two beds represents a change in the pattern of sedimentation. The sequence as a whole is cross-bedded; in other words, some beds contain inclined layers of sand (Plate 4c). Units in which the bedding lamination is parallel to the bed as a whole are likely to yield rectilinear blocks of stone, while those in which the bedding lamination is inclined with respect to the bed as a whole are likely to yield irregularly shaped blocks.

Some cut (sawn) surfaces of Liddle's Quarry sandstone show that parts of the sequence consist of small, tightly packed, irregularly shaped 'packets' of sandstone rather than simple, regular beds (Plate 4d). These sections may represent beds of sand that became disrupted after deposition, because the bed collapsed (slumped) or as water escaped under pressure from deeper in the sediment pile. This feature was not observed in the bedrock at Liddle's Quarry.

Curved and coiled grazing traces are a common feature on exposed bed surfaces (Plate 5a). These were produced by mobile organisms which fed at or near the sediment surface during relatively quiet periods in the depositional history of the sandstone. Some bed surfaces reveal thin gritty layers (Plate 5b) with scattered granules (<10 mm) of feldspar, quartz and rock fragments.

A layer of glacial till (poorly sorted, non-consolidated sediment deposited beneath an ice sheet during the last glaciation) up to around 1.5 metres thick overlies the sandstone bedrock (Plate 2d). The glacial till is in turn overlain by a thin layer of peat on which heather, grass and moss is growing today.

2.5.2 Stratigraphy

The sandstone exposed in Liddle's Quarry is part of the Upper Stromness Flagstone Formation, which was deposited between 398 and 385 million years ago in the Mid Devonian Epoch. The unit is a division of the Caithness Flagstone Group, which is in turn a division of the Old Red Sandstone Supergroup. On Orkney, the Caithness Flagstone Group is divided into the Upper Stromness Flagstone Formation and Lower Stromness Flagstone Formation. Together, these units consist of more than fifty cycles of very thinly bedded (laminated) siltstone and sandstone (Mykura, 1976; Trewin and Thirlwall, 2002). Cycles are typically 5-10 metres thick, and each one represents a fluctuation in the level of a large, shallow lake (the 'Orcadian Lake') that occupied the Orkney-Caithness area at this time. The cycles are usually dominated by siltstone (sediment with grain-size in the range 0.004 to 0.064 mm), with beds of sandstone (sediment with grain-size in the range 0.064 to 2 mm) typically being thin and subordinate. The sandstone unit exposed in Liddle's Quarry is at least 6 metres thick, which is considerably thicker than is typical of the Caithness Flagstone Group as a whole. However, sandstone beds are known to be thick and laterally persistent in the lowest cycles of the Upper Stromness Flagstone Formation (Mykura, 1976).

2.5.3 Discontinuities

Discontinuities are features that interrupt or terminate the continuity of rocks and other geological materials. The most common discontinuities are fractures, which consist of two main types: joints and faults. Discontinuities play an important role in building-stone quarries; their distribution and orientations determine how easy it is to extract stone blocks from the bedrock, and they control the maximum size and the shape of dimension stone blocks.

Joints

Joints (fractures along which the rock has parted by simple opening displacement) are by far the most common type of geological discontinuity at Liddle's Quarry. Even so, they are relatively sparse compared to many rock masses. All the joints in the quarry are interpreted to have formed when the previously buried and compressed stone relaxed as uplift and erosion brought it towards the ground surface. Two categories of joints are recognised in the quarry.

- *Bedding joints* form parallel to, and exploit, bed surfaces. The bed surfaces in a unit of sandstone are usually near-horizontal at the time the sand was deposited, so bedding joints will also usually be near-horizontal when the rock is quarried, provided the rock mass has not been tilted or folded significantly since deposition. At Liddle's Quarry, bed surfaces typically dip gently (10-20 degrees from horizontal) towards north-west (Plate 1a), and bedding joints have the same orientation. The ground surface around Liddle's Quarry is essentially parallel to bedding joints in the bedrock; hence, the orientation of bedding joints appears to have controlled the evolution of the ground surface on this flank of Gruf Hill.
- Other joints in Liddle's Quarry have not exploited pre-existing planes of weakness (such as bedding) in the rock – instead, their orientations reflect the principal stresses acting on the rock mass as it was uplifted in the geological past. They tend to be steeply inclined (near-vertical), and are referred to hereafter as *steep joints* to distinguish them from the gently inclined bedding joints. Forty-five measurements of steep joint orientations from pits 1 and 3 are presented in Table 1 and plotted in Figure 5. The measurements reveal that steep joints in Liddle's Quarry are dominated by two groups of near-parallel joints (i.e. two 'sets'): one trending NE-SW and one trending NW-SE. The steep joints forming each set are typically spaced several metres apart, which is a relatively wide spacing for rock at outcrop (Plate 5c).

Faults

Only one feature that may represent a minor fault (i.e. a fracture along which lateral, or 'shearing', displacement has occurred) was observed in Liddle's Quarry, in a low cliff face bounding the north-east side of the island in Pit 3 ([HY 31009 06596]). The feature consists of several closely spaced, near-vertical, sub-regular to anastomosing fractures around which the sandstone is noticeably decomposed (Plate 5d). This structure is part of a zone 3 to 4 metres wide of somewhat irregular fractures and unusually small block size. No clear evidence for shearing displacement was observed, but the density of fractures and the decomposed character of the adjacent sandstone suggest the feature may be a weak fault. The structure is exposed on a vertical cliff face and its orientation is difficult to judge; it appears to be trending towards 075° (ENE).

2.5.4 Minerals formed in joints

Open joints are pathways along which fluids can move through a rock mass. Depending on its chemical character, water moving through joints can deposit minerals or dissolve minerals in the joints.

Iron sulphide minerals

Traces of fresh, greenish iron sulphide mineralisation are preserved on some joint surfaces in Liddle's Quarry. This is probably mainly pyrite (FeS_2), but some chalcopyrite, ($CuFeS_2$) may also be present. These minerals commonly form as a patchy veneer on joint surfaces (Plate 6a); however, close inspection of some joint surfaces also reveals mm-scale cubic moulds indicating that small euhedral crystals of pyrite were formerly present but have weathered out.

Table 1 Orientation measurements for steep joints in Liddle's Quarry.

Grid reference	Location	Dip amount	Trend (strike)
HY 30908 06652	Farthest north corner of Pit 2.	90	067
		90	125
		90	031
HY 30942 06632	Farthest SSE part of Pit 2.	90	134
		90	068
HY 30944 06621	Farthest SSE part of Pit 2.	80	246
HY30995 06542	South edge of the island, Pit 3.	80	254
		80	310
HY 31008 06554	South-east edge of the island, Pit 3.	80	255
		90	043
HY 31006 06579	East of the well building, Pit 3.	85	310
HY 31008 06556	East edge of the island, Pit 3.	80	058
		90	123
		85	277
		85	195
HY 31014 06593	North-east edge of the island, Pit 3.	80	237
		90	123
		80	240
HY 30981 06629	North edge of Pit 3.	85	313
		80	066
HY 30991 06634	North edge of Pit 3.	90	057
		90	124
HY 31001 06632	North edge of Pit 3.	85	306
		80	207
		75	238
HY 31012 06629	North-east edge of Pit 3.	85	311
		80	047
		85	078
HY 31026 06613	North-east edge of Pit 3.	90	037
		90	128
		68	065
HY 31032 06610	North-east edge of Pit 3.	80	058
		90	127
		80	210
HY 31030 06598	North-east edge of Pit 3.	80	190
		90	059
		90	134
HY 31031 06591	North-east edge of Pit 3.	75	190
		90	093
		80	127
HY 31040 06576	East edge of Pit 3.	90	134
		90	008
HY 31050 06548	East edge of Pit 3.	90	008
		90	121
		90	090

