Two qualities of Severan Period masonry
Abstract

The purpose of this project is to identify the sources of the building stones at Vindolanda and to establish the pattern of their use in different periods and parts of the site. The work carried out in the first two years has been reported in McGuire (2011). This document describes further work carried out in 2012 and the conclusions reached in the project as a whole.

The principal work in 2012 has been the preparation and analysis of 24 thin sections, stained to highlight feldspar grains, from sandstone specimens from the site and from candidate quarries. These have allowed objective estimates to be obtained of the feldspar content, porosity and apparent grain size of the specimens together with descriptions of other lithological characteristics.

Each of the quarries thought most likely to be of Roman origin produces stone with a different range of feldspar contents. By comparing the feldspar content of site specimens with these ranges, and taking into account the archaeological context of each specimen, it has been possible to propose a sequence of use and re-use of the stone from each quarry over more than 200 years of Roman occupation of Vindolanda.

The number of specimens sectioned and analysed has been limited by cost, time and the need to minimise damage to archaeological material. This, together with the numerous sources of geological and archaeological variability in the stones, limits the degree of confidence in the findings. A quicker, cheaper and less damaging method of analysis would be needed to improve this confidence but, as yet, no suitable technique has been found. Characteristics other than feldspar content have proved less useful in correlating the masonry with its sources, but do provide support for some of the feldspar correlations.

A few of the many other sandstone quarries in the area may have been stone sources for Roman Vindolanda but more recent use of all of them is also possible and no clear lithological correlations have been found pointing to Roman-period exploitation. Likewise there are some sandstones present in the Roman masonry which do not have appear to have counterparts in any of the quarries from which specimens have been analysed. Neither of these shortcomings is sufficient to cast significant doubt on the proposed sequence of use of the main quarries. Two natural sources of Roman stone have also been identified.

There is still some mismatch between the estimated yield of the likely Roman quarries and the estimated volume of stone present when masonry at Vindolanda was at its most extensive but it is unlikely that a further major source of Roman stone has been missed.

All the carved and inscribed stones examined in the Vindolanda Museum are sandstone, as are the various altars from Vindolanda which can be observed, albeit from a greater distance, in the museum at Chesters. None of these sandstones appears, from surface examination, to be inconsistent with sandstone sources in the immediate area.
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All photographs and drawings are by the author unless otherwise stated.

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1 Introduction

1.1 Background

The project had its inception in 2008 as a contribution to the research objective of the 2008-2012 Sites and Monuments Consent (SMC) to investigate the extent to which the fort wall formed a divide between the military and civilian communities. If the two communities were using different stone sources at the same time, this might imply a distinction between military and civil administration. On the other hand, the use of a common source, probably under army control, would suggest significant military involvement in the life of the vicus.

The author of this report, a volunteer with some amateur geological experience, was asked to investigate how this work might be progressed and to take the initial steps needed to get the project under way. The author’s role has subsequently developed into that of Lead Volunteer for the project which has involved carrying out nearly all the work.

In 2009, staff from the British Geological Survey visited Vindolanda and took away for analysis 28 specimens, 18 from the site and 10 from possible Roman quarries. They carried out a physical examination of these and produced a preliminary report (Lawrence et al., 2010). A thin section was produced from each specimen. BGS staff, particularly David Lawrence and building stones petrologist Luis Albornoz-Parra, have continued to be a very valuable source of advice and expertise.

The first project report (McGuire, 2011) described the work carried out between 2009 and 2011, gave some preliminary conclusions and recommended how the work should be progressed. In October 2011, the Vindolanda Trust’s Research Committee considered the first report, authorised further work on the project and recommended some additional lines of investigation. This report describes how these two sets of recommendations have been taken forward in 2012.

1.2 Objectives

The project has four overall objectives.

1. To identify the sources of stone used by the Roman builders of Vindolanda.
2. To determine which sources were exploited during the various phases of masonry construction of Vindolanda.
3. To identify any differences in the sources used in different parts of the site at any one time, particularly between the vicus and the fort during the Stone Fort 2 period (post AD 213).
4. To determine the feasibility of applying the techniques developed for objectives (1)-(3) to other structures throughout the Hadrian’s Wall World Heritage Site.

The Research Committee also asked that attention be paid to the carved and inscribed stones in the Vindolanda Museum to see if any of them might have been sourced from outside the Vindolanda area.
1.3 Methodology

The methodology for the project involves four activities.

1. Survey the stone types and quantities in the Roman masonry and correlate these with archaeological context and historical period, area of the site and type of structure.

2. Survey the surrounding area to identify potential sources of Roman stone, observe the lithologies present and estimate the potential yield.

3. Assess and apply techniques for petrological examination and comparison of hand specimens and thin sections taken from the site and from possible quarry sources.

4. Attempt to make correlations between quarry and site lithologies and consider whether these point to any consistent patterns of use.

This report describes the work carried out on each of these activities in 2012.

1.4 Scope of work for 2012

The following work was planned and undertaken during 2012. This programme was devised to meet the Research Committee’s recommendations and to pursue the recommendations of the 2009-11 report where possible but had the primary purpose of meeting the project’s main objectives by the end of the 2008-2012 SMC.

1. Extend the quarry survey to cover some additional areas and to study in more detail some of the quarries identified earlier.

2. Take a small number of further specimens from the site and the quarries.

3. Obtain feldspar-stained thin sections from a sub-set of all the site and quarry specimens, selected to cover the widest possible range of source lithologies and masonry phases.

4. Use digital photographic and image-processing techniques to obtain from these thin sections objective estimates of feldspar content, porosity and apparent grain size and descriptions of other lithological parameters.

5. Use these estimates to provide a more detailed correlation between the stone sources and masonry phases.

6. Consider whether any alternative techniques might be available to provide such correlations more quickly and cheaply and less destructively than by thin sections.

7. Examine a range of the carved and inscribed stones found at Vindolanda to see if any might be from non-local sources.

1.5 Purpose and scope of this report

The primary purpose of the report is to make the Trust aware of the work carried out during 2012 and of the overall outcomes of the project. It is intended to complement the archaeological reports and conclusions at the end of the 2008-2012 SMC.
2  Further sources of stone

Figure 2.1 shows all the locations examined during the project, including those described in the 2009-11 report and some additional examinations carried out in 2012 which are described below.

![Geological map of the Vindolanda area showing locations studied throughout the project, limestone and dolerite outcrops and the Doe Sike fault.](image)

Geology after BGS 1:50,000 sheets E13 & E19; background after OS 1:25,000 sheet OL43.

2.1  Low Fogrigg

The small valley which runs eastwards into the Chineley Burn valley at Low Fogrigg (at NY771657) has extensive outcrops of the Chineley Sandstone along its steep, densely wooded south side. This area is not easily accessible but observation from across the valley in Spring 2012, before the trees were fully in leaf, revealed no signs of any exposures which might be the result of quarrying.
2.2 Barcombe Sandstones

It has not proved possible to establish a definitive stratigraphic sequence for the quarries and other sandstone exposures on Barcombe Hill. Modern GPS techniques allow accurate grid references and relative heights of the exposures to be determined but conversion of these into a stratigraphic sequence is highly dependent on the assumed angle and direction of the dip of the strata. These values are almost impossible to determine with sufficient accuracy and clearly vary considerably across the area. These difficulties are exacerbated by the presence of at least one significant SE-NW fault. Differences between the feldspar contents and other lithological characteristics (see sections 3 and 4) provide a more useful way of differentiating the stratigraphic levels, even if the exact sequence remains unclear.

