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The building stones of Thirlwall Castle, Northumberland National Park

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This study was commissioned by the Northumberland National Park, but the views expressed in it are not necessarily those of the National Park.

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PREFACE

This report describes the results of a survey of the stones present within the visible standing fabric of the building. The work was undertaken as a contract (No GA/00F/112) between the British Geological Survey and Northumberland National Park. Fieldwork was carried out by B Young and C Vye during November 2000. Petrographical examination of thin sections of selected rock types, taken from the building, was undertaken by E Phillips during December 2000.

The assistance of staff of Northumberland National Park; The Archaeological Practice, Department of Archaeology, University of Newcastle upon Tyne, and Historic Building services is gratefully acknowledged.

1. INTRODUCTION

Thirlwall Castle (Figure 1) is one of the finest surviving examples of a mid-14th century Borders Hall House. It stands on a high bank on the north bank of the Tipalt Burn approximately 2.5 km east of Gilsland, about 0.75 km north of Greenhead and approximately 120 m north of the course of Hadrian's Wall. Since coming into the care of Northumberland National Park the castle has been the subject of a variety of studies, including its history and archaeology (Ryder, 1993/1997) and the lichen flora found on the walls (Simkins, 2000a; 2000b, 2000c).

At the time of this investigation scaffolding was in place to the full height of the building. All parts of the external and internal walls, accessible at the time of the investigation were examined. Some areas, not safely accessible, were not examined at close range though general features of the stonework were observed from appropriate vantage points. Lithological characteristics discernible on site, e.g. rock type, comparative grain size, colour, reaction to 10% hydrochloric acid, state of weathering, etc. were noted. In addition, samples of a number of characteristic rock types were obtained, under the supervision of Northumberland National Park staff and masonry contractors, for more detailed petrographical examination. The study concentrated on the geological materials present in the original fabric of the building. This report offers comments on stone types and the associated mortar. Care was taken to distinguish any materials incorporated into the fabric during the restoration work on the building.

The descriptions and discussion presented in this report are based entirely upon available published sources, unpublished BGS and other records, the observations made during site visits during November 2000 and the results of petrographical examination of rock samples obtained from rock samples collected during the investigation. No attempt has been made at any appraisal of the structural condition of the building or of the ground conditions beneath them: the report is not in any sense the report of a structural survey. None of the data contained in this report should be regarded as a substitute for full and appropriate structural and geotechnical investigations if any remedial or other works are contemplated.

2. GEOLOGICAL SETTING OF THE CASTLE SITE

Thirlwall Castle lies on the outcrop of rocks of Lower Carboniferous age. In the published geological mapping (Institute of Geological Sciences, 1980) and descriptive accounts of the area (Trotter and Hollingworth, 1932; Johnson, 1997) these rocks are classified as belonging to the Lower, Middle and Upper Limestone Groups. The geological setting of the castle, and a review of the most up to date stratigraphical classification of these rocks, is contained in a separate report on the geological setting of the castle and its neighbourhood (Young, 2000).

The Carboniferous rocks of this area typically comprise a repetitive sequence of limestones, sandstones, siltstones and mudstones, locally with a few coal seams. The Carboniferous rocks are intruded by a suite of basic igneous intrusions of Permo-Carboniferous age, mainly comprising the dark grey rock known as dolerite, and collectively known as the Whin Sill.

These rocks are exposed in the bed and banks of the Tipalt Burn, both immediately beneath the castle and upstream for several kilometres. They are also exposed along the course of Hadrian's Wall and in the surrounding countryside where they give rise to a very distinctive topography distinguished by well-marked scarp and dip features on the outcrop of the comparatively resistant sandstones and limestones, with corresponding belts of low, or 'slack' ground marking the outcrop of weaker beds such as siltstones and mudstones. The hard and extremely resistant Whin Sill typically gives rise to prominent ridges and cliffs, along which the course of Hadrian's Wall runs for many kilometres east of the Thirlwall area.

Over much of the area in the immediate neighbourhood of the castle, these 'solid' rocks are concealed beneath a mantle of superficial or 'drift' deposits, mainly of glacial or later origin.

Boulder clay, or till, is the most widespread of these deposits. This is a variable, generally heterogeneous accumulation of clay or sandy clay with a substantial proportion of included pebbles, cobbles or boulders. It comprises the debris carried by the ice sheets and deposited both beneath the ice and dumped by the ice as it melted. The included rock fragments give important clues to the derivation, and thus direction of flow, of the ice sheets. Whereas locally derived rock types such as Carboniferous sandstones and limestones, together with Whin Sill dolerite, predominate in the Thirlwall area, substantial numbers of far-travelled, distinctive rock types, known as erratics, are also present. These include boulders of granite derived from the Criffell area of SW Scotland, boulders of dark greenish-grey greywacke sandstone also from SW Scotland, and distinctive lavas and other volcanic rock types from the Lake District. Numerous examples of these glacial erratics may be seen as 'clearance stones' in the nearby fields, incorporated into field walls and in parts of Thirlwall Castle.

The superficial deposits also include areas of glacial sand and gravel. These are accumulations of generally well-sorted sands and gravels deposited by water during melting of ice sheets. Comparatively extensive spreads of such deposits occur near Gilsland, though the 1:10 560 scale geological map Northumberland (New Series) 88 NE notes a very small patch of such glacial sand and gravel immediately beneath the castle.

Narrow belts of alluvium and associated river terrace deposits, which flank the lower reaches of the Tipalt Burn, comprise a variable mixture of silts, sands and gravels.

3. ECONOMIC GEOLOGICAL OF THE THIRLWALL AREA

A variety of mineral products have been obtained from the 'solid' and 'drift' deposits of the area.

Many of the sandstones have been quarried as a local source of building stone. Small, long-abandoned, quarries may be seen in most of the sandstone outcrops. It is almost certain that at least some of these served as sources of stone to the Roman masons in the construction of Hadrian's Wall, though undoubted examples of Roman quarries cannot be identified within the Thirlwall neighbourhood.