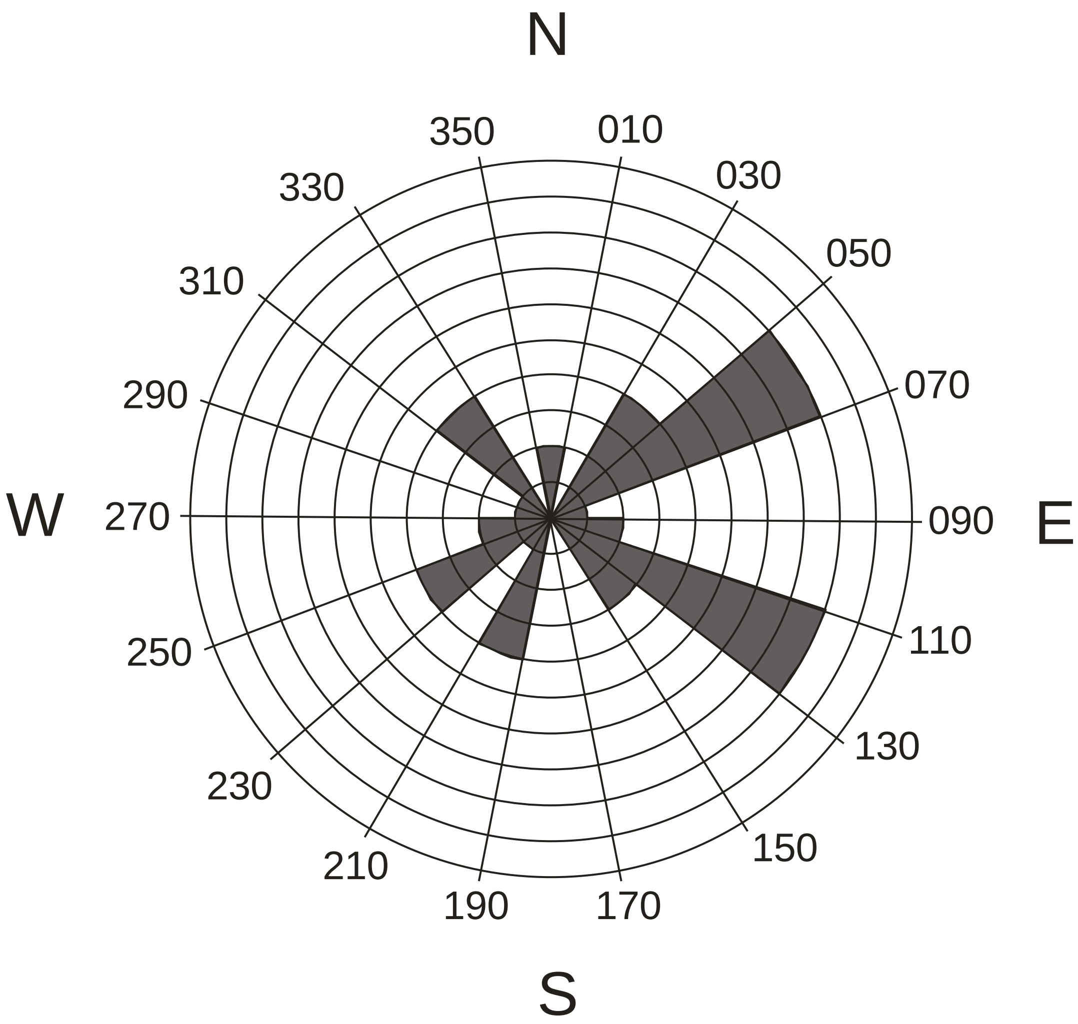

Figure 5 Orientation patterns of steep joints in Liddle's Quarry.

In this 'rose diagram', the concentric circles represent number of measurements (innermost circle = 1 measurement, outermost circle = 10), and the numbers represent degrees on a compass. Dark grey areas represent the data; for example, eight of the forty-five measured joints have strike (trend) orientations between 050° and 070°. The diagram reveals two main sets of steep joints: one trending NE-SW and one trending NW-SE.

Iron and manganese oxyhydroxide minerals

Most of the open or exposed joint surfaces in Liddle's Quarry are coated by a veneer of light to dark orange and brown iron oxyhydroxide minerals (probably mainly goethite [FeOOH]) (Plate 6b). These are sometimes preserved as thin, colloform (cauliflower-shaped) patches (Plate 6c) which probably formed by direct replacement of iron sulphide patches like those in (Plate 6a). Discontinuous veneers of black manganese oxyhydroxide minerals have also developed on some joint surfaces, but these are much less common and less abundant than the orange-brown iron oxyhydroxide. The oxyhydroxide minerals formed in the geologically recent past, as uplift and erosion brought the rock near to the ground surface. This allowed oxygen-rich surface water (rainwater) to penetrate along the joints, causing the iron sulphide minerals to oxidise and decompose. This is effectively a process of 'rusting', and the iron released from the sulphide minerals has re-coated the joint surfaces as ochre-coloured iron oxyhydroxide minerals. These minerals have commonly been deposited in several layers, suggesting they formed in a number of discrete episodes.

Liesegang bands (parallel and often concentric, coloured bands of iron oxide/oxyhydroxide minerals that typically cut across bedding in sandstone) are commonly developed parallel to the surfaces of bedding joints and steep joints in Liddle's Quarry, extending up to several centimetres into the fresh stone (Plate 6b and Plate 6d).

Carbonate minerals, such as calcite ($CaCO_3$) and dolomite ($CaMg[CO_3]_2$), form much of the mineral cement in Liddle's Quarry sandstone (see section 2.5.1). These minerals are prone to dissolve in contact with rainwater, and release small quantities of iron and manganese as they dissolve. Some of the iron and manganese oxide mineralisation that now coats open joint surfaces in the quarry has probably formed because rainwater moving through the joints has dissolved carbonate minerals in sandstone adjacent to the joints.

Rare, thin veins of calcite have developed locally along bedding joints and very rarely cut through the sandstone.

2.5.5 Development of flaggy sandstone

Sandstone with a 'flaggy' character (i.e. that breaks naturally, or can easily be broken, to form slab-like blocks with one short (<10 cm) dimension, suitable for paving) is a feature of only the shallowest 1 to 1.5 metres of bedrock in Liddle's Quarry; i.e. the zone of bedrock immediately beneath the covering of glacial till and peat. In this zone, the near-absence of overlying rock for the past several thousand years has allowed the sandstone to relax, or 'unload', such that it has parted, or begun to part, along closely-spaced, sub-parallel bedding joints, developing a 'flaggy' character (Plate 7a). Beneath this zone the weight of overlying rock has prevented the stone from relaxing in this way; partings along bedding joints are therefore still relatively widely spaced (typically 10-40 cm) and the sandstone therefore does not have a flaggy character (Plate 7b). The quarry does not contain the well known 'Caithness style' flagstone (which is laminated siltstone rather than flaggy sandstone).

In a previous study of Liddle's Quarry, the bedrock is depicted as consisting of two thin (1 to 1.5 metre thick) units of 'flags' (i.e. flaggy sandstone) separated by a 4 metre thick bed of non-flaggy sandstone (see Map 5 and Map 6, prepared by John Brown [local Orkney geologist] in Tracey et al., 2012). The 'upper flags' unit described in that study corresponds to the zone of flaggy sandstone forming the shallowest 1 to 1.5 metres of bedrock described in this study, but no evidence has been found in this study for a second, deeper unit of 'flags' below a thick unit of non-flaggy sandstone.

2.6 RESOURCES

As part of this resource assessment of Liddle's Quarry estimates have been made of the amount of material already extracted and of the amount of remaining exploitable sandstone. The results given below are intended to be indicative only. Geological and/or technical issues that could limit further exploitation have also been identified.