2.3 Barcombe East quarries

The two small quarries at the eastern end of Barcombe Hill (locations T7 and T8 on figure 2.1) are likely candidates for the association suggested by Clayton (1859) with stone used on Hadrian’s Wall, especially at Milecastle 37. These quarries have been examined without success for evidence of Roman working. A possible 3rd century use at Vindolanda is suggested in section 4.

Although these quarries are at some distance from Vindolanda, it is worth noting that they are close to the first point east of Vindolanda along the Stanegate where access to Barcombe Hill can be obtained without the need for a significant climb up onto the Hill. The modern lane which leads southwards from this point may well have been a route by which stone was taken from the Hill and other parts of Thorngrafton Common in Roman times.

Nowadays the tarmac lane leads first southwards from the Stanegate and then turns westwards into Thorngrafton, so it is referred to in these reports as Thorngrafton Lane. However, it is not named on generally available modern maps. On the Enclosure Map (Fryer 1797) it is called Crowhall Road since, in the days before tarmac, it continued southwards to Crow Hall near the modern A69.

2.4 Firestone Sill

Along the southern edge of Thorngrafton Common and, after a step to the northward, continuing to the east of Thorngrafton Lane is a prominent ridge of hard, fine-grained sandstone. Although at a lower altitude than Barcombe Hill, this ridge is clearly stratigraphically higher than the Barcombe Sandstones and is assumed to represent the “Firestone Sill” marked on the stratigraphic column of the BGS 1:50,000 map (sheet E19). It was noted in the 2009-11 report that the many loose boulders down the north slope of the ridge were probably detached by periglacial forces during the cold period from around 12,500BP to 11,500BP. They must have been produced after the main ice sheet retreated by about 15,000BP and seem very unlikely to be of human origin since a large amount of effort would have been expended for no apparent reason.
There has been considerable quarrying at the western end of the eastern section of the ridge (locations T9 and T10 on figure 2.1). The presence at the smaller quarry T10 of a lightweight rail, typical of a small wagonway, and of many more such rails cemented into the nearby field wall to carry a strand of wire, suggests a 19th century date for much of this quarrying, although a Roman precursor is possible.

![Figure 2.2 The eastern end of the western section of the Firestone Sill.](image)

Naturally detached boulders can be seen on the right. In the centre and left, the boulders have been removed. On the left, sheep pens have been constructed.

The slope in front of the western section of the ridge appears to consist mainly of detached boulders, many of them large and naturally well-squared, although much of this slope is grassed over. At the eastern end of this section (location T11, figure 2.2), most of the boulders have been removed over a length of around 25 m, exposing the sandstone face to a depth of up to 2 m. Subsequently a group of sheep pens has been built, mainly of smaller stones, in front of the face but it seems very unlikely the boulders would have been removed specifically to make way for this. No evidence has been observed of any quarrying from this section of the ridge but further investigation would be justified. There is no evidence of similar clearance anywhere along the eastern section of the ridge (location T1).

The fact that locations T9 and T11 are on parts of the ridge closest to Thorngrafton Lane, which as discussed above may well have been the most convenient route from Thorngrafton Common to Vindolanda, makes it quite likely that one or both could be sources of Vindolanda stone. The availability of many large, strong, naturally-squared stones along the western section of the ridge would make location T11 a particularly attractive source.

### 2.5 Other Barcombe quarries

Further examination was undertaken during 2012 of the “railway sleeper” quarries on Barcombe Hill as part of a detailed investigation of the circumstances of the Thorngrafton Find. No evidence of Roman precursors to any of these quarries was seen. Results of this investigation are being published elsewhere (see also section 6). The investigation has also involved a detailed examination of the big Barcombe quarry (location Q4). One possibility identified during this examination is that because of the considerable, but unquantifiable, depth of waste stone in the bottom of this quarry the “missing volume” calculated in the 2009-11 report may be a significant underestimate.
## 2.6 Summary

Table 2.1 lists all the stone sources identified during the project.

<table>
<thead>
<tr>
<th>ID</th>
<th>Name</th>
<th>Location</th>
<th>Size</th>
<th>Significant features</th>
</tr>
</thead>
<tbody>
<tr>
<td>B4</td>
<td>Cockton Burn</td>
<td>South side of valley next to the North Field</td>
<td>Medium</td>
<td>Top of valley side; soft shale below</td>
</tr>
<tr>
<td>C1</td>
<td>Chesterholm</td>
<td>North of Chesterholm drive entrance</td>
<td>Small</td>
<td>Close to Chesterholm, especially the Hedley Building</td>
</tr>
<tr>
<td>C2-9</td>
<td>Bradley Burn</td>
<td>South side of valley near Crindledykes</td>
<td>Large total</td>
<td>Many small-medium workings served by 19th C wagon way</td>
</tr>
<tr>
<td>M3</td>
<td>Museum grounds</td>
<td>East side of valley below the metal foot-bridge</td>
<td>Small</td>
<td>Source of large boulders in valley bottom</td>
</tr>
<tr>
<td>A1</td>
<td>Chineley Burn</td>
<td>East side of valley 700 m south of Chesterholm</td>
<td>Medium</td>
<td>Close to 19th C colliery building</td>
</tr>
<tr>
<td>Q1</td>
<td>Long Stone</td>
<td>80 m south west of the Long Stone</td>
<td>Small</td>
<td>Close to top of track up from Crindledykes</td>
</tr>
<tr>
<td>Q3</td>
<td>Barcombe small</td>
<td>Left-hand quarry as seen from Vindolanda</td>
<td>Medium</td>
<td>Roman carvings, notably a phallus</td>
</tr>
<tr>
<td>Q4</td>
<td>Barcombe big</td>
<td>Right-hand quarry as seen from Vindolanda</td>
<td>Large</td>
<td>Partially cut block in NE part; shot-holes in SW part</td>
</tr>
<tr>
<td>T7/8</td>
<td>Barcombe East</td>
<td>East end of the Hill near Thorngrafton Lane</td>
<td>Small</td>
<td>Two areas, one 100 m south of the other; near the Stanegate</td>
</tr>
<tr>
<td>T2-6</td>
<td>(Barcombe Hill)</td>
<td>Several locations on the south slope of the Hill</td>
<td>Large total</td>
<td>Contain large amounts of waste stone</td>
</tr>
<tr>
<td></td>
<td>(Barcombe Hill)</td>
<td>Many locations on the Hill</td>
<td>Large total</td>
<td>Small, shallow, overgrown workings</td>
</tr>
<tr>
<td>T9/10</td>
<td>Firestone Sill East</td>
<td>Thorngrafton Common east of the lane</td>
<td>Medium</td>
<td>Discarded wagon-way rails found nearby</td>
</tr>
<tr>
<td>T11</td>
<td>Firestone Sill West</td>
<td>Thorngrafton Common west of the lane</td>
<td>Medium</td>
<td>Area cleared of naturally-formed boulders</td>
</tr>
<tr>
<td></td>
<td>(Valley bottoms)</td>
<td>Parts of all valleys especially Cockton Burn</td>
<td>Large total</td>
<td>Extensive areas of loose stone, many water-worn</td>
</tr>
</tbody>
</table>

Table 2.1 List of locations/(areas) where stone appears to have been quarried or may have been scavenged.