Other long abandoned small quarries may be seen in the outcrops of many of the limestones. These are most likely to have provided raw material for burning to produce quicklime and slaked lime for soil improvement, though it is extremely likely that some also provided the source of lime mortar for the construction of Hadrian's Wall and later structures including Thirlwall Castle.

There is evidence that some of the thin coal seams of the area have been worked in the neighbourhood of the Tipalt Burn, possibly to supply fuel for lime burning. Coal working from the Little Limestone seam continues today at Blenkinsop Colliery near Greenhead.

The dolerite of the Whin sill has been worked, mostly in comparatively recent years, as a source of high quality roadstone and for the making of setts for road making. Walltown Quarry, approximately 1 km east of Thirlwall Castle, was a major source of this material until its closure in 1978. Because of its generally intractable nature the Whin Sill was rarely, if ever, quarried as a source of building stone. Indeed, the Roman masons and engineers clearly avoided its use, except very locally in the rubble core of Hadrian's Wall.

River gravels and glacial sands and gravels have provided local sources of aggregate for building and the making of mortar.

Bricks and tiles were used by the Romans in the construction of buildings within the Hadrian's Wall area. Whereas some may have been imported from outwith the area, it is likely that some were produced locally using such raw materials as glacial or alluvial clays or silts. A few very small fragments of broken brick or tile are present within the fabric of Thirlwall Castle.

An adit on the south bank of the Tipalt Burn is said, by Trotter and Hollingworth (1932) to have been driven southwards in search of lead ore. The reasons for the exploration are not clear as no fault or other potential mineralised structure can be detected here and no signs of lead ore, or other mineralisation, can be found here today. It is possible that the adit was driven in search of coal, as thin coal seams are known to occur nearby between the Single Post and Scar limestones, though the adit is not well-sited to explore either of these.

4. STONE TYPES WITHIN THE CASTLE FABRIC

Even to a casual observer a first glimpse of the walls of Thirlwall Castle reveals a varied pattern of stone colours within the external walls. Closer examination discloses that the castle is almost wholly constructed of sandstone, though it is clear that several distinct sandstone types are present, derived from several, probably quite separate, sources. It is also clear from the very distinctive shape and dimensions of many of the blocks, that much of the stone, within the main body of the walls, has been derived from nearby sections of Hadrian's Wall. It seems that the builders of Thirlwall Castle quite understandably exploited the Wall as an extremely convenient source of ready-made building blocks, thus reducing the requirement for rather more costly newly quarried stone. An examination of the walls reveals that Hadrian's Wall was probably not the sole source of building materials, and, as discussed later, there are grounds for suggesting that some stone may have been specifically quarried for particular uses within the castle.

Detailed examination of the building reveals that a variety of other stones are present, mainly within the rubble core of the walls.

The descriptions of stone types which follow are based mainly upon the characteristics observable on site. In order to provide more detailed petrographical descriptions, thin sections were prepared from seven samples of stone obtained either from loose blocks available during restoration work, or from small fragments specially collected from blocks *in situ* in the walls. Descriptions of these thin sections are incorporated in the following accounts. The thin sections have been added to the British Geological Survey collection of English rocks under the registration numbers quoted.

4.1 Sandstones

For the purposes of this report the sandstones present within the castle will be considered as two main groups.

4.1.1 Sandstones in the main walls

Within the main body of the castle walls a very large proportion of the stone appears to be re-used blocks from Hadrian's Wall. It is likely that the Roman masons were supplied with sandstone from a variety of sources, perhaps with stone from different quarries and different geological units being employed simultaneously in the construction of any individual stretch of wall. The re-use of Roman stone in the castle is likely to have further confused or mixed the stone types.

The present investigation has revealed that, for the purposes of description, the sandstones within the main body of the walls may be grouped into three broad types referred to here as types 'A', 'B' and 'C' respectively. The essential characteristics of these are described below.

These three categories have been adopted as the most convenient and effective means of describing the essential characteristics of the stone present in the building. Whereas the stone within each type shares most, or all, of a number of general distinguishing characteristics, it is not implied or suggested that each type is necessarily derived from a single source such as an individual quarry, or even the same geological unit. Clearly, when examining stone *in situ* in a building of this sort it is not always possible to obtain freshly broken samples and thus the grouping adopted here depends to a considerable extent upon the appearance of the stone in long-weathered masonry faces. Wherever possible during the investigation, broken examples of the main stone types, generally derived from blocks available during the restoration work on the walls, were examined as carefully as possible. The amount of such material was, however, limited and it was clearly not possible to examine all aspects and features within the individual stone types.

Despite these considerable limitations, the descriptions which follow give a useful insight into the essential features of the main stone types. It is hoped that these will give a clearer understanding of the materials present within the fabric of the building, and may serve as a guide to future studies of the nature and sources of stone within Hadrian's Wall and more recent structures constructed of materials re-cycled from it.

A very small number of blocks of reddened sandstone may be seen locally in the walls: these are described separately below.

'Type A' Stone

This is typically a medium to coarse-grained, sandstone in which kaolinised feldspar is conspicuous as white or very pale buff earthy-looking grains in hand specimens. The stone may be regarded as a sub-arkosic sandstone The rock exhibits no reaction to 10% hydrochloric acid, indicating that there is no calcareous cement or calcareous components. Some examples of the rock are slightly micaceous. It is generally massive (Figure 2) but faint traces of bedding are present locally (Figure 3). The colour varies slightly between blocks from pale buff to dull yellow. An ochreous speckling, perhaps representing oxidised pyrite or siderite grains, is evident in some blocks. Several blocks exhibit conspicuous concentrations of secondary iron oxides in the form of Liesegang ring structures (Figures 4 and 5). In several places differential weathering of the comparatively hard ferruginous cement has given rise to striking honey-comb weathering (Figures 6 and 7). A few blocks contain hard concentrations of secondary iron oxide as narrow veins and spherical nodules, which protrude from the weathered face by up to 1 cm (Figures 8 and 9).