The figures given below are based on the following observations and estimates, which are in turn based on field observations and the new map of Liddle's Quarry (Figure 4):

- the boundary fence encloses an area of approximately 27,500 m^2 (0.0275 km^2);
- bedrock has been extracted from ground underlying approximately 17,500 m^2 (equivalent to seven 50x50 metre squares on the map);
- unexploited bedrock underlies approximately 10,000 m^2 (equivalent to four 50x50 metre squares on the map);
- the bedrock geology is essentially consistent in all parts of the site, and there is nothing to indicate that the character of the bedrock changes significantly in any part of the site within the exposed depth range.

2.6.1 Flaggy sandstone

All of the flaggy sandstone within the quarried parts of the site has been extracted. Elsewhere, a layer of flaggy sandstone up to one metre or so thick is likely to exist beneath the spoil and natural superficial deposits within the area defined by the boundary fence and on the hillside beyond. For the purposes of this assessment, the layer of flaggy sandstone is assumed to be on average one metre thick across the site.

Based on these considerations and the figures above, the volume of exploited flaggy sandstone within the area of the boundary fence is approximately 17,500 m^3 and the volume of remaining flaggy sandstone within the boundary fence is approximately 10,000 m^3. In practice, the volume of recoverable, useable flaggy sandstone is likely to be significantly smaller due to operational constraints and waste. Neither of these factors has been constrained accurately for this study, but nominal figures of 70% and 40% respectively (i.e. only 70% of the potential volume is recoverable and only 40% of that consists of commercially viable flaggy sandstone) would imply a recoverable volume of 2,800 m^3 of flaggy sandstone.

2.6.2 Non-flaggy (massive) sandstone

Field observations have shown that massive sandstone (i.e. all the rock beneath the near-surface zone in which flaggy sandstone occurs) is largely homogeneous in all parts of the quarry where it is exposed, including the deepest part of the quarry. The recoverable volume is therefore not obviously limited by geological factors. The following calculations assume the water table (see section 2.6.4 below) presents the main practical/technical limit to exploitation. The figures below also assume that:

- in quarried parts of the site, bedrock (flaggy and massive sandstone) has been extracted to an average depth of 4 metres;
- the layer of massive sandstone between the base of the flaggy sandstone and the water table is on average four metres thick across the site.

Using these figures, the volume of exploited massive sandstone within the area of the boundary fence is approximately 52,500 m^3 and the volume remaining is approximately 57,500 m^3. As with the flaggy sandstone, the volume of recoverable, useable massive sandstone will be reduced by operational constraints and waste. Again, neither of these factors has been measured accurately for this study, but nominal figures of 70% and 60% respectively (i.e. only 70% of the potential volume is recoverable and only 60% of that consists of commercially viable massive sandstone) would imply a recoverable, useable volume of 24,150 m^3 of massive sandstone.

2.6.3 Spoil

Liddle's Quarry currently contains a substantial volume of spoil (Figure 4), which is made up largely of sandstone blocks. In general, mounds of old spoil (dating to earlier phases of quarrying activity) consist of relatively small blocks of stone, though some mounds in Pit 2 consist of relatively large blocks (Plate 1b). Mounds of new spoil, which have been moved by machine, include much larger blocks reaching up to 2 metres in longest dimension. The spoil mounds contain a substantial volume of stone, some of which might have a commercial value if it can be matched to a suitable use. Weathering is likely to have reduced the quality of the stone to some degree, particularly in the mounds of old spoil.

2.6.4 Geological and technical factors that could limit further exploitation

The bedrock geology is consistent and essentially homogeneous in all parts of Liddle's Quarry where it is exposed, including the deepest part of the quarry. Only one minor fault was identified within the site, and BGS geological maps reveal no nearby faults or changes in bedrock lithology that might reduce the quality of the stone or limit quarry expansion. Further extraction of snadstone is therefore not obviously limited by geological factors. Other factors that might limit further exploitation at the site include:

- *the water table* - the deepest part of the recent quarry excavation contained standing water throughout the four days of this field visit; if this represents the level of the water table then exploitation below this level will require pumping; however, the standing water sits directly on low permeability bedrock and may simply be unable to drain;
- *spoil* - the quarry contains a substantial volume of spoil, and large mounds of spoil restrict access to rock faces and the bedrock floor in much of the site; additional new spoil will be generated if quarrying operations continue, and the cost of moving the spoil may affect the commercial viability of the quarry;
- *power line* – a row of pylons carrying power lines runs roughly north-west–south-east some 60-80 metres ENE of the north-eastern part of the boundary fence (Plate 7c); the power lines, or more specifically a 'protected zone' around them, may limit the extent to which the quarry could be extended towards the north-east.

2.7 ENVIRONMENTAL IMPACT

A brief assessment has been undertaken of the current environmental impact of Liddle's Quarry (primarily in terms of visual impact) and of the degree to which further quarrying activity might impact on the environment (visually and otherwise).

2.7.1 Current environmental impact

Liddle's Quarry is cut into a west-facing hillside at an elevation of approximately 90 metres OD. Gruf Hill (189 metres OD) rises to the east of the quarry, and the quarry might be visible from its higher slopes. However, the almost total lack of human presence in this area of uninhabited hill and moorland means the visual impact from this side is negligible.

South, west and north of the quarry the ground consists of sparsely inhabited farmland traversed by two public roads: the A964 (a quieter alternative to the busy A965 linking Stromness and Kirkwall) and the C-class 'Scorradale Road" which runs below the quarry on its west side in a rising traverse southwards towards Scorra Dale pass. All sightlines towards the quarry from the west and north are from lower elevations, so a slightly irregular skyline created by mounds of old spoil is the only visual evidence of the quarry from these areas (Plate 7d and Plate 8a). South of the quarry, the Scorradale Road rises to an elevation of 113 metres OD, but the curve of intervening hillsides means the quarry cannot be seen from the road (Plate 8b).

The town of Stromness faces south-east across Hoy Sound towards Clestrain and Liddle's Quarry, but the distance (~6.5 km) between the two is such that the quarry is essentially not visible to the naked eye from the town.

The quarry may be visible from the island of Graemsay, the closest part of which is ~4 km west of the quarry and separated from Mainland by Clestrain Sound. The island has a small permanent population, but again the distance to the quarry is such that its current visual impact is likely to be negligible.

2.7.2 Potential environmental impact of future quarrying activity

Visual impact

Quarrying more flaggy sandstone would require moving old spoil heaps and/or stripping vegetation and superficial deposits from the surface of unquarried parts of the site, then working the stone immediately beneath; such activity is likely to be visible from parts of the surrounding area.

The focus of recent quarrying activity has been massive (non-flaggy) sandstone. Removing more massive sandstone from the existing quarry faces will have negligible visual impact on the surrounding area, as the faces are below sightlines from all directions other than east.

Water quality

Recent quarrying activity in Liddle's Quarry has opened joints in the rock that are mineralised by metal sulphide minerals (probably mainly pyrite, and possibly also chalcopyrite and others). These minerals oxidise on exposure to air or rainwater. This process has created much of the orange iron oxyhydroxide mineralisation that coats and colours the fresh joint surfaces exposed on the quarry walls. It also releases other metal ions (which can include arsenic, copper, lead and zinc) that can be contained in small quantities in the iron sulphide minerals, and lowers the pH (i.e. raises the acidity) of water passing through or across the joints. Acidified water is able to transport much higher concentrations of metal ions than non-acidified water. This problem, which is common in old mining areas, is known as acid mine drainage, and where it occurs metal concentrations can reach toxic levels. There clearly isn't a lot of metallic mineralisation associated with Liddle's Quarry (compared with, say, an ore deposit), and any such problem is therefore likely to be mild. However, if quarrying activities (working quarry faces and/or moving spoil) continue or are increased it may be prudent to test the water in the stream draining the main part of the quarry at periodic intervals to monitor its chemical composition and quality.