Size ranges are by estimated potential yield as follows:-
Small – below 250 m³; Medium – 250 to 1000 m³; Large – over 1000 m³.
3 Petrological observations

3.1 Specimens collected

During 2012, three further specimens were collected to add to the list given in the appendix to the 2009-11 report. These were:-

V12Q-S01  from the eastern (inner) face of the large, later 2\textsuperscript{nd} century wall uncovered in the \textit{vicus} at the end of the 2011 excavation season (V11Q-S01 is from the outer face)

V12Q-S02  facing stone from an internal wall of the Severan Period fort, about 15 m east of the previous specimen

V12Q-T9/1 from the large quarry in the eastern section of the Firestone Sill (see figure 2.1).

3.2 Thin sections prepared

In the 2009-11 report, recommendation 1.3 suggested that quantitative estimates of K-feldspar content should be obtained by means of chemically stained thin sections. This was based on a single thin section prepared in 2010 using this technique. A further 24 such thin sections have been prepared by the BGS laboratory during 2012. To ensure the technique was effective before all the costs were incurred, and to ensure an effective choice of specimens, these thin sections were produced in three batches. Table 3.1 lists all the 25 stained thin sections now available.

Feldspars are a very common group of alumino-silicate minerals containing a combination of the metals sodium, potassium and calcium. The crystal structures of these minerals fall into two main types depending on the metal content. Plagioclase feldspars contain mainly sodium and/or calcium. Feldspars containing mainly potassium are called K-feldspar (K is the chemical symbol for potassium). K-feldspar is a major component of granite, where it is often visible as large white or pink crystals, and is the source of the pink colour in the Shap Granite glacial erratics which are sometimes encountered in the Vindolanda area.

In the thin sections, the staining process gives a mottled orange colour to K-feldspar grains. It does not affect plagioclase feldspar but this mineral is not common in these particular sandstones. In section 3.3 of this report the term “K-feldspar” is generally used, to emphasise that it is this mineral which is being analysed. Elsewhere in the report “feldspar” is often used for simplicity but does refer explicitly to K-feldspar unless otherwise stated.
<table>
<thead>
<tr>
<th>Specimen ID</th>
<th>Specimen source</th>
</tr>
</thead>
<tbody>
<tr>
<td>V09Q-S01</td>
<td>Stone Fort 2 granary</td>
</tr>
<tr>
<td>V09Q-S06</td>
<td>Early bath house – flagstone</td>
</tr>
<tr>
<td>V09Q-S07</td>
<td>Early bath house – internal voussoir</td>
</tr>
<tr>
<td>V09Q-S08</td>
<td>3rd century vicus – foundation stone (site 76)</td>
</tr>
<tr>
<td>V09Q-S09</td>
<td>3rd century vicus – foundation stone from east wall of courtyard building</td>
</tr>
<tr>
<td>V09Q-S10</td>
<td>Severan barracks</td>
</tr>
<tr>
<td>V09Q-S11</td>
<td>3rd century vicus – foundation stone (site 28)</td>
</tr>
<tr>
<td>V09Q-S12</td>
<td>Stone Fort 2 barracks</td>
</tr>
<tr>
<td>V09Q-S14</td>
<td>3rd century vicus – large sandstone plinth (2009 area B)</td>
</tr>
<tr>
<td>V10Q-S03</td>
<td>Foundation stone of building in vicus (2010 area B)</td>
</tr>
<tr>
<td>V10Q-S06</td>
<td>Stone Fort 1 barracks</td>
</tr>
<tr>
<td>V10Q-S08</td>
<td>Stone Fort 1 centurion's quarters</td>
</tr>
<tr>
<td>V11Q-S01</td>
<td>Late 2nd century wall in vicus (annex wall, outer face)</td>
</tr>
<tr>
<td>V12Q-S01</td>
<td>Late 2nd century wall in vicus (annex wall, inner face)</td>
</tr>
<tr>
<td>V12Q-S02</td>
<td>Severan fort</td>
</tr>
<tr>
<td>V10Q-B4/7</td>
<td>Cockton Burn quarry</td>
</tr>
<tr>
<td>V10Q-C2/2</td>
<td>Bradley Burn quarry</td>
</tr>
<tr>
<td>V10Q-Q1/6</td>
<td>Long Stone quarry</td>
</tr>
<tr>
<td>V10Q-Q1/7</td>
<td>Long Stone quarry</td>
</tr>
<tr>
<td>V09Q-Q3/1</td>
<td>Small Barcombe quarry</td>
</tr>
<tr>
<td>V09Q-Q3/2</td>
<td>Small Barcombe quarry</td>
</tr>
<tr>
<td>V09Q-Q4/1</td>
<td>Big Barcombe quarry (19th century face)</td>
</tr>
<tr>
<td>V10Q-Q4/2</td>
<td>Big Barcombe quarry (Roman face)</td>
</tr>
<tr>
<td>V10Q-T7/1</td>
<td>Barcombe East quarry</td>
</tr>
<tr>
<td>V12Q-T9/1</td>
<td>&quot;Firestone Sill&quot; quarry</td>
</tr>
</tbody>
</table>

Table 3.1 List of specimens from which K-feldspar stained thin sections have been prepared.

3.3 Analysis of stained thin sections

Photomicrographs using plane-polarised light were taken of at least three 5.16 mm x 4.16 mm areas of each of the 25 stained thin sections, using an Axioplan 2 microscope at the BGS Keyworth laboratories. These digital photographs were analysed using the software package Corel PaintShop Pro Photo version XI. Three types of analysis were performed to produce objective values for the three parameters K-feldspar content, porosity and grain size. Results are shown in table 3.4.

All the thin sections were penetrated with blue-dyed resin to reveal the porosity. Under plane-polarised light the predominant quartz crystals appear white or pale grey, sometimes with a dusting of pale orange to black iron oxides. The staining colours K-feldspar crystals a
mottled orange-brown. Sometimes these crystals may be very fragmented due to chemical alteration. Areas of pale grey-blue between the grains are clumps of clay particles. Long, thin shapes are cross-sections through plate-like mica crystals. All these features can be seen in the left hand part of figure 3.1.

Figure 3.1 Photomicrograph of part of a thin section from specimen V10Q-Q4/2. In the left-hand part, red arrows point to the mica grains, the green arrow points to a clump of clay particles and the circle encloses a K-feldspar grain undergoing chemical alteration. In the right-hand part, the K-feldspar grains have been coloured (rgb=50,0,0) and the histogram shows the resultant spike in the red channel.

3.3.1 K-feldspar content

The proportion of K-feldspar in the specimen was estimated by colouring the stained crystals a standard colour (rgb=50,0,0) using the “pen” tool in the software, as in the right-hand part of figure 3.1. The additional proportion of this colour in the image can be determined by use of the histogram function in the software. (Note that in figure 3.1 this value is given as 5.2% for the spike in the red channel at 50. This value only reflects the part of the image where the K-feldspar grains have been coloured. The value for the whole photograph is 11.5% once the background level of 0.1% is subtracted.) This value gives an estimate of the volume % of K-feldspar in the specimen.