Sandstone distinguished here as 'Type A' stone, is the main constituent of the castle. Most of the blocks of 'Type A' stone are roughly hewn squares between 20 and 30 cm across when seen in the faces of the wall. In parts of the building, notably in parts of the north and west walls, it is conspicuous due to its greater susceptibility to weathering compared to the much more resistant 'Type B' stone. (Figures 2, 10 and 11). The tendency of blocks of this stone to exhibit a crude spheroidal weathering is discussed below.

A thin section (ED 74390 (Figure 39 a & b), prepared from a loose block of this stone, reveals a medium-grained, well sorted, compositionally mature, matrix-poor, quartz-rich sandstone (quartz-arenite) which possesses a closely packed, clast-supported texture. The primary intergranular porosity within this sandstone forms approximately 10 to 15% of the total rock. A minor amount ($\leq$ 1% of the total rock) of the porosity present is secondary in nature and formed due to the dissolution of feldspar.

Clastic grains are angular to subrounded in shape with a low to locally moderate sphericity. However the shape of the clasts has been modified due to pressure solution of the quartzose grains and development of quartz overgrowths. Pressure solution resulted in the main mode of cementation within this sandstone. The detrital assemblage is mainly composed of monocrystalline quartz. Quartz is strained to unstrained with a variably developed undulose extinction. Minor to accessory detrital components include plagioclase, polycrystalline quartz, tourmaline, muscovite and microcline.

Traces of a patchily developed cavity lining opaque coating is present within this sandstone and may locally partially fill the intergranular pore space. The development of this opaque lining to some pore spaces post-dated pressure solution of the quartzose grains and development of quartz overgrowths. Traces of a brown strained carbonate cement were also noted within this sandstone.

The stone of the quoins and windows very closely resembles the 'Type A' stone of the main body of the walls.

'Type B' Stone

This is typically a fine to medium-grained, massive, dull grey, quartzose sandstone. The stone is characteristically hard and exhibits an irregular hackly fracture suggesting a siliceous cement (Figure 10). The rock exhibits no reaction to 10% hydrochloric acid, indicating that there is no calcareous cement or calcareous components. A few blocks contain vague carbonaceous streaks which may represent rootlet traces. One block of this stone, in the south wall exhibits conspicuous hollows which almost certainly represent weathered-out rootlet traces (Figure 12). Very small brown ferruginous flecks, perhaps due to the oxidation of very scattered original pyrite or siderite grains, are localised in thin bands. The presence of rootlet traces suggests that the rock represents a fossilised sandy soil. Such siliceous sandstones, found within sequences of Carboniferous rocks of this sort, are commonly termed ganister.

Most of the blocks of 'Type B' stone are roughly hewn and present a squared section of between 20 and 30 cm across when seen in the faces of the wall. The distinctive grey colour on the weathered surfaces, and the tendency of this stone to stand proud from the castle walls, in contrast to the other sandstones, is a highly characteristic feature of this stone (Figures 10, 11 and 13). Indeed, these weathering features allow comparatively ready identification of 'Type B' stone even in the heavily lichen-encrusted faces of the south wall.

A thin section (ED 7440) (Figure 40 a & b), prepared from a loose block of this stone, reveals a fine- to medium-grained, well sorted, compositionally mature, matrix-poor, slightly feldspathic, quartz-rich sandstone which possesses a closely to very closely packed, clast-supported texture. The porosity forms approximately 10% of this sandstone and is mainly primary, intergranular in nature. However, trace amounts of a secondary porosity caused by the dissolution and removal of feldspar is also present

Detrital grains are angular to subrounded in shape with a low to moderate sphericity. However, grain shape has locally been highly modified due to pressure solution of quartzose grains and the development of quartz overgrowths. Pressure solution led to the main form of cementation within this sandstone and resulted in the development of sharp planar, curved to locally serrated/interlocking grain boundaries. The clast assemblage is dominated by monocrystalline quartz which possesses a variably developed undulose extinction. Minor to accessory detrital components include plagioclase, microcline, K-feldspar and muscovite.

Traces of a patchily developed cavity lining opaque coating is present within this sandstone and may locally partially fill the intergranular pore space. The development of this opaque lining to some pore spaces post-dated pressure solution of the quartzose grains and development of quartz overgrowths. Trace amounts of a cryptocrystalline chloritic or clay-rich matrix/cement were also noted within this matrix poor sandstone

'Type B' stone is distributed throughout all the external faces of the walls of the castle, though its abundance appears show a general decrease with height.

'Type C' Stone

Sandstones distinguished here as 'Type C' stone comprise a number of generally fine to medium-grained sandstones. None of the 'Type C' stone tested gave any reaction to 10% hydrochloric acid, indicating that there is no calcareous cement or calcareous components. Crude lamination, including ripple cross-lamination, is characteristic and is commonly accentuated by weathering (Figures 14 and 15). Kaolinised feldspars are common, and vertical to sub-vertical carbonaceous rootlet traces transect the sedimentary laminations in some blocks (Figure 16). 'Type C' stone is generally pale buff to yellowish brown in colour. Local concentrations of iron oxide form dark brown patches up to 1 cm diameter and in places, for instance in the lower courses of the western outer face of the north wall, Liesegang rings are also present and appear to follow bedding surfaces.

A thin section of a sample of this stone (ED 7441) (Figure 41 a & b) reveals a fine- to very fine-grained, moderately to locally poorly sorted, matrix-poor, closely to very closely packed, clast supported quartz arenite which possesses a well developed/preserved sedimentary lamination and/or cross lamination. Primary intergranular porosity forms approximately 10% of the total rock. Trace amounts of a secondary porosity were also recognised formed by the dissolution and removal of feldspar. A variation in the porosity of the sandstone appears to be partially controlled by the sedimentary lamination/lithology.