Dust, noise and vibration

The recent activity in Liddle's Quarry has utilised machinery rather than blasting to extract new blocks of stone. The blocks have been transported to Heddle Quarry, near Finstown (around 16 kilometres by road from Liddle's Quarry), for processing. Spoil has also been moved using machines. According to the quarry operator (Orkney Aggregates Ltd), at the time of this site visit (March 2012) approximately 1,800 metric tonnes of raw stone had been extracted from the quarry in the previous two-year period. A further 1,500 tonnes was still required at that time to complete the repaving of Stromness and for a proposed new project to regenerate/reconstruct the pierhead in Stromness. These quantities of stone are small compared to a typical aggregate quarry, and the quarrying activity at Liddle's Quarry has been (and is likely to be) periodic rather than continuous.

The extraction methods used at Liddle's Quarry do not generate significant amounts of dust or noise, and they are employed largely below the level of the surrounding ground surface. The house at Quarryfield, which is less than one hundred metres from the quarry entrance, will to a small extent be affected by dust, noise and vibration caused by vehicles entering and leaving the quarry, and may also be subjected to some noise associated with quarrying. Otherwise, at the current levels of activity and with the methods currently being used, dust, noise and vibration related to quarrying activity should have negligible environmental impact.

3 Past uses of Liddle's Quarry stone in Orkney

3.1 STROMNESS

Historical and geological evidence reported in Tracey et al. (2012) showed that Liddle's Quarry was the source for the historical paving slabs, central setts and kerbstones used in Stromness. The first Stromness paving scheme (Phase 1) was implemented during the mid- to late-19th century. The stone was sourced from Liddle's Quarry.

The Phase 1 paving began at the road in front of Stromness Hotel at Pierhead (R.H. Robertson photographic archival records, 1898-1912, Stromness Museum Archives). At this time, Pierhead was paved using setts. South of Pierhead, the historical paving stone continued down Victoria Street (as paving slabs, central setts and kerbstones) to South End. North of Pierhead, only the sidewalk forming the west side of the main road was paved using Liddle's sandstone. This sidewalk terminated at the end of John Street.

Two other phases of paving in Stromness were identified in Tracey et al. (2012). Phase 2 took place in the mid-20th century and Phase 3 in the late-20th century. Neither phase used paving stone sourced from Liddle's Quarry, and both resulted in some loss of the historical (original) paving stone. By 2008 the historical paving on road surfaces remained only between Alfred Street and South End (Plate 8c). However, original sidewalk paving and kerbstones (Plate 8d) were still present in many parts of the conservation area at the time of the survey.

Several other historical uses of stone probably sourced from Liddle's Quarry were identified in Stromness by Tracey et al. (2012). These include stone stairs and stone paths (Plate 9a), and street furniture such as stone benches (Plate 9b). More recently (as part of the ongoing Stromness Townscape Heritage Initiative), Liddle's sandstone has been used to replace historical skews on the roofs of houses in Stromness (Plate 9c); it is not clear if the original skews also employed stone sourced from Liddle's Quarry.

Sandstone blocks have been used to construct large parts of the old harbour walling at Pierhead (Plate 9d). The weathered sandstone surfaces have similar characteristics to Liddle's sandstone, but there is insufficient evidence to state conclusively that the stone was sourced from Liddle's Quarry. A detached building on Pierhead has sandstone walling which in general has characteristics similar to Liddle's sandstone (Plate 10a). However, the stone contains rare iron rich nodules (Plate 10b), which have not been observed in Liddle's Quarry (in either the bedrock or in spoil). The presence of the nodules means either that the stone was not sourced from Liddle's Quarry, or that nodule-bearing sandstone was extracted in the past from Liddle's Quarry (perhaps restricted to just a single bed of sandstone) but is no longer exposed.

3.2 KIRKWALL

3.2.1 Buildings

Oral accounts provided by descendants of Marcus Liddle (occupier and operator of Liddle's Quarry around the turn of the 20th century; see section 2.2) have indicated that 6-10 West Tankerness Lane in Kirkwall is constructed of sandstone from Liddle's Quarry. The site is a two-storey terrace made of ashlar blocks with a rough natural (occasionally stugged) finish laid in diminishing courses (block height generally reduces with elevation in the front facade walling; Plate 10c). Some blocks are notably long – up to ~3.5 metres. Block lengths and heights are broadly similar to those of the newly stockpiled blocks in Liddle's Quarry (Plate 3c).

The stone is fine- to medium sandstone, which is in general massive but in detail has centimetre-scale parallel-bedding (lamination). Orange Liesegang bands are commonly developed parallel, and adjacent, to one or two of the surfaces in many blocks. These surfaces were probably natural partings (joints) in the stone that were exploited by the mason. In all the above respects the stone is similar to Liddle's sandstone. However, many of the blocks in the Tankerness Lane buildings are characterised by clusters of centimetre-scale iron nodules with 'rusty' stains around and below them (Plate 10d). Similar iron nodules were observed in sandstone walling of a building at Pierhead in Stromness (Plate 10b). They have not been observed in Liddle's Quarry, but as noted in section 3.1 they may have been a feature of one or more sandstone beds that have been extracted and no longer crop out in the quarry.

Exposed (weathered) stone surfaces are buff with a greenish-grey tinge, but rare surfaces of fresher stone (exposed in chipped block edges) are light grey and reveal a speckled character due to fine, scattered black to reddish grains.

3.2.2 Paving

Flaggy sandstone with characteristics similar to Liddle's sandstone is still present as sidewalk paving on a number of streets in Kirkwall. These include: the north side of West Tankerness Lane, immediately in front of the terrace forming numbers 6-10[2] (Plate 10c); both sides of the A960 (the main road into Kirkwall from the south) between Palace Road and Bignold Park (Plate 11a); a short section at the junction of George Street and St. Rognvald Street; at Orkney Arts Theatre on Mill Street; several lanes and closes around Albert Street and Bridge Street (here the paving can occupy the whole carriageway).

3.3 OTHER PARTS OF SOUTHERN MAINLAND

A rapid survey of roadside structures in southern Mainland was conducted in March 2012 to determine whether Liddle's sandstone has been used more widely in this part of Orkney. The survey encompassed all of the main roads south of Hestwall and west of Kirkwall.

A number of structures made of Liddle's sandstone (or very similar sandstone) were identified. These are concentrated along the A965 between Bridge of Waithe [HY 281 113] and Rennibister [HY 397 124], and along the A964 between Bridge of Waithe and the village of Orphir.

All of the main elements of Bridge of Waithe (piers, walling, arches and copestones) are made of sandstone (Plate 11b). The bridge was not examined in detail, however the sandstone appears to be closely similar to Liddle's sandstone. The copestones on the bridge walls have a distinctive character, with keystone blocks forming curved terminations at either end.

Several other bridges along the A965 have flagstone walling and dressed sandstone copes. The walling is clearly not Liddle's sandstone, but the copestones may be Liddle's sandstone. Good examples of such bridges occur at Tormiston (one bridge), and between Cursiter [HY 380 127] and Rennibister (three bridges).

Several fence posts (Plate 11c), bridges (Plate 11d) and milestones (Plate 12a) along the A964 are made of sandstone that is essentially similar in character to Liddle's sandstone. Given the proximity of this stretch of roadway to Liddle's Quarry, there is a good chance that the stone was sourced from the quarry.