When colouring the stained areas, a degree of judgement is required as to the exact extent of the staining, particularly where a grain has become fragmented. The key requirement is
that this judgement must be exercised consistently to give meaningful comparisons between specimens. To check that this requirement was being met, all 3 of the photographs from each of 5 of the specimens were recoloured about 6 months after they had first been analysed. Table 3.2 shows the results of this exercise.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>January 2012</th>
<th>July 2012</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Field1</td>
<td>Field2</td>
</tr>
<tr>
<td>V09Q-S01</td>
<td>7.7</td>
<td>6.6</td>
</tr>
<tr>
<td>V09Q-S06</td>
<td>2.8</td>
<td>2.9</td>
</tr>
<tr>
<td>V10Q-Q1/7</td>
<td>1.8</td>
<td>2.8</td>
</tr>
<tr>
<td>V09Q-Q3/1</td>
<td>3.9</td>
<td>6.0</td>
</tr>
<tr>
<td>V10Q-T7/1</td>
<td>0.7</td>
<td>1.2</td>
</tr>
</tbody>
</table>

Variation between corresponding fields: minimum 0.0, mean 0.15, maximum 0.4

Table 3.2 Variation between two analyses of K-feldspar content (vol %) of 15 photographs.

Because the K-feldspar grains are of a similar size, shape and density to the quartz grains, there is unlikely to have been significant segregation of these two grain types during transport and deposition. So the K-feldspar should be quite evenly distributed through each specimen. However, there is likely to be some small scale variation from one photographed area to another. To check whether this could produce significant uncertainty in the results, a further three photographs were taken of different areas of 5 specimens. These groups of three photographs were analysed for K-feldspar using the same technique as described above. Table 3.3 shows the results of this exercise.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Field1</th>
<th>Field2</th>
<th>Field3</th>
<th>Mean</th>
<th>Field4</th>
<th>Field5</th>
<th>Field6</th>
<th>Mean</th>
<th>Δ</th>
<th>Δ%</th>
</tr>
</thead>
<tbody>
<tr>
<td>V09Q-S01</td>
<td>7.7</td>
<td>6.6</td>
<td>6.9</td>
<td>7.1</td>
<td>6.2</td>
<td>9.2</td>
<td>5.0</td>
<td>6.8</td>
<td>0.3</td>
<td>4.2</td>
</tr>
<tr>
<td>V09Q-S06</td>
<td>2.8</td>
<td>2.9</td>
<td>2.9</td>
<td>2.9</td>
<td>3.4</td>
<td>2.8</td>
<td>4.2</td>
<td>3.5</td>
<td>0.6</td>
<td>20.7</td>
</tr>
<tr>
<td>V10Q-Q1/7</td>
<td>1.8</td>
<td>2.8</td>
<td>3.0</td>
<td>2.5</td>
<td>2.5</td>
<td>2.3</td>
<td>3.3</td>
<td>2.7</td>
<td>0.2</td>
<td>8.0</td>
</tr>
<tr>
<td>V09Q-Q3/1</td>
<td>3.9</td>
<td>6.0</td>
<td>5.7</td>
<td>5.2</td>
<td>4.6</td>
<td>4.7</td>
<td>6.4</td>
<td>5.2</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>V10Q-T7/1</td>
<td>0.7</td>
<td>1.2</td>
<td>1.4</td>
<td>1.1</td>
<td>0.8</td>
<td>1.2</td>
<td>0.9</td>
<td>1.0</td>
<td>0.1</td>
<td>9.1</td>
</tr>
</tbody>
</table>

Mean variation between corresponding means 0.24 8.4

Table 3.3 Variation between analyses of K-feldspar content (vol %) of 2 groups of 3 fields on each of 5 thin sections.

3.3.2 Porosity

A similar analysis technique was used to estimate the porosity (as volume %) in each of the 25 specimens. Although the blue dye penetration of the pores does not produce a precisely constant colour on the photographs, the colour is within a sufficiently small and distinctive range that the colour-replacer tool in the software can be used to convert the pores to a constant colour for analysis. In this case, the conversion was to pure black (rgb = 0,0,0). The tolerance setting on the replacer tool was chosen to give a good visual match of the black areas to the pores and this setting was then used for all the analyses. Figure 3.2 shows this
analysis method applied to the same area as in figure 3.1. The porosity calculated from this using the histogram function is 16.5%.

![Photomicrograph of part of a thin section from specimen V10Q-Q4/2.](image)
The blue-dyed areas of porosity have been converted to pure black.

### 3.3.3 Apparent grain size

In any rock specimen consisting of individual grains which can be seen with the naked eye or with a hand-lens, the most basic petrological procedure is to estimate the average grain size. For such a fundamental parameter, getting an objective and reasonably precise value of grain size is fraught with many difficulties and uncertainties. These include the problem of defining exactly what is meant by “average” and the difficulties which arise when the shape of the grains is very variable. The usual procedure is to make a visual comparison between the grains and a standard grain-size chart. The problem with the Vindolanda sandstones is that they almost all have grain sizes between two adjacent steps on the most commonly used chart – i.e. they all have grain sizes between 0.25 mm and 0.5 mm (the range categorised as “medium grained”). Nevertheless, it is clear that there are significant differences in the grain sizes of the specimens being considered here and the possibility exists that these differences might be, to some extent, characteristic of the stone sources. So a more precise comparison is desirable.

Determining grain size from a thin section introduces a further complication because grains are generally not sectioned through their largest dimension. What appears to be a small
grain may just be a corner of a large grain. So the grain size determined from a section will be an underestimate. It is almost impossible to calculate the extent of this underestimation but for comparison purposes between similar rocks it seems reasonable to assume that, on average, the “apparent” grain size will be a roughly constant proportion of the “true” grain size.

One way to determine the apparent grain size is to count the number of grains in a defined area. However, this is a lengthy and tedious process and the result is an average grain area which cannot readily be converted into a meaningful linear size. A somewhat less onerous alternative is to count the number of grains intersected by a known length of straight line. This method is not ideal, because the line does not cut the widest part of the grain in most cases, but it does give a linear dimension which ought to be a reasonable proxy for the actual grain size.

On each photograph, four lines were drawn, two horizontal and two vertical. The number of grains intersected by each was counted and divided into the line length, with an allowance for the porosity. The apparent grain size was averaged over the four lines and over the three photographs for each section.

Comparison of the results (last column of table 3.4) with observations of hand-specimens suggests that the values of apparent grain size obtained in this way are approximately 50% of the true values. This gives values between 0.24 and 0.44 mm, a range which is consistent with the classification of all these specimens as medium-grained sandstones (grain size 0.25 to 0.5 mm). However, for this project all comparisons are made between the measured values of apparent grain size.
3.3.4 Summary of results