The sedimentary lamination is defined by a change in clast grain size with the finer grained laminae also containing a higher modal proportion of detrital micas. Clastic grains are angular to rounded in shape. However, the grain shape has been modified due to pressure solution and localised development of quartz overgrowths. Pressure solution led to the main form of cementation within this sandstone and the development of interlocking, serrate grain boundaries.

The clast assemblage is dominated by monocrystalline quartz. Minor to accessory detrital components include plagioclase, K-feldspar, muscovite, zircon, opaque minerals, allanite, tourmaline and chlorite. Compaction of this sandstone resulted in localised kinking of detrital micas.

'Type C' stone is found rather sparingly throughout the outer faces of the castle walls. Good examples are to be seen in the topmost course of the plinth near the foot of the north wall (Figure 15).

Reddened sandstone

A few blocks of reddened sandstone are present locally within the rubble core of the walls.

A few fragments in the rubble within the lower part of the eastern end of the south wall comprise medium-grained sandstone of a generally uniformly brick-red colour (Figure 17). In the rubble core, high on the eastern part of the north wall, a few blocks of medium-grained yellowish brown sandstone exhibit a rather patchy brick-red colouration (Figure 18).

The few examples of reddened sandstone, present within the building, appear to be Carboniferous sandstones which have suffered some form of secondary reddening, perhaps due to exposure to fire, prior to their incorporation into the fabric. No examples of red sandstones from the Permo-Triassic rocks of Cumbria or SW Scotland have been recognised in the castle.

4.1.2 Sandstone quoins and windows

A striking feature of the building is the presence of comparatively large sandstone blocks as quoins and casings to the windows. Unlike the stone employed throughout the remainder of the walls, the stone of the quoins and windows has clearly been dressed and shaped specifically for its purpose (Figures 19 and 20). Moreover, the similarity of the stone within these blocks is conspicuous and is consistent with a common source.

Examination of the quoins and windows reveals that the stone is typically a coarse-grained sandstone. Scattered kaolinised feldspar grains are sufficiently abundant to apply the term sub-arkosic sandstone to the rock. No mica was seen in hand specimen. The rock gives no reaction to 10% hydrochloric acid, indicating that there is no calcareous cement or calcareous components. The rock generally exhibits a pale buff colour on weathered faces, commonly with a number of small rather darker brown ochreous flecks, perhaps reflecting the weathering of very scattered iron minerals such as pyrite or siderite, though no examples of these were observed during the field examination. Very rarely iron oxides occur in small rounded concentrations giving the appearance of small nodules up to approximately 2 cm across (Figure 20). These almost certainly result from local concentration of iron salts during weathering. Colour differences between blocks is within the range of variation which may be expected within a single quarry or outcrop. Crude lamination is clearly apparent on many blocks, commonly with clear evidence of cross-bedding (Figures 21 and 22). A hollow cast of a fossilised plant stem is conspicuous in the edge of a block within the lowest window on the south wall (Figure 23).

A thin section (ED 7438) (Figure 42 a & b) of a sample taken from a fallen quoin shows a medium-grained, moderately to well sorted, compositionally mature, massive, slightly feldspathic quartzose sandstone (quartz-arenite) which possesses a moderate to open packing resulting in a clast supported texture. This sandstone has a relatively high porosity, with open intergranular pore spaces forming approximately 25 to 30% of the total rock. In general the porosity is a primary feature of the rock. However, a minor proportion of the pore spaces appear to have been formed by the dissolution and removal of detrital feldspar.

Clastic grains are subangular, subrounded to rounded in shape with a low to moderate sphericity. However, the shape of these grains has been modified due to pressure solution and the development of quartz overgrowths. These overgrowths and pressure solution between adjacent quartzose grains resulted in the main modes of cementation within this sandstone. Pressure solution also resulted in the etching of clast grain boundaries which have become increasingly serrated and locally interlocking.

The clast assemblage is dominated by monocrystalline quartz with subordinate to minor polycrystalline quartz, plagioclase and K-feldspar. Both feldspars appear to have been susceptible to alteration and dissolution. Quartz is strained to unstrained and possesses a variably developed undulose extinction. Other minor to accessory detrital components present include chloritised biotite, sericitised rock or feldspar, quartz-muscovite rock, mudstone/siltstone, muscovite and opaque minerals.

Minor kinking of detrital micas was noted. Very little obvious matrix has been recognised within this clean, quartz-rich sandstone. However, trace amounts of a cryptocrystalline chloritic and/or clay cement/matrix were recorded.

The general characteristics of the stone used in the quoins and windows resembles that previously described as 'Type A' stone elsewhere in the main body of the walls.

Other aspects of the uses of this stone, its weathering characteristics and possible sources, are discussed below.

4.2 Other stones

A variety of other stone types are present in the rubble cores of the walls.

4.12.1 Limestone

Angular blocks of medium grey bioclastic limestone, mainly up to about 15 cm across, occur sparingly within the original rubble core of the building. Good examples were observed in the un-restored rubble exposed in the eastern walls (Figure 17), as well as in the large fallen blocks of masonry at the foot of the eastern wall.

Several rather larger angular blocks (up to 25 cm across) of extremely similar grey limestone are incorporated into the rubble core of the walls at the very top of the building and also locally within the upper sections of the east wall. Discussions with the masons engaged on restoration work at the time of this investigation indicate that these have almost certainly been introduced during stabilisation of the walls.

4.2.2 Greywacke sandstone

Greywacke is a name applied to a poorly sorted sandstone with a high proportion of fragments of material such as shale or siltstone.

Pebbles of dark greenish grey greywacke sandstones may be seen within the original mortar in several parts of the building). Cobbles and small boulders up to 15 cm across are present in the rubble core of the tops of the western walls (Figure 24).