A war memorial in the village of Orphir has walling and a stepped base made of sandstone that may have been sourced from Liddle's Quarry (Plate 12b). A house in Orphir has a small amount of visible sandstone walling on the front elevation and, while it was not possible to examine the stone closely, its general characteristics and relative proximity to Liddle's Quarry suggest it may have been sourced from there (Plate 12c). This is the only recorded example outside Kirkwall and Stromness where Liddle's sandstone may have been used in the walling of buildings.

Other than in Stromness, no structures made of Liddle's sandstone (or Liddle's-like sandstone) were identified west of Bridge of Waithe and north of the A965.

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[2] The sandstone paving on this side of West Tankerness Lane extends further along the lane than the terrace, which may indicate that more buildings with Liddle's sandstone walling once existed on West Tankerness Lane.

4 Possible future uses of Liddle's Quarry stone

The fresh stone extracted from Liddle's Quarry is broadly uniform, strongly cohesive, and largely impermeable mid-grey sandstone which typically develops a buff (yellowish-brown) colour on weathered surfaces. Natural (joint) surfaces are typically coated with ochreous orange to brown iron oxyhydroxide minerals. Orange to brown Liesegang bands have also formed locally in some parts of the stone adjacent to joints. The shallowest 1 to 1.5 metres of bedrock develops closely spaced bedding joint partings which give the stone a flaggy character. Beneath this shallow zone, the rock has a massive (non-flaggy) character, with relatively widely spaced bedding joints and steep joints. As a result, blocks of massive sandstone extracted from the quarry tend to be quite large (up to several metres long and half a metre or more thick). A compressive strength value of 94.8 MPa places Liddle's sandstone in the middle of the range (50-132 MPa) displayed by other UK sandstones that are commonly used for paving (Tracey et al., 2012). We are not aware of any other geotechnical test results for Liddle's sandstone.

The stone does not have a distinctive geological character or aesthetic quality, or geotechnical advantage, and is therefore unlikely to be sufficiently commercially attractive to find a market outside Orkney. However, the fresh stone should provide a good quality, durable building stone with a wide range of potential uses. As indicated in section 3 of this report, Liddle's sandstone has historically been used for a range of functions across Orkney Mainland, including paving (flagstones, setts and kerbs), steps, street furniture, skews, walling, dressings, copestones, milestones and fence posts. We have seen no indication that the stone has performed poorly in any of these settings, and there is therefore no reason to think it would not be suited to all of the above (and similar) uses in future[3].

However, the following points should be noted.

1. Most sandstones used as building stone are more permeable than Liddle's sandstone. The very low permeability of fresh Liddle's sandstone should add to its durability, and its ability to withstand salt-affected weathering (see below). However, it also means the stone will not transmit moisture easily (i.e. it will not 'breathe'). As such, in masonry, Liddle's sandstone should not be placed adjacent to other sandstone that is significantly more permeable. For example, it should not be used as the replacement stone in repairs to a building made of more permeable sandstone, because the impermeable Liddle's stone may stop moisture escaping from adjacent blocks of more permeable stone, leading to accelerated stone decay in those blocks. Additionally, if Liddle's sandstone is used as the walling in new buildings, consideration should be given to providing adequate ventilation (e.g. vents through the wall, and/or the use of a permeable mortar) that will prevent moisture from accumulating within the building.

2. Many sandstones can suffer accelerated decay when they are used in an environment containing salt (this includes the sodium chloride [NaCl] salt found in seawater and commonly used to keep roads and pavements free of ice, and other naturally occurring salts). The salt enters the pore structure of stones dissolved in water or water vapour, and crystallises in the pores as the moisture dries out. Salt crystals expand as they grow, and the growing crystals can prise apart the constituent grains in sandstone, causing the stone to suffer granular disintegration and accelerated decay. Coastal environments (which essentially includes the whole of Orkney) and carriageways (and adjacent buildings) where road salt or grit are used in winter, are particularly susceptible to salt-affected stone decay. Locations where salt-laden moisture is able to repeatedly enter stone and dry out, such as harbour walls, will be most susceptible, and stone with particularly good resistance to salt weathering will be required in such settings. The low porosity and permeability of fresh Liddle's sandstone should mean it has good resistance to salt weathering, and this is supported by a lack of evidence to the contrary from existing structures in

[3] Appropriate geotechnical tests should be performed before the stone is considered for specialist uses, such as facing/cladding panels.

which Liddle's stone has been used. However, Liddle's sandstone that has suffered some weathering (typically revealed by buff, orange and brown discolouration) will be more porous and more permeable than the fresh (grey) stone, and will therefore be more susceptible to salt-affected weathering. Some settings in Orkney will be very exposed to salt-laden moisture, and it might be prudent to test samples of fresh and weathered Liddle's sandstone for its resistance to salt weathering before the stone is used for important projects in such settings.

3. The main accessible stone in Liddle's Quarry is massive (non-flaggy) sandstone. Natural joints are typically quite widely spaced in the massive sandstone, with the result that quarried blocks are typically relatively large. This, combined with the hardness of the stone, means that Liddle's sandstone requires a significant amount of processing (mechanical breaking and sawing) to produce dimension stone blocks. The blocks produced recently to re-pave carriageways in Stromness are not true flagstones; they consist of massive sandstone that has been sawn on all surfaces to produce blocks with the typical dimensions of historical paving stones, setts and kerbstones. Liddle's sandstone may therefore be relatively expensive to produce as dimension stone, compared to some other sandstones which break more readily along natural joints and can be shaped more easily.

4. The stone that is currently being (and would in future be) excavated from Liddle's Quarry is mainly of mid grey colour, with some orange to brown surfaces and bands. The fresh grey stone will weather to a buff colour over time. The fresh stone is cohesive and relatively impermeable, and as such it does not absorb water and is therefore likely to weather and decay relatively slowly in most environments. However, the weathered stone (including zones of orange to brown sandstone adjacent to natural joints and forming Liesegang bands) is more porous and more permeable than the fresh stone. Observations in the quarry and on recently repaved parts of Stromness streets have shown that the weathered stone absorbs moisture (rainwater) and takes longer to dry out than fresh stone (Plate 12d). It will therefore be more prone to salt weathering, freeze-thaw action and dissolution of the mineral cement than fresh stone, and can be expected to suffer accelerated decay relative to the fresh stone as a result.

Finally, the spoil in Liddle's Quarry, of which there is a substantial quantity, represents a significant resource of sandstone blocks for which there may be a range of uses, including rubble walling and dry stone walling. The sandstone blocks in mounds of old spoil (produced by historical quarrying) are likely to be weathered to some degree and less durable than blocks in piles of new spoil produced by recent quarrying.

5 Conclusions

This study has produced the following conclusions.

Liddle's Quarry consists of three separate pits that were developed sequentially between the mid-19th century and the present day. The two earliest pits have been long disused, and are now spoil-filled and overgrown. The youngest (and largest) pit was opened in the early part of the 20th century and may have been inoperative from the 1930s. It was re-opened again in 2010 to provide stone for repaving Stromness.

The quarry is sited in sandstone of the Upper Stromness Flagstone Formation (part of the Caithness Flagstone Group, which is in turn part of the Old Red Sandstone Supergroup). The rocks are of Mid Devonian age (398-385 million years old).

The bedrock underlying the quarry consists entirely of fine-grained, quartz-rich sandstone with a well developed mineral cement of quartz and carbonate minerals. When fresh, the sandstone is mid grey, cohesive and relatively impermeable. Weathered sandstone surfaces are buff.

The sandstone is intersected by near-horizontal bedding joints and by two main sets of relatively widely spaced steep joints, one trending NE-SW and one trending NW-SE.

Iron sulphide minerals (pyrite and possibly chalcopyrite) have formed in the geological past on some joint surfaces. Rainwater percolating through the joints (prior to, and during, the quarrying history) has chemically altered the sulphide minerals, and has locally dissolved the carbonate mineral cement in the adjacent sandstone. As a result, secondary iron and manganese minerals now form a thin orange to brown coating on many joint surfaces.