<table>
<thead>
<tr>
<th>Specimen</th>
<th>K-feldspar content (vol%)</th>
<th>Porosity (%)</th>
<th>Apparent grain size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V09Q-S01</td>
<td>7.1</td>
<td>10.2</td>
<td>0.22</td>
</tr>
<tr>
<td>V09Q-S06</td>
<td>2.9</td>
<td>10.9</td>
<td>0.19</td>
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<td>V09Q-S07</td>
<td>5.9</td>
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<td>V09Q-S08</td>
<td>3.8</td>
<td>5.2</td>
<td>0.13</td>
</tr>
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<td>10.1</td>
<td>0.17</td>
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<td>0.17</td>
</tr>
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<td>V09Q-S11</td>
<td>1.2</td>
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<td>0.14</td>
</tr>
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<td>V09Q-S12</td>
<td>7.7</td>
<td>6.2</td>
<td>0.18</td>
</tr>
<tr>
<td>V09Q-S14</td>
<td>4.7</td>
<td>7.1</td>
<td>0.21</td>
</tr>
<tr>
<td>V10Q-S03</td>
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<td>4.2</td>
<td>0.15</td>
</tr>
<tr>
<td>V10Q-S06</td>
<td>0.0</td>
<td>12.6</td>
<td>0.18</td>
</tr>
<tr>
<td>V10Q-S08</td>
<td>5.6</td>
<td>11.3</td>
<td>0.23</td>
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<td>V11Q-S01</td>
<td>5.2</td>
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<td>V12Q-S01</td>
<td>3.7</td>
<td>9.5</td>
<td>0.21</td>
</tr>
<tr>
<td>V12Q-S02</td>
<td>3.4</td>
<td>12.2</td>
<td>0.20</td>
</tr>
<tr>
<td>V10Q-B4/7</td>
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<td>5.3</td>
<td>0.13</td>
</tr>
<tr>
<td>V10Q-C2/2</td>
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<td>8.8</td>
<td>0.15</td>
</tr>
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<td>V10Q-Q1/6</td>
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<td>15.2</td>
<td>0.18</td>
</tr>
<tr>
<td>V10Q-Q1/7</td>
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<td>13.1</td>
<td>0.19</td>
</tr>
<tr>
<td>V09Q-Q3/1</td>
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<td>9.3</td>
<td>0.19</td>
</tr>
<tr>
<td>V09Q-Q3/2</td>
<td>5.7</td>
<td>11.4</td>
<td>0.21</td>
</tr>
<tr>
<td>V09Q-Q4/1</td>
<td>6.6</td>
<td>18.7</td>
<td>0.19</td>
</tr>
<tr>
<td>V10Q-Q4/2</td>
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<td>0.17</td>
</tr>
<tr>
<td>V10Q-T7/1</td>
<td>1.1</td>
<td>10.2</td>
<td>0.18</td>
</tr>
<tr>
<td>V12Q-T9/1</td>
<td>0.1</td>
<td>6.3</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Table 3.4 Results of analyses of K-feldspar stained thin sections.
Each figure is an average of values for three photographed fields as described in section 3.3. The specimens are identified in table 3.1.

3.3.5 Correlations between parameters

Figure 3.3 shows cross-plots of each of the three pairs of parameters from table 3.4. Although positive linear trends are shown in most cases, the scatter of the points is such that it must be assumed there is no meaningful correlation between any pair of parameters.
Figure 3.3  Cross-plots between K-feldspar content, porosity and apparent grain size.  
For each pair of parameters, the 15 specimens from Vindolanda masonry and the 10 specimens from quarries are plotted separately, with linear trend-lines.
3.4 Other observations

3.4.1 Other lithological factors

**Figure 3.4 Thin section from Barcombe east quarry T7.**
Silica overgrowths are made visible by 1) dust line surrounding the original grain, 2) development of unabraded crystal facets, 3) cementation of groups of grains more closely together than achievable by compaction.

**Figure 3.5 Thin section from Bradley Burn quarry C2.**
The vertical axis of the specimen is from left to right in the picture. 1) distorted mica flake; 2) pore filled by iron minerals; 3) pore filled by clay.
All the thin sections were examined and significant lithological factors were recorded. Examples of these are shown in figures 3.4, and 3.5.

When sands are deposited as loose sediments they typically have porosities close to 50%. As time passes, and particularly as the weight of overlying sediments increases, changes occur which substantially reduce the porosity. Apart from the two specimens from the big Barcombe quarry (see section 3.4.2) all the specimens in table 3.4 have porosities between 5% and 15%. Three processes have contributed to this reduction in density – deposition of silica on the silica grains (referred to as “overgrowths”), compaction and infilling of pores by fine-grained material.

Figure 3.4 shows evidence of silica overgrowths. Solubility of silica in water is very low under typical earth-surface conditions but increases as the temperature and pressure increase, and as the chemistry of the pore water changes, during burial of the sediment. Thus pore water may contain a significant concentration of silica, which can precipitate on the silica grains as the solubility is very sensitive to small, local variations in the physical and chemical conditions. Such an overgrowth is optically continuous with the grain on which it formed and cannot always be distinguished in thin section, although features such as those shown in figure 3.4 sometimes make this possible. All the sandstones observed in this project have some degree of silica overgrowth and the difficulty in distinguishing how much is present makes it impossible to use this as a clear discriminating factor. Discriminating between sources on the basis of differences in grain morphology is also difficult because the overgrowths mask the original grain shapes.

Evidence of compaction is seen in figure 3.5 where a flake of mica has been bent and fractured as the surrounding, harder silica grains have been shuffled more closely together under stress. Mica flakes settle more slowly than similar-sized silica grains and tend to be deposited in distinct bands, corresponding with periods of slower water flow. Specimens from all the quarries contain some mica and, although the amounts vary from quarry to quarry, this uneven distribution makes it impossible to use mica as a quantitative discriminator between sources.

In figure 3.5, both pale clays and dark iron minerals can be seen filling some of the pores. The extent of this phenomenon can vary considerably, even within a single specimen, and is generally not useful in distinguishing sources, although some are consistently “cleaner” than others (compare the amount of dark material in figure 3.5 with its almost total absence in the left-hand part of figure 3.1).
3.4.2 Weathering

When stone is exposed, by human action or natural processes, to the atmosphere it may undergo physical and chemical changes known collectively as weathering. These processes generally make the stone more susceptible to erosion. The stone sourced from the Cockton Burn quarry, mainly it seems during the Antonine period, provides a particularly clear example of this. The upper part of figure 3.6 shows a specimen from the quarry, with large amounts of iron minerals in the pores. The lower part of the figure 3.6 shows a specimen from a stone taken from an Antonine Period barracks shortly after excavation in 2010. Iron minerals are absent and the thin blue lines between the grains show they are becoming detached from each other. These effects have probably been exacerbated by the stone’s many centuries of burial in wet conditions under a thin layer of soil.

![Figure 3.6 Thin sections from quarry B4 (above) and from an Antonine Period barracks. Weathering has removed the iron minerals from this part of the barracks stone and the grains have started to separate.](image)
The effects of the winter of 2010/11 on stones in the same wall and in a Severan Period round-house are clearly seen in figure 3.7. Formation of ice in the pores of structures such as that in figure 3.6 (lower) has crumbled the surfaces almost back to the original sand. The iron minerals have been carried to the surface layers where they oxidise to form characteristic bright orange coloured minerals. The archaeologists have long associated this colour of stone with sources from the Cockton Burn Valley and with Antonine Period masonry (Birley, R. 2009). The analysis given above confirms why this is a reliable diagnostic feature.

Figure 3.7 The effect of one winter’s exposure on stone in an Antonine Period barracks (left) and a Severan Period round-house (right).
An opposite effect has been observed in stone from the big Barcombe quarry. In figure 3.8 it can be seen that a specimen from the Roman part of the quarry face has a considerably greater porosity (17.0%) than that from the masonry (6.2%). A specimen from the part of the face exposed during the 19th century has an even greater porosity (18.7%) and is particularly friable.