A thin section (ED 7442) (Figure 43 a & b) prepared from a sample of greywacke sandstone from within the rubble core of the walls reveals a medium- to coarse-grained, immature, altered, poorly sorted, matrix-rich, immature, massive, slightly feldspathic greywacke sandstone which possesses a moderately packed, matrix to locally clast supported texture. Very little or no obvious porosity has been recognised within this sandstone. Clastic grains are angular to subangular in shape with a low sphericity. A weak preferred alignment of elongate clastic grains was also noted; clasts possibly aligned parallel to bedding.

The mixed clast assemblage is mainly composed of monocrystalline quartz, feldspar and variably degraded lithic clasts. Metasedimentary rock fragments are a common minor component within this wacke sandstone. The lithic clasts are composed of a range of lithologies including: siltstone, felsite/cherty rock, very fine-grained igneous/volcanic rock, mica-rich schist or phyllite, quartzite, very fine-grained psammite, very fine-grained sandstone and quartz mylonite or schistose rock. Other minor to accessory detrital components include plagioclase, K-feldspar, polycrystalline quartz, white mica/muscovite, chlorite, chloritised biotite, perthite, micrographic intergrowth and opaque minerals.

Minor amounts of a chlorite cement is present within this sandstone. Trace amounts of carbonate were noted replacing detrital feldspar. Compaction resulted in the localised kinking of detrital micas and the fracturing of more rigid detrital quartz and feldspar grains. Unstable lithic clasts are flattened and/or moulded around neighbouring more rigid clasts.

4.2.3 Slate

Small thin slabs of medium grey slate are present very locally in both the north and west walls, where they have clearly been employed as fillets to pack the space between quoins in order to present a level base (Figures 25 and 26).

A thin section (ED 7444) (Figure 45 a & b), prepared from a small sample of the slate present between the quoins in the west wall, reveals a very fine-grained, highly foliated, very low-grade metamudstone (slate). A well developed, homogeneous, closely spaced slaty cleavage is defined by aligned white mica flakes. The rock also contains disseminated opaque minerals and small relict muscovite and quartzose detrital grains. Small porphyroblasts and aggregates of chlorite (± white mica) are also present and exhibit a preferred shape alignment parallel to the slaty cleavage.

The source of this material is discussed below.

4.2.4 Granite

At least two well-rounded boulders of coarse-grained granite are present in the rubble cores of the walls.

The clearest example is a roughly ovoid boulder approximately 30 cm across within the upper, internal parts of the north wall (Figure 27). Although it was not possible to break, or collect a specimen from this boulder, its external features are consistent with it being an example of the Criffell Granodiorite, boulders of which are comparatively common in the clearance stones of nearby fields, derived from the underlying boulder clay.

A second granite boulder, up to 25 cm across, is present in the rubble core at the head of the southern wall (Figure 28). The smooth surface of this boulder, together with a significant covering of encrusting lichen, prevents a detailed description of the rock type, though it is likely to be very similar to the previously described boulder.

4.2.5 Porphyritic dacite

A single block of this stone occurs within the rubble core at the head of the western wall (Figure 29). The block is up to 25 cm across and is a broken portion of a larger comparatively well-rounded boulder. It is a fine-grained pinkish buff rock in which abundant small (up to 10 mm) phenocrysts of white feldspar and a few glassy quartz phenocrysts, are conspicuous. A thin section (ED 7443) (Figure 44 a & b) of a fragment of this block reveals a fine-grained, altered, microporphyritic to very weakly macroporphyritic dacite (originally would have been termed a porphyry) which comprises an inequigranular assemblage of plagioclase, chlorite, quartz, biotite, K-feldspar and white mica. Alteration of this dacitic rock resulted in the sericitisation of feldspar phenocrysts and the matrix, as well as the total replacement of biotite by chlorite, white mica and opaque oxide.

The phenocrysts are composed of plagioclase, biotite and quartz. Biotite originally formed anhedral to weakly subhedral flakes which exhibit a weakly developed preferred shape alignment, defining a weakly developed igneous foliation. Plagioclase forms anhedral to subhedral, equant to lath-shaped crystals which locally possess a well developed oscillatory zonation. Plagioclase phenocrysts range up to 3.0 mm in size, but are typically $\leq$ 1.6 mm in length. They typically occur in clusters of 3 to 4 randomly orientated crystals which locally exhibit minor rounding due to partial resorption. Rounded quartz phenocrysts range up to 2.0 mm in diameter. Quartz is unstrained to weakly strained and may be enclosed within a very fine-grained radiating, quartzose reaction rim.

The groundmass is massive and composed of a cryptocrystalline felsitic mosaic of plagioclase, quartz and K-feldspar. The groundmass also contains finely disseminated opaque oxides resulting in a dusty appearance in plane polarised light. Rosettes and aggregates of fine-grained white mica/sericite and small rods of apatite are also present within the groundmass.

4.2.6 Coal

The original mortar exposed in various parts of the building exhibits small (generally less than 1 cm) fragments of coal. These are especially conspicuous in parts of the eastern wall (Figure 30), and in the large block of fallen masonry at the foot of this wall. All coal fragments examined are un-burnt, though are commonly rather friable due to weathering.

4.2.7 Miscellaneous rock types

Original sections of the rubble core and masonry locally exhibit pebbles and a few small cobbles, up to approximately 5 cm, of dark greenish grey volcanic sediments, closely resembling rock types found within the Ordovician Borrowdale Volcanic Group rocks of the Lake District (Figures 17 and 31). A systematic study of these rocks would require the removal of a substantial number of examples and would result in a level of damage to the walls which could not be justified by the information to be gained. For the purposes of this investigation these rocks are therefore recorded as comprising a suite of volcanic rocks derived from the Lake District.

A few small pebbles of white vein quartz, of unknown provenance, were noted locally.