Flaggy sandstone (sandstone with parallel bedding joints spaced ~10 cm apart, suitable for paving) is a feature of the shallowest 1 to 1.5 metres of bedrock in Liddle's Quarry. Beneath this zone, the sandstone is massive (non-flaggy), and characterised by widely spaced joints.

A substantial resource of flaggy sandstone and massive sandstone remains within the area of the boundary fence around Liddle's Quarry. Based on the simple evaluation performed for this study, there is approximately 2,800 m^3 and 24,000 m^3 of recoverable, useable flaggy sandstone and massive sandstone respectively, within the area of the boundary fence.

The bedrock geology is consistent and essentially homogeneous in all parts of Liddle's Quarry where it is exposed, and BGS geological maps reveal no nearby faults or changes in bedrock lithology that might reduce the quality of the stone or limit quarry expansion. The available resource is therefore not obviously limited by geological factors. Exploitation and expansion of the quarry may at some point in the future be limited or restricted by the water table, by the large quantity of spoil within the quarry, and by a row of nearby electricity pylons.

Further exploitation of the flaggy sandstone would involve working on presently unquarried ground beside the existing pits, and would require the removal of peat, glacial till and possibly old spoil to access new bedrock; such workings would probably be visible along sightlines from a number of public roads and dwelling houses in the area around Liddle's Quarry.

Further exploitation of the massive sandstone at current volumes and using the same methodology is likely to have negligible visual impact on the surrounding area, and little impact in terms of dust, noise and vibration. The presence of iron sulphide minerals on joints in the rock raises the possibility that metallic elements could be transported in acidified water draining the quarry. The concentration of metallic elements is unlikely to reach toxic levels, but it may be prudent to conduct tests on drainage water if further quarrying goes ahead.

This study has found evidence that Liddle's Quarry sandstone (and possibly sandstone that is visually very similar to Liddle's sandstone but sourced from one or more other quarries) has historically been used widely on Orkney Mainland and for a range of applications. These include: paving (flags, setts and kerbstones), street furniture, skews and possibly walling in

Stromness; paving (flags and kerbstones) and terraced housing walling in Kirkwall; and bridge copes, milestones, fence posts and monument walling within a radius of at least ten kilometres around Liddle's Quarry.

Fresh Liddle's sandstone should provide a good quality, durable building stone with a wide range of potential uses. However, the stone does not have a distinctive geological character or aesthetic quality, or a desirable geotechnical property, and is therefore unlikely to be sufficiently commercially attractive to find a market outside Orkney.

In its fresh state, Liddle's sandstone is tightly cemented and essentially impermeable. This should add to its durability, and its ability to withstand salt-affected weathering. However, it also means the stone will not transmit moisture easily. As such, in masonry, the stone should not be placed adjacent to stone that is significantly more permeable, and consideration should be given to providing adequate ventilation if the stone is used as the walling in new buildings.

Plates

a

b

c

d

Plate 1 (**a**) Looking north to the largest current exposure of bedrock in Pit 2, forming the back wall in the northern-most corner of the pit. Blue hammer for scale. (**b**) Looking east across Pit 2. The small escarpment beneath overhanging peat and heather marks the position of the back wall of the pit. The floor of the pit (foreground and middle ground) is concealed beneath heather-covered mounds of spoil. Some piles containing large stone blocks have not been covered by heather. Blue hammer for scale. (**c**) Looking west from the back wall on the east side of Pit 3, across the access roadway to the island, the top of which is approximately 3.5 metres above the roadway. The small hut to the right of centre on top of the island houses a well. Below and to the right of the hut is a large stockpile of quarried stone. At the left side of the view, a smaller stockpile of stone blocks sits below a recently worked (orange coloured) face. (**d**) Looking north-west from unquarried ground south-east of Pit 2, across heather-covered mounds of old spoil which cover the ground along the north-west edge of Pit 3.

a

b

c

d

Plate 2 (**a and b**) Looking broadly north from the south-east corner of Pit 3 in October 2008 (a) and March 2012 (b). Renewed quarrying activity since 2010 has resulted in: the formerly grassy roadway being replaced by a dirt surface; the removal of a ‘bench’ 2-3 metres high of bedrock that previously existed where the grassy roadway ended (see Plate 2c); the creation of large mounds of new spoil on the east (right) side of the roadway and beyond the roadway in the north part of the pit, where the rock bench used to be. (**c**) Photo taken in October 2008 of the bedrock ‘bench’ that existed then at the end of the access roadway in Pit 3, and has since been quarried and replaced by a large mound of fresh spoil (see Plates 2a and 2b). (**d**) Looking north in the northern part of Pit 3. New spoil fills the floor of the pit, with the back wall of the pit beyond. The left part of the back wall was excavated historically, by blasting; the cliff face here is relatively irregular and contains occasional blast marks. The right part of the back wall was excavated recently, by mechanical means, and is characterised by large, clean rock faces. Note the section through glacial till that has been exposed on top of the newly excavated cliff face. The cliff face on the right is approximately 4 metres high.

a

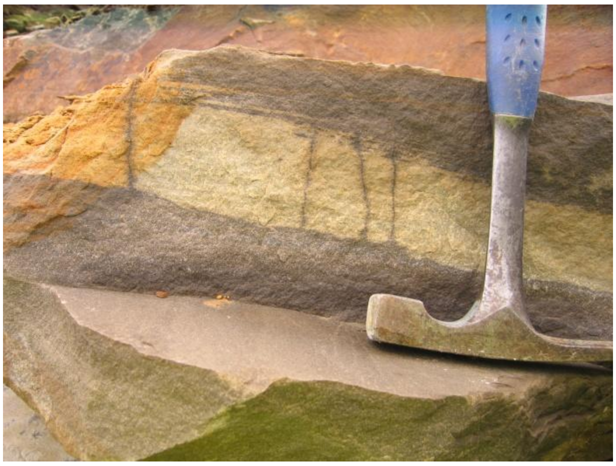
b

c

d

Plate 3 (**a**) Looking west across a large mound of new spoil lining the roadway access to Pit 3. (**b**) Looking south-east over the 'deep level' in Pit 3, which is filled by standing water. (**c**) Stockpiled blocks of Liddle's sandstone in Pit 3. Blue hammer for scale. (**d**) Small stream issuing from a culvert just outside the boundary fence (visible in background) around Liddle's Quarry. The stream, which appears to drain Pit 3, is the only obvious drainage issuing from Liddle's Quarry.

a



b

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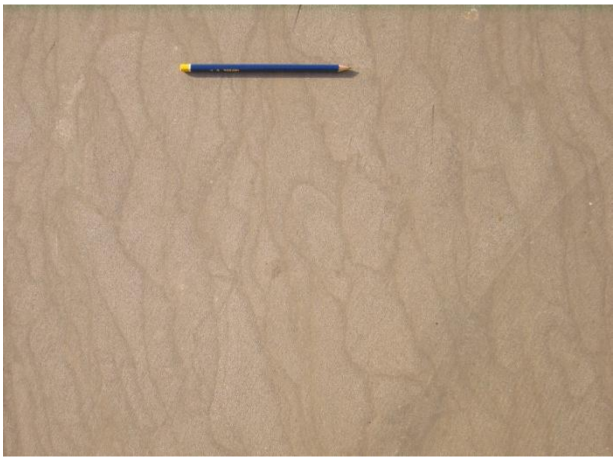


d

Plate 4 (**a**) Fresh Liddle's Quarry sandstone, showing mid grey colour and essentially homogenous character apart from faintly visible bedding lamination (closely spaced, parallel bands). (**b**) A rare zone of very pale yellowish-green 'bleached' stone in a quarried block of Liddle's sandstone. The mid grey stone above and below the bleached zone is typical of fresh Liddle's sandstone. (**c**) The back wall of Pit 3, in the northern part of the pit, showing the cross-bedded character of the sandstone. The wall exposes two beds of sandstone: in the lower bed the layers are dipping to the left, whereas in the top unit the layers are horizontal. (**d**) Patterns visible on the surface of this sawn slab of Liddle's Quarry sandstone (part of the recently laid paving in Stromness) show that the stone consists of irregularly shaped 'packets' of sandstone rather than simple, regular beds.