Figure 3.8 Thin sections of stones from a 3rd century barracks and from quarry Q4. The two pictures are to the same scale. The greater porosity of the specimen from the Roman part of the quarry face (right) is apparent.
3.4.3 Specimens from other quarries

In addition to the Cockton Burn quarry, four other quarry locations have been identified in sandstones stratigraphically below those on Barcombe Hill. They are marked on figure 2.1 as locations C1, C2-9, M3 and A1. The first two are in the same sandstone as the Cockton Burn quarry (B4). A thin section from location C2 in the Bradley Burn quarries is shown in figure 3.5. Its similarity to the thin section from B4 in figure 3.6 (upper) is obvious. However, as figure 3.9 upper right shows, the thin section from location C1, the small quarry just north of Chesterholm, is rather different. Iron minerals are largely absent and the grain size is somewhat larger than in the adjacent picture from B4.

A thin section from the small quarry in the valley side below Chesterholm (location M3, figure 3.9 lower left) is also significantly different from B4. The range of grain sizes is much greater and the grains are more angular. This particularly hard sandstone is the source of the large boulders in the valley bottom. This quarry is in the next sandstone stratigraphically above that in the Cockton Burn quarry.

The next sandstone up again was quarried at location A1, further down the Chineley Burn valley near the former Birkshaw Colliery. Stone from this quarry (figure 3.9, lower right) is distinguished from that from quarry B4 by the presence of a small amount of feldspar.

![Figure 3.9 Thin sections from quarries B4, C1, M3 and A1.](image)

All the pictures are to the scale given on the first picture.
3.4.4 The Firestone Sill

A thin section of the very hard stone from the Firestone Sill (described in section 2.4) is shown in figure 3.10. This has the finest grain size of all the specimens analysed and also has a very small range of grain sizes. The angular grains are tightly interlocked and, although silica overgrowths are not well seen, the porosity is amongst the lowest measured. Only a very small amount of feldspar is present, but an unstained thin section from location T1, in the Firestone Sill about 100m from T9, clearly has a somewhat higher feldspar level, albeit still probably below 1%.

Figure 3.10 Thin section from quarry T9.
A single mottled-orange stained K-feldspar grain can be seen near the centre.
4 Discussion

4.1 Proposed correlations

On the basis of the results reported in section 3, the following correlations are proposed between stones from the Vindolanda masonry and their sources.

<table>
<thead>
<tr>
<th>Masonry specimen</th>
<th>Proposed source</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID</td>
<td>Period and location</td>
</tr>
<tr>
<td>V09Q-S06</td>
<td>Early bath house – flagstone</td>
</tr>
<tr>
<td>V09Q-S07</td>
<td>Early bath house – internal voussoir</td>
</tr>
<tr>
<td>V10Q-S06</td>
<td>Stone Fort 1 barracks</td>
</tr>
<tr>
<td>V10Q-S08</td>
<td>Stone Fort 1 centurion’s quarters</td>
</tr>
<tr>
<td>V11Q-S01</td>
<td>Late 2nd century annex wall</td>
</tr>
<tr>
<td>V12Q-S02</td>
<td>Severan fort</td>
</tr>
<tr>
<td>V09Q-S10</td>
<td>Severan barracks</td>
</tr>
<tr>
<td>V09Q-S01</td>
<td>Stone Fort 2 granary</td>
</tr>
<tr>
<td>V09Q-S12</td>
<td>Stone Fort 2 barracks</td>
</tr>
<tr>
<td>V09Q-S08</td>
<td>3rd century vicus – foundation stone</td>
</tr>
<tr>
<td>V09Q-S09</td>
<td>3rd century vicus – foundation stone</td>
</tr>
<tr>
<td>V09Q-S11</td>
<td>3rd century vicus – foundation stone</td>
</tr>
<tr>
<td>V09Q-S14</td>
<td>3rd century vicus – sandstone plinth</td>
</tr>
<tr>
<td>V10Q-S03</td>
<td>Foundation stone of building in vicus</td>
</tr>
</tbody>
</table>

Table 4.1 Proposed sources of masonry stones, in approximately chronological order.

The list is limited to those stones from which stained thin sections were prepared.

Note 1 – This stone has similar grain size and porosity to the other vicus foundation stones but has a significantly higher feldspar content.

Note 2 – These stones have hardness and grain size typical of the Firestone Sill. For reasons given in section 2.4, they are more likely to be from location T11 than from the locations from which thin sections were prepared, T1 and T9. They have extensive silica overgrowths and the lowest porosities (below 5%) of all the thin sections.

4.2 The unstained thin sections

Some less precise, but nevertheless useful, observations of the unstained thin sections were set out in tables 4.2 and 4.3 of the 2009-11 report. Now, having observed many stained feldspars, it is possible to identify more reliably the feldspars in the unstained thin sections. All these have therefore been re-examined in the light of the correlations proposed above and the following additional comments can be made.

From the Antonine period fort, V10Q-S07 is almost identical to V10Q-S06 (figure 3.6 lower) from the other end of the same wall, with extensive grain separation which is also seen in V09Q-S18 from the fort wall. V09Q-S03 from the west gate is very similar to specimens from the Cockton Burn quarry (B4) such as that shown in figure 3.9 top left, although it does
contain a very small number of feldspar grains. Correlation of all these three specimens with the Cockton Burn quarry is possible.

However, the two specimens from the Antonine period vicus, V09Q-S15 and V09Q-S17, contain far too much feldspar to be consistent with the Cockton Burn quarry. Instead, they are similar in this and other respects to the specimens from the small Barcombe quarry (Q3) and to those from the later 2nd century annex wall and the Severan fort which are all correlated with Q3 in table 4.1. Neither of these stones showed signs of significant erosion, unlike the Cockton Burn quarry stones (figure 4.1).

Figure 4.1 Stones in the Antonine period vicus. (Photograph Ewan Hyslop)
Stone V09Q-S17, the large stone at bottom right, shows little sign of erosion but around it are many heavily eroded stones. In the centre are three rounded dolerite cobbles showing typical “onion skin” weathering. Elsewhere, orange coloured stones, probably from the Cockton Burn quarry, have suffered substantial disintegration (c.f. figure 3.7).

Specimen V09Q-S02 from a 3rd century barracks block, although originally assigned only a moderate feldspar content, can now been seen to have a much higher content. Neither this specimen, nor V09Q-S04 from the 3rd century fort wall, nor V09Q-S05 from a building just outside the fort’s south gate, has a feldspar content inconsistent with a source in the big Barcombe quarry (Q4) as proposed for the other specimens from the 3rd century fort.

Specimen V10Q-S10 was taken from the first course above the foundation of the rectangular building excavated in the North Field in 2010. Its lack of feldspar and extensive dark pore-filling material make it similar to the nearby Cockton Burn quarry. However, the fine grain size and low porosity make it a better match with specimens from the Firestone Sill such as V12Q-T9/1 (figure 3.10). Specimen V09Q-S16 is very similar to V09Q-S11 (table 4.1) and so is also a good match to the Firestone Sill.
Specimen V09Q-S13 is from the early 4th century “Riacus” building which overprints one of the 3rd century buildings just inside the west gate of the fort. It is from one of a number of large stone blocks forming the base of the building’s external wall and has the same low feldspar content, porosity and grain size, and extensive silica overgrowths, as the large foundation stones from the vicus. Although its original source was probably also the Firestone Sill, it may well have been re-used from the vicus buildings, by then abandoned, just outside the gate (e.g. V09Q-S11). One stone, close to that carved with the name “Riacus”, is considerably coarser-grained so may not be from the same original source.