4.2.7 Brick

Although not a rock type, the presence of a fragment of broken brick, up to 4 cm across, was recorded within the mortar in the wall core of the northern part of the east wall (Figure 32). This is clearly an original component of the wall.

5. MORTAR

Although substantial areas of the building's original mortar had been effectively concealed beneath areas of modern repair work at the time of this investigation, considerable areas of original mortar remained accessible within the rubble cores of the walls. The most extensive areas of original mortar visible during this investigation were within the lower parts of the eastern walls and locally within the lower parts of the west wall.

The detailed characteristics of the mortar, including its chemistry, are beyond the scope of this report.

The mortar visible in the walls contains an abundance of pebbles and small cobbles, incorporated as aggregate. The various rock types present within this material has been outlined above (**4.2.2, 4.2.7** and **4.2.8**). The generally well-rounded form of these pebbles and cobbles clearly indicates that they must have been derived either from nearby river shingle or from patches of glacial sand and gravel. It is worth recalling that a very small patch of glacial sand and gravel is mapped beneath the site of the castle on British Geological Survey sheet Northumberland (New series) 88NE. It is likely that this was exploited by the castle's builders as an extremely convenient source of gravel. No exposures of this material were visible at the time of the investigation.

As noted above (**4.2.6**) coal fragments are locally common within the mortar. It is extremely unlikely that these were deliberately included within the mix, as they would contribute nothing to the properties of the mortar. It seems probable that they represent a form of contamination, perhaps from a stockpile sited near the lime kilns from which the mortar was supplied.

6. SPECIALISED USES OF STONE WITHIN THE CASTLE

The comparatively unsophisticated design of the building placed few demands on its builders to seek, or employ, particular stone types for specialised purposes. There is no evidence of stone being required for fine carving or for any other ornamental use.

The major parts of the walls clearly were constructed from a rather random assortment of sandstone blocks, most of which were almost certainly obtained by re-using stone from the nearby Hadrian's Wall. The characteristic squared form of Roman stones was ideally suited to their re-cycling into a building of this sort. Rough or un-dressed stone was employed throughout for the rubble cores of the walls. Much of this was, no doubt, also derived from broken blocks from Hadrian's Wall, though smaller amounts of stone in the form of rounded boulders was also used for this purpose. These stones may have been obtained from clearance stones from the neighbouring fields, or from the excavation of the castle foundations. Some of these may perhaps have been re-cycled from Hadrian's Wall where the Roman builders too, may have employed convenient cobbles and boulders of this sort. The generally sound state of large areas of the walls, particularly on the south side of the castle, testifies to both the quality of much of the stone and to the skill of the masons.

A small area of surviving arching in the NW turret is constructed of comparatively large slabs of sandstone which most closely resembles the 'Type A' stone described above (Figure 33). Some of these slabs exhibit a slight wedge-shaped form, ideally shaped to form the components of an arch. It seems likely that in this arch the natural tendency of cross-bedded stone of this sort to split into wedge-shaped blocks has been very effectively exploited by the builders. The stones do not appear to have been deliberately cut or dressed to this shape.

The construction of the substantial walls and associated windows, required large blocks of stone to provide quoins and window components. As noted above there is a very marked similarity of stone type in all quoins and windows, consistent with the stone being derived from a common source. There seems little doubt that the blocks employed were dressed specifically for the purpose, perhaps with 'offcuts' being employed within the main body of the wall.

In addition to the quoins and windows, comparatively large slabs of sandstone have been widely employed throughout the castle in the top course of the plinth. Although, no doubt, formerly present at the base of all external walls, this course is today best seen along the foot of the northern and southern faces, with a small area still exposed at the northern end of the western face. Unlike the quoins and windows, the uppermost course of the plinth appears to be composed of a number of sandstone types. Extensive lichen coverage, especially on the southern wall, precludes a detailed examination of the stone types. However, it is clear that stones exhibiting the characteristics of types 'A', 'B' and 'C' stone are present (Figures 13 and 14).

In several parts of the castle small thin slabs of stone have been employed to level courses of stone, particularly some quoins. In most instances thin slabs of sandstone have been employed (Figure 21, 22, 25 and 34). An interesting use of slate for this purpose has been noted in part of the north wall (Figure 25) and the west wall (Figure 26).

The provenance of these stones, including their possible derivation from blocks recovered from Roman structures, is discussed below (**8**).

7. WEATHERING OF STONE

The external masonry of Thirlwall Castle has been exposed to weathering for over 6 centuries. The re-cycled Hadrian's Wall stones had clearly suffered several centuries of weathering prior to their being incorporated into the castle, though for part of this time many of the blocks may have been partially of wholly buried beneath overgrown portions of the Wall. Many of the stones have therefore experienced many centuries of weathering. Since its abandonment as a residence, and its decline to becoming a roofless ruin, the internal walls have also suffered substantial weathering. In addition to weathering, significant vegetation growth on the walls, has caused severe deterioration to parts of the building (Figure 35).

It might be expected that during the long period of weathering to which the castle's stones have been subjected, that the aspect of individual walls may have affected the behaviour of the stone. There seems little clear evidence for this. It is however, worth noting the prolific growth of encrusting lichens on the south walls compared to the other walls, notably the dark north wall.

An inspection of any of the external walls reveals considerable local variation in the susceptibility of different stone types to weathering. Whereas many of the blocks in the castle appear to have been re-cycled from a previous use within Roman structures, others may have been new blocks obtained for the construction of the castle. It is therefore impossible to be certain that all blocks in any given portion of the castle have experienced the same length of exposure to weathering.

In the main body of the walls the three main stone types, recognised in this study, exhibit individually distinctive styles of weathering. Indeed, the weathering characteristics comprise an important element in classifying the stone types.