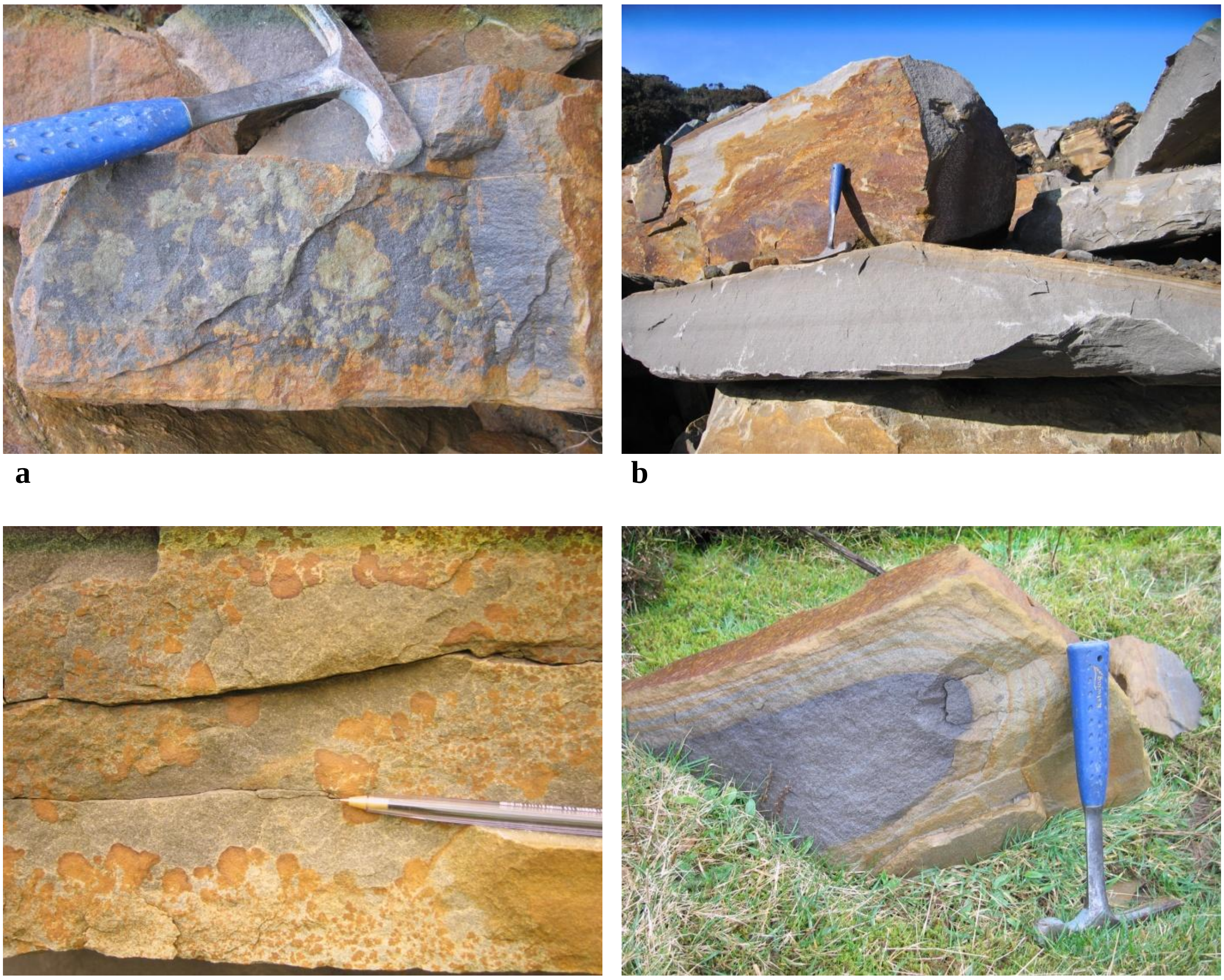
a

b

c

d

Plate 5 (**a**) Curved and coiled patterns on this bed surface in a loose block of Liddle's sandstone are grazing traces produced by mobile organisms which fed at or near the sediment surface as the sandstone was deposited. (**b**) A thin layer of gritty sand consisting of scattered granules of feldspar, quartz and rock fragments produces a faint speckled character on this bed surface in a loose block of Liddle's sandstone. The orange lines are Liesegang bands, which in this case cut across the bedding at right angles. (**c**) Back wall, north-east part of Pit 3, above the 'deep level', looking north-east. The recently quarried wall consists of large, steeply inclined, intersecting joint surfaces, which have a veneer of orange to brown iron minerals produced by weathering. The wall is approximately six metres high. Thick (up to 1.5 metre) beds of sandstone defined by widely spaced bedding joints dipping gently towards north-west (left) are visible in the largest joint surface. (**d**) Looking south-west onto part of the cliff bounding the island at its north-east side. This zone of rock, which contains irregular fractures bounded by decomposed sandstone, may be a weak fault.



a **b** **c** **d**

Plate 6 (**a**) Patches of fresh, greenish iron sulphide (probably pyrite, FeS_2) form a discontinuous coating on a joint surface in a loose block of Liddle's sandstone in Pit 3. Orange to brown iron oxyhydroxide minerals have replaced the iron sulphide on parts of the joint surface. (**b**) Large blocks of Liddle's sandstone stockpiled in Pit 3 showing mid-grey fresh sandstone on mechanically broken surfaces and veneers of orange to brown iron oxyhydroxide minerals on natural joint surfaces. (**c**) Colloform (cauliflower-shaped) patches of 'rusty' orange to brown iron oxyhydroxide partly coating a joint surface in a loose block of Liddle's sandstone. The iron oxide has replaced an iron sulphide mineral, probably pyrite; compare with Plate 6a. (**d**) A loose block of Liddle's sandstone beside the access roadway in Pit 3, showing well developed Liesegang bands developed concentrically in weathered (buff) stone around a core of fresh grey sandstone.


a


b


c


d

Plate 7 (**a**) Flaggy sandstone developing in the top 1.5 metres of bedrock on the back wall of the south-east corner of Pit 3. Note the relative concentration of closely spaced bedding joints in the top part of the exposed bedrock and their relative absence from the lower part. Blue hammer for scale. (**b**) A gently dipping bed of massive (non-flaggy) sandstone exposed in the lower part of the back wall of Pit 3. Massive sandstone like this, lacking closely spaced bedding joints, is typical below the near-surface zone of flaggy sandstone in all parts of Liddle's Quarry. (**c**) Looking east across the northern part of Pit 3 to a row of electricity pylons sited some 60-80 metres east-north-east of the boundary fence behind the back wall of Pit 3. (**d**) Looking north-west towards Liddle's Quarry from the Scorradale road. The building on the left is Quarryfield, which sits close to the quarry entrance. To the right of the house a slightly irregular skyline formed by mounds of old spoil (and clumps of trees) is the only visual sign of the quarry from this direction.