4.3 Variability of lithological characteristics

The primary basis for the correlations proposed in table 4.1 is feldspar content. In order to assess how reliable these correlations are, a number of possible sources of variability must be considered.

The results in table 3.2 suggest that the measurement process is quite repeatable and does not give rise to significant uncertainty. Likewise, the results in table 3.3 suggest that the areas measured constitute sufficiently representative samples of the thin sections. The variations observed are not large enough to cause the ranges of feldspar content of the quarries to overlap. Care was taken to ensure that the thin sections were cut from areas away from the surfaces of the stones, which could be unrepresentative of the bulk because of weathering effects. Overall, the method of assessing the feldspar content of a stone appears to be sufficiently reliable to produce good results for comparisons.

Some of the likely source quarries have faces of considerable length and/or depth and variations in feldspar content between different parts of any one quarry are possible. Because of the cost and practical difficulties involved in taking samples representative of the whole face, particularly the higher parts, the samples taken from the larger quarries may not reflect the full range of feldspar contents present. Where there is other supporting evidence, it may still be reasonable to correlate a masonry stone with a particular quarry even if it has a feldspar content outside the range implied by the quarry samples. A particular case is the two specimens V10Q-S01 and V10Q-S02 which are correlated in table 4.1 with the small Barcombe quarry even though their feldspar contents (3.7% and 3.4%) are significantly lower than those of the quarry specimens (5.7% and 6.4%). It seems reasonable to propose that these two were from the same source as nearby specimens from the same masonry periods, on the basis that they may have come from a higher part of the quarry face where it was not possible to sample. The ranges of feldspar contents in specimens from the two main Barcombe quarries almost overlap and it may be necessary to use supporting archaeological or other evidence to determine the source of any future masonry specimens with feldspar contents in the range 6% to 7%.

There are good reasons why the amount of feldspar should remain reasonably constant both vertically and laterally in a sandstone unit. The similarity of the size, shape and density of the feldspar and silica grains means that their relative proportions do not vary much under
changing conditions of deposition. Gradual changes in the feldspar content of different sandstone units, and within the larger units, would result from slow changes in the source rock and drainage pattern of the rivers supplying the sediment. Hence it is no surprise that feldspar content turns out to be the best feature of the lithology for characterising the quarry sources. This is in marked contrast to factors such as grain size and mica content which vary considerably with changes in the speed of the water current from which deposition took place, which commonly varies both laterally and with time. The variations in such factors, within an otherwise uniform sand deposit, can lead in turn to differences in the way in which the sand becomes lithified into sandstone and hence in the porosity, cementation and pore-filling materials. The differences in porosity between the Stone Fort 2 samples and the samples taken from the big Barcombe quarry (figure 3.8) probably arise because the latter happen to have been taken from areas in the quarry where, for reasons not now apparent, the sand grains were not as well cemented. This more friable stone would probably have been avoided by the masons and hence would not appear in the Vindolanda masonry.

4.4 Supporting evidence

Evidence used to support the feldspar-based correlations may take a variety of forms. The following are examples.

- As section 4.3 makes clear, neither porosity nor grain size is likely in isolation to provide useful evidence on which to assign masonry stones to quarry sources, but they can sometimes provide supporting evidence. The correlation of specimen V09Q-S09 from the 3rd century vicus with the Barcombe East quarry T7 is based on the similarities of all three measured quantities – feldspar content, porosity and grain size (table 3.4).
- Established archaeological interpretations provide some of the key evidence and correlations inconsistent with these must be regarded as suspect. The association of orange-weathering Antonine stone with the Cockton burn quarry is, as discussed in section 3.4.2, a good example of geological evidence being in harmony with long-established archaeological experience. Correlation of these stones with the Cockton Burn rather than Bradley Burn quarries (C2-C9) is based primarily on the proximity of the site to the Cockton Burn valley.
- It seems clear that the first stone fort at Vindolanda was built using stone from the Cockton Burn quarry, the nearest quarry to the site. However, at some time during the Antonine period – the later part of the 2nd century – a change was made to using Barcombe stone, probably from the small Barcombe quarry. This may well have reflected the poor weathering qualities of the Cockton Burn stone. Barcombe stone was used for some rebuilding within the fort and for both faces of the wall around the annex to the west of the fort (figure 4.2). Both types of stone occur in the area of the Antonine vicus (figure 4.1). This change in quarry source may help in clarifying the sequence of modifications to Stone Fort 1 and its vicus.
• The short-lived Severan period fort was built on the site of the Antonine vicus and stone originating from the small Barcombe quarry seems to have been used for this. The fort’s unusual siting may have been influenced by the opportunity to re-use materials of better quality than those on the site of the previous fort. The latter, the Cockton Burn quarry stones, seem to have been re-used for the array of round-house bases thought to represent a “refugee camp” (frontispiece).

• A key requirement is that the volumes of stone “missing” from the various quarries should be in proportion to the volume of masonry constructed from new stone correlated with the quarry. The prime example of this is the association of the largest single volume of masonry, in the 3rd century fort, with the largest quarry in the area.

• The timescale of a particular phase of building is also an important consideration. For a single large project such as either the 2nd century or the 3rd century fort, a single large source is likely to have been used for speed and efficiency. On the other hand, during a period of gradual development, such as the 3rd century vicus, a range of sources may well have been used with stone chosen to meet specific requirements. For example, natural boulders from the Firestone Sill seem to have been attractive as foundation stones but may have been too hard for easy shaping into facing stones.

• Ease and speed of transport were also considerations in the choice of quarry. A single large quarry with a convenient transport route to the site characterises the building of both the main stones forts. For the 3rd century vicus, ease of transport was less of an issue and the opportunity may well have been taken to keep the troops occupied by seeking out the most suitable stone in more distant locations.

• As explained in the 2009-11 report, cobbles collected from the valley bottoms appear to have been used extensively for wall-fill at all periods.
4.5 Other analytical techniques

It is clear that it is the chemical composition of the Vindolanda stones, in particular their feldspar content, which is the key discriminator in determining their sources. The observations described in the 2009-11 report show that, even with a freshly broken surface, conventional field observations cannot determine the feldspar content with sufficient accuracy. However, a technique for rapid, non-destructive, in situ chemical analysis of the sandstones would be very helpful. Two modern techniques, X-ray fluorescence and gamma-ray spectroscopy, might be applicable. However, there are at present some limitations with both of these, even for laboratory analysis. Both analyse only a thin surface layer of the stone and the weathered faces of both quarries and masonry would not give representative results. Some form of surface preparation would be needed which would be both time-consuming and damaging.

X-ray fluorescence can give a complete chemical analysis and portable devices for use in the field are available but there are significant health and safety issues involved in using X-ray devices in an uncontrolled environment. Field devices for analysis by gamma-ray spectroscopy are available and are not unduly expensive but only analyse the three elements with naturally-occurring long-lived radioactive isotopes – potassium, uranium and thorium. The last two are present as trace-elements only and, although they do vary between one sandstone and another, it is by no means clear that these variations would be of use in this case. Potassium is present in the feldspars but also in most mica and some clays and it would remain to be seen whether the proportion of this element would be distinctive in the various sandstone sources.

For the moment it seems unlikely that the costs of an investigation into the use of either of these techniques could be justified. However, both these technologies, and possibly others, are likely to develop in the future and their potential for use at Vindolanda will be kept under review.

4.6 Progress with project objectives

Progress with the objectives set out in section 1.2 is as follows.

1. Four sources of stone used by the Roman builders of Vindolanda have been identified – a quarry in the Cockton Burn valley, the two main Barcombe quarries, and the valley bottoms as sources of wall fill. Three more sources seem likely – small quarries near the Long Stone and at the east end of Barcombe Hill and the boulders associated with the Firestone Sill. Other quarries in the Bradley and Chineley Burn valleys, and in the Firestone Sill east of Thorngrafton Lane, may have had Roman precursors but have mainly been worked in the Industrial period.

2. A chronology of the use of the Roman quarries can now be proposed (see section 6).
3. There are some differences in the sources used in the *vicus* and the fort during the Stone Fort 2 period (post AD 213). However, these differences are likely to represent the different timescales involved rather than any administrative separation.

4. The techniques developed for objectives (1)-(3) could be applied to other structures within the Hadrian’s Wall World Heritage Site. However, the degree of success in identifying the stones sources used will depend on the extent of the differences in feldspar content of the sandstone units exploited in each part of the Wall.
5 Carved and inscribed stones

In May 2012 a visual examination was carried out of many of the carved and inscribed stones from Vindolanda. Most such stones in the museum were examined, either with a hand-lens or by eye from as close as possible. A few fragments not on display were also examined with a hand-lens. In addition, all the altars and other stones from Vindolanda in the museum at Chesters were examined from as close a distance as was possible without obtaining special access. None of the stones observed in this exercise appear to be composed of a material unusual for the area.

All the stones are medium-grained sandstones, with a range of grain sizes and grain morphologies very similar to those seen in the masonry and stone sources studied in this project. The visible contents of feldspar, mica, clay and iron minerals also vary within the ranges encountered in the stones on site. The same comments apply to the porosity, colour and friability. There are no very fine or coarse grained stones and no gritstones with the wide range of grain sizes found in some parts of the Pennines. Nor are there any of the redder sandstones with very rounded grains typical of the aeolian Permo-Triassic sandstones “native” to the western third of the Wall. Whilst it would not be possible to say that all of the stones examined came from the immediate vicinity of Vindolanda, it would be very surprising if any turned out to be anything other than sandstones of Carboniferous age from sources relatively close to the Wall.

Nevertheless, the variation in all these parameters is sufficient to suggest they came from a range of sources, so it does not appear that any one source was particularly prized for this purpose. No attempt was made to correlate the visible characteristics of the stones with their archaeological context, but it would not be a surprise if most of them came from the sources identified (see section 6) as in use for masonry at the time they were originally worked.
6 Project conclusions

The following timeline is proposed for the sources of Vindolanda stone.

1. Pre-Hadrianic stone buildings used sources from Barcombe Hill, possibly near the Long Stone and where the small Barcombe quarry was later developed.

2. Initial construction of the Antonine period fort used stone from a quarry about 500 m to the NW in the Cockton Burn valley. This coincides with well-established archaeological interpretations based on the strong colour and rapid weathering of these stones.

3. The small Barcombe quarry was probably developed for later modifications to the Antonine fort and for the associated annex wall.

4. The stones of the Severan period fort also seem to originate from the small Barcombe quarry and may well represent re-use of Antonine period stone. The unusual siting of this fort, west of the earlier fort, could have been influenced by the availability of better-quality stone in this area.

5. The Severan period round-house bases, which were built on the earlier fort platform, re-used the lower-quality Antonine period stone from the fort.

6. The big Barcombe quarry was opened for the construction of Stone Fort 2 from AD 213. This correlation is consistent with the obvious association between the largest building phase and the largest quarry.

7. For the gradual development of the 3rd century vicus a variety of sources was used, each presumably chosen to match specific requirements. Stone from quarries at the eastern end of Barcombe Hill and naturally occurring boulders from the Firestone Sill were amongst those used.

8. In the 4th century there is likely to have been little, if any, quarrying of new stone. There will have been ample supplies of stone in the abandoned vicus for the rebuilding work carried out within the fort walls.

9. At all periods, stone scavenged from valley bottoms appears to have been used extensively for wall-fill and for cobbled surfaces, although waste stone of all kinds was probably also used.

A number of other conclusions have been reached.

10. The maximum amount of stone in use at Vindolanda is difficult to estimate accurately, as is the cumulative yield of the likely Roman quarries. A rough estimate of the yield of the quarries is somewhat less than an estimate of stone used, but the discrepancy is not sufficient to suggest that a major source remains to be identified.

11. The very similar sandstones in the Vindolanda area can be distinguished only by detailed study of their lithology, principally using feldspar-stained thin sections. Whether these techniques would be applicable to other Roman masonry in the
central Hadrian’s Wall area would depend, at least in part, on the extent to which feldspar contents vary between local sources.

12. The conclusion that Roman use of the big Barcombe quarry was wholly or largely confined to the 3rd century is at odds with the commonly-held view that the (Hadrianic) Thorngrafton Find was discovered there. An alternative interpretation of evidence about the Find is being published elsewhere.

13. The large boulders in the valley bottom below Chesterholm have their source in a small quarry in the valley side and were not rolled down from the big Barcombe quarry as some people have speculated. It has not been possible to clarify whether this small quarry is of Roman origin.

14. The shape of the landscape in the area, and particularly the size of the valleys, is largely unchanged in the past 15,000 years so the Chineley Burn valley around Chesterholm cannot have been a major source of Roman stone.

15. Apart from the quarry sources described in table 4.1, none of the other quarries listed in table 2.1 can be clearly linked to Vindolanda. Most of them are likely to be of 18th or 19th century origin.

16. Analytical techniques other than the use of thin sections are available which might in future provide a cheaper, more rapid and less destructive method of distinguishing the sandstones concerned. However, none are yet sufficiently mature to have been applicable to this project.

17. The carved and inscribed stones examined in the Vindolanda and Chesters museums are all of types of sandstone to be found in the locality.

Finally it should be noted that, although conclusions 6 and 7 above do not support the idea that the 3rd century fort and vicus operated as an integrated settlement, neither should they be taken as evidence to the contrary. Rather, the distinction between the sources of the fort and vicus stones is likely to represent a distinction between the circumstances in which these structures were built. Initial construction of the fort will have been a single, rapid undertaking of considerable scale, for which a single, well-organised source of stone was required – i.e. the big Barcombe quarry. The vicus, on the other hand, not only incorporated stone from earlier buildings but also was constructed over a longer period as a series of individual buildings or complexes for which time was available to seek out the most appropriate materials.
7 References and Acknowledgements


I am most grateful to Andrew Birley for his unstinting support for the project and for much helpful advice and guidance. Barbara Birley kindly arranged for me to examine the carved and inscribed stones in the Vindolanda Museum. Luis Albornoz-Parra, the building stones petrologist at the British Geological Survey in Edinburgh, has been my mentor in understanding and interpreting the thin sections. John Fletcher prepared the thin sections at the BGS in Keyworth, where Tony Miladowski arranged for me to use one of the Survey’s microscopes. Other BGS experts have provided much helpful advice. Throughout the project, I have been helped by discussions with so many of the staff, Friends and volunteers at Vindolanda that to name them all would be impossible, but their support and enthusiasm have been invaluable.
An interpretation of quarrying evidence in the Vindolanda area