Although clearly a durable stone, 'Type A' stone typically exhibits pronounced weathering. It is much less resistant to weathering than 'Type B' stone. Much of the 'Type A' stone appears to be comparatively massive with many blocks displaying little sign of original lamination. Many blocks exhibit a rather exfoliated form with the successive spalling of thin layers parallel to the sides of the block, removing corners and angles. This results in a very characteristic style of weathering, seen in many parts of the building, particularly the north wall, where a progressive rounding of the outline of 'Type A' stone blocks is conspicuous (Figure 36). 'Type A' stone in which original lamination is conspicuous may be seen in parts of the south wall, where differential weathering of the individual laminae imparts a fluted appearance to the blocks (Figures 3 and 4). In a few blocks, classified as 'Type A' stone, small rounded concentrations of secondary iron oxides form out-weathered nodular protuberances on exposed surfaces (Figure 8). In other blocks similar iron oxides are concentrated in complex Liesegang ring structures. Like the iron oxide-rich nodules these too are comparatively resistant to weathering, resulting in a distinctive 'honey comb' like weathering in affected blocks. Several conspicuous examples of this weathering are present in the south wall (Figures 6 and 7).

'Type B' stone is typically extremely resistant to weathering. Most blocks of this stone exhibit comparatively sharp edges to the blocks, suggesting that little abrasion due to weathering has affected them over many centuries of exposure. 'Type B' stone commonly is conspicuous by its almost freshly quarried appearance when seen in juxtaposition with other stone types, notably 'Type A' stone. Good examples of this contrast are visible on the lower parts of the north wall (Figures 2, 10 and 13) and locally on the west wall (Figure 11). 'Type B' stone typically exhibits few signs of original lamination and very few, if any blocks of this stone appear to show any form of deterioration due to inappropriate placing in the wall.

The sandstone here classified as 'Type C' stone characteristically exhibits a strong laminated fabric, commonly with ripple-cross lamination. Weathering typically exploits this lamination and accentuates its appearance on exposed surfaces (Figures 14 and 15). In a few blocks this weathering results in a rather blocky surface deterioration of the stone surface, with fragments a few millimetres across readily becoming detached (Figures 37).

It has long been appreciated that it is good masonry practice to place sedimentary rocks, where possible, with original lamination horizontal, and ideally in the original geological orientation. Most blocks of sandstone within the castle walls, where original lamination can be detected, appear to be well placed. Blocks which have been placed with their original lamination vertical, and parallel to the plane of the wall surface, are said to be 'face bedded'.

A common consequence of such placing, especially in stones vulnerable to weathering, is a much more rapid deterioration than in correctly placed blocks of otherwise identical composition and texture. Few undoubted examples of 'face-bedding' have been observed in the walls of Thirlwall Castle, though a good example in 'Type C' stone is present in the north wall (Figure 38), and it is possible that some deterioration in 'Type A' stone in parts of the building may also be due in part to them being 'face-bedded'.

Although the large sandstone blocks forming the quoins and windows closely resemble the 'Type A' lithology many appear much less strongly weathered than much of the 'Type A' stone in the main body of the walls. In many of these blocks weathering has accentuated cross bedding. It seems likely that the quoins and window blocks were dressed to shape prior to incorporation in the building. The lesser degree of weathering seen in these blocks therefore seems to reflect the shorter period of weathering of these compared to the very similar stone in the smaller, Roman blocks, seen in the main body of the walls.

Weathering has clearly caused very severe deterioration to large areas of exposed mortar and rubble within the wall cores. Lime mortar becomes very friable and is readily removed by rain or even wind. Such deterioration renders the wall structure unstable with both facing stones and blocks within the rubble cores becoming susceptible to falling out of place.

The coal fragments within the mortar are very friable due to weathering.

Weathering has had little perceptible effect on the greywacke sandstones, granite and microgranite cobbles within the rubble cores, or on the pebbles of Lake District volcanic rocks within the mortar.

8. PROVENANCE OF BUILDING MATERIALS

The construction of a building such as Thirlwall Castle requires an accessible source of suitable stone ideally as close as possible to the site. The Thirlwall neighbourhood offers an abundance of suitable building materials. The Carboniferous rocks contain a variety of sandstones, many of which are capable of supplying stone suitable for a building of this type. In addition the area contains readily available sources of limestone suitable for producing lime mortar, as well as coal for lime burning, and sands and gravels for aggregate.

The close proximity of Hadrian's Wall to the castle site clearly offered the castle's builders a convenient source of ready-made building blocks, which they clearly exploited fully. The roughly squared outline of blocks mainly around 20 – 30 cm section, so characteristic of Roman masonry, is a conspicuous feature of the castle walls. Indeed, it seems likely that such re-cycled blocks comprised by far the greatest proportion of the stone employed in the main walls. Broken, or otherwise unsuitable, blocks of Roman stone probably contributed the major proportion of the material used for the rubble fill of the walls. However, as already noted, a number of rather exotic rock types, mainly glacially derived erratic blocks, are present in the rubble. These may have been obtained on site, or close by, from foundation and other excavations, and incorporated into the fabric as convenient rough stone. It is conceivable that some of these too may have been derived from Roman structures where they may have been similarly employed.

As has already been noted, the castle includes a variety of sandstone types. Although Carboniferous sandstones of this area, including those within Thirlwall Castle, display a variety of individually distinct features, these are shared by many individual sandstone units. Whereas all can confidently be regarded as having been obtained from nearby outcrops of Carboniferous sandstones, it is impossible to identify individual quarry sites for any of the stone types. It is, however, reasonable to assume that the Roman masons would have obtained sandstone with the desired properties as near to the working site as possible. As many of the local sandstones were capable of providing suitable stone it is almost certain that the builders of Hadrian's Wall were supplied from a large number of, mainly small, quarries along the length of the Wall. A considerable amount of mixing of stones thus almost certainly took place in the construction of individual stretches of wall. Such mixing of stone would have been reflected in the construction of later buildings such as Thirlwall Castle, where much Roman stone was re-cycled. Several exposures of sandstone in the neighbourhood of the castle, both in the Tipalt Burn and in the surrounding country, show evidence of long-abandoned quarrying. Whereas some of these no doubt were used to supply stone for farm walling and local building in more recent times, it is perfectly possible that at least some supplied stone to the Roman masons.

Whereas the abundance of small squared blocks from Hadrian's Wall offered an easy supply of material for the main body of the castle walls, the quoins and windows called for a more demanding stone specification.

It is understood that, during the current archaeological studies at Thirlwall Castle, the possibility of the quoins and window stones being obtained from Roman sources has been canvassed. In any consideration of the possibilities of this it is important to take the following geological factors into consideration.

A striking feature of the castle is the very great similarity of stone type employed in the quoins and windows throughout the building. Although minor differences can be observed, mainly in the form of slight colour variations, grain size, prominence of lamination etc. these are all well within the limits which might be expected in stone derived from a single source. The evidence obtained during this investigation is consistent with the quoins and window stones being obtained from such a common source. Such a suggestion does not *ipso facto* preclude the stone being obtained from previous Roman structures. However, it should be noted that where Roman stones have been used in the main body of the walls, a considerable variation in stone type is present. Use of re-cycled Roman blocks for quoins and windows might also be expected to exhibit some variation in stone type. Moreover, because of the need to dress stone to the shapes and sizes required in the castle, any Roman blocks would have originally been substantially larger than those seen today in the castle. If Roman stone was re-used for quoins and windows, a sufficient source of suitably large blocks of a comparatively uniform lithology must have been available to the castle's builders

Whereas the geological evidence alone cannot confirm that the quoins and windows are re-used Roman stones, it gives little or no support to the hypothesis. The overall similarity of stone type throughout these blocks and their likely origin from a single source suggest the possibility that this stone may have been specially quarried for the construction of the castle.

As noted above, the identification of the exact sources of individual sandstones of the types present at Thirlwall, is difficult or impossible. However, it is worth noting that sandstone very close in appearance and characteristics to the quoin and window stones, is exposed in a long-abandoned quarry [NY6773 6736] on the north bank of the Tipalt Burn, approximately 250 m SE of Greengate Well Farm. This sandstone lies above the Bank Houses Limestone.

The presence, albeit in very small quantities, of grey slate within the walls calls for comment.

The nearest natural sources of slate of this appearance is in parts of SW Scotland and in parts of the southern Lake District: no such material occurs *in situ* within the solid rocks of the Thirlwall neighbourhood. The material has thus been introduced to the site from a considerable distance.

The slate could conceivably have been deliberately introduced by the builders. However, it is most unlikely to have been introduced solely for the extremely limited use seen today in the fabric. It is obviously tempting to explore the possibility that the slate was waste from other uses, for example roofing. However, the slate is present in the walls, and thus was used well before any roof construction. It is not known what roofing material was used, though slate from such far-travelled sources at that period seems unlikely. Moreover, had slate been so employed some vestiges of it would almost certainly be apparent in the soil and debris on the site. No such slate debris is known. Re-use of slate, previously present in Roman structures, might be considered, though the use of such imported material by the Romans is not known. It is possible that a travelling mason, working on the castle at the time of its construction, had within his possession, a few fragments of slate, perhaps left over from a previous task, and employed them as a matter of convenience in this way.

The presence of a variety of rock types, as glacially transported erratics, within the Thirlwall neighbourhood, has been noted above. No slate erratics have been seen during the present investigation, and although such material is likely to be extremely rare within the erratic it is not inconceivable that a fragment or two was discovered. If so a block of such fissile stone is bound to have attracted the attention of the castle's builders who might well have employed it in the way seen in the walls today.

The construction of a building of this size required the availability of a very substantial amount of lime mortar. A number of prominent beds of limestone crop out within the neighbourhood of the castle, and small abandoned quarries can be seen in several of these. Thin coal seams are also known locally and could have provided the necessary fuel for lime burning. Whereas it is impossible to identify with certainty the sites of quarries which may have supplied coal or limestone for the making of mortar, it is extremely likely that this material was obtained very close to the site.

9. POTENTIAL FOR GEOLOGICAL INTERPRETATION

Whereas the historical and archaeological features of the castle are the most obvious features to be interpreted to visitors, the site also offers a first class opportunity for much more wide-ranging and imaginative interpretation. Stone buildings offer superb opportunities to explore aspects of the landscape of which they are such a vital part. Thirlwall Castle invites explanations not only of its builders and successive occupants but, as a consequence of its construction from re-cycled Roman materials, provides an obvious link to the Roman world. The story need not end there. The very stones of the castle enable the history of this part of Britain to be taken back over millions of years. This small site thus has a huge amount to offer visitors of every age.

The stones which make up the castle walls can be used to tell of the earliest history of what is now Northumberland. These sandstones, in their variety, were laid down as soft sand on the banks of rivers and delta flats in Carboniferous times between about 350 and 310 million years ago, when this area lay close to the equator. It is perfectly feasible to point to features in the stone which allow this story to be told. For example, the obvious composition of the stone as a compacted and cemented sand, the presence within it of ripple marks, cross-bedding, fossil rootlets and traces of fossilised wood all are clearly displayed in blocks in the castle walls accessible from ground level. An interesting linking theme could be to compare the re-cycling of Roman building blocks in the medieval castle with the natural re-cycling of sand grains in the Carboniferous sandstones. The continuity of earth processes over geological time, as reflected in the textures and features such as ripple marks and rootlets, exactly similar to their modern counterparts, in the stone of the castle walls, can be clearly demonstrated. Moreover, the use of stone, and the way in which it has been employed in the castle, its different appearances and different rates and styles of weathering, can be used to highlight the importance of these rocks both as building materials here and elsewhere, and as the essential basis of the landscape itself.

The erratic boulders present within the castle walls, and abundantly present in the adjoining field and walls, invite an explanation of the effects of the last glacial period