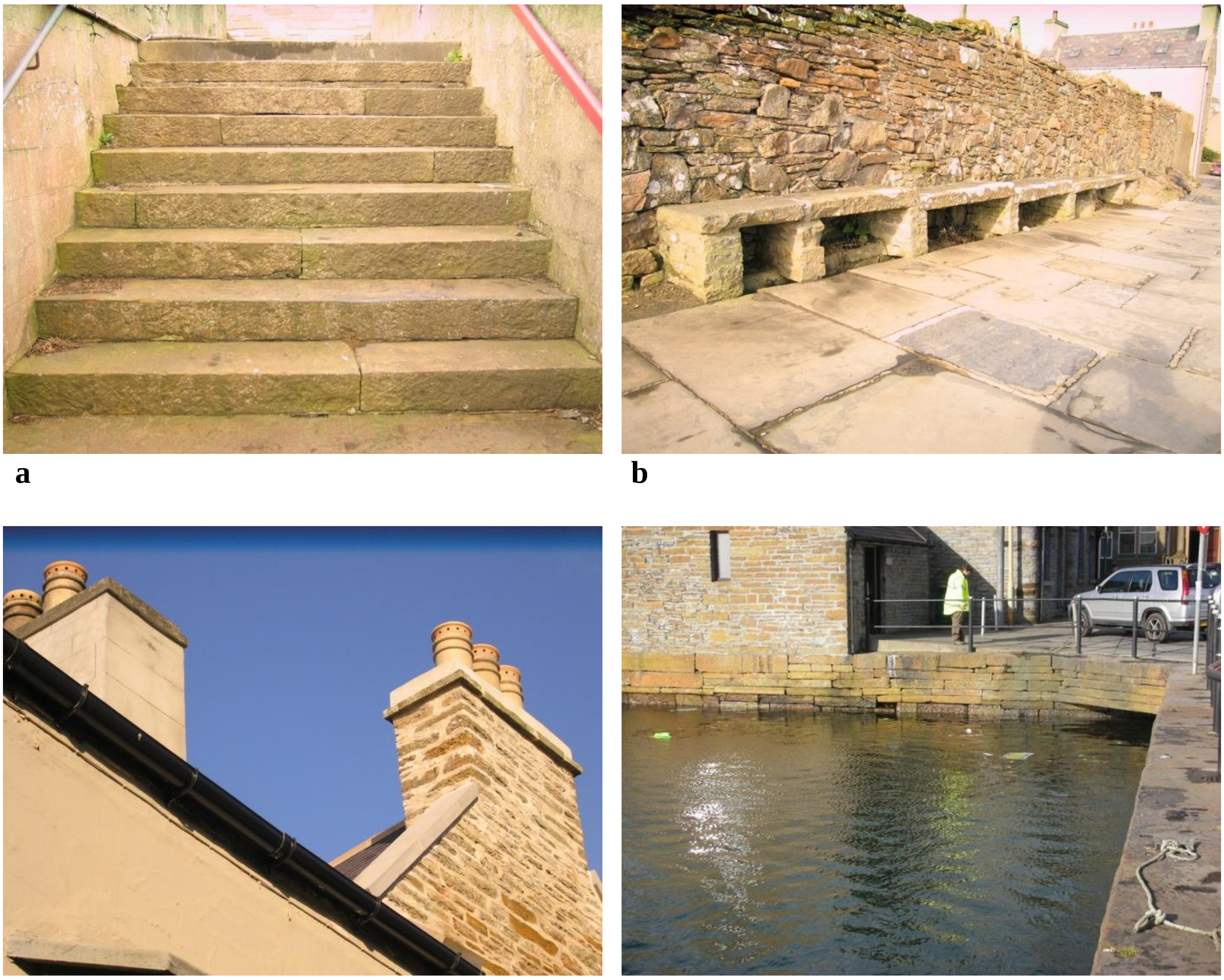
a

b

c

d

Plate 8 (**a**) Looking east-north-east from the A964 road towards Liddle's Quarry. The quarry sits in heather-covered ground on the left side of the image, just above where the brown heathery ground meets the yellow grassy ground. The buildings are Quarryfield, and the track running diagonally uphill to the left of Quarryfield is the access track from the Scorradale road into Liddle's Quarry. From this direction, the quarry appears as slightly irregular ground (formed by heather-covered mounds of old spoil) to the left of Quarryfield, but the recently quarried faces and new spoil are not visible. (**b**) Looking north-west towards Liddle's Quarry from the Scorradale road a short distance below Scorra Dale pass, where the road is at a higher elevation than the quarry. The quarry sits towards the left side of the heathery (brown) ground above the large farm in the centre of the image, and is essentially not visible from this direction. (**c** and **d**) Historical paving in Stromness using flaggy sandstone from Liddle's Quarry (surveyed in 2008). The sandstone was used for paving (carriageways and sidewalks), kerbstones, and setts.



a b

c d

Plate 9 (**a**) Stone steps in Stromness made of Liddle’s sandstone, or similar sandstone from another quarry. (**b**) Stone benches in Stromness made of Liddle’s sandstone, or similar sandstone, from another quarry. The carriageway paving is also Liddle’s sandstone. (**c**) Recent repairs to stone skews and chimney head in Stromness using Liddle’s sandstone; it is not known if the original skews and chimney head were also built with Liddle’s sandstone. (**d**) Some parts of the old harbour walling at Pierhead in Stromness may consist of sandstone sourced from Liddle’s Quarry.

a

b

c

d

Plate 10 (**a**) Detached building at Pierhead in Stromness built with stone of similar character to Liddle's sandstone. (**b**) Clusters of cm-scale iron rich nodules are a feature of the ashlar blocks used to build the structure at Pierhead in Stromness (Plate 10a). (**c**) A terrace of houses in West Tankerness Lane, Kirkwall that may have been built using stone from Liddle's Quarry. The ashlar blocks have a rough natural (occasionally stugged) finish and have been laid in diminishing courses (i.e. block height generally reduces with elevation in the front facade walling). (**d**) Clusters of cm-scale iron nodules with 'rusty' stains are a feature of the ashlar blocks used to build houses in West Tankerness Lane, Kirkwall (compare with Plate 10b).

a

b

c

d

Plate 11 (**a**) Flaggy sandstone probably from Liddle's Quarry used as pavement paving and kerbstones on Bignold Park, Kirkwall. (**b**) Copestones and possibly other parts of Bridge of Waithe, on the A965 road between Stromness and Kirkwall, may consist of sandstone sourced from Liddle's Quarry. (**c**) Many stone fence posts in Stenness and Orphir parishes may consist of sandstone sourced from Liddle's Quarry. The fence post pictured here, one of many beside the A964, is made from a large, squared block of sandstone. (**d**) Copestones on some bridges in Stenness and Orphir parishes may consist of sandstone sourced from Liddle's Quarry. The distinctive curved termination of the bridge wall formed by keystone copestones is a feature of many bridges in this part of Mainland. The rounded fence post to the left of the bridge is also built with sandstone that may have been sourced from Liddle's Quarry.

a

b

c

d

Plate 12 (**a**) Stone milestones on the A964 road between Bridge of Waithe and Orphir may consist of sandstone sourced from Liddle's Quarry. (**b**) The walling used in the Orphir War Memorial, located in the centre of the village on the north side of the A964 overlooking Scapa Flow, may consist of sandstone sourced from Liddle's Quarry. The stone is closely similar to that used in the walling of terraced housing in West Tankerness Lane, Kirkwall (compare with Plate 10d), including the presence of scattered iron nodules. (**c**) The small areas of stone walling visible on the ground floor of this building (in the east end of the village of Orphir on the north side of the A964) may consist of sandstone sourced from Liddle's Quarry. (**d**) Detail of a new sandstone paving slab in Stromness, the top edge of which consists of weathered (orange-brown) sandstone (mainly above the pencil), while the remainder is fresh grey sandstone. The weathered sandstone dries more slowly than the fresh sandstone, as can be seen in this image. In this example, the weathered sandstone has also begun to develop cracks.

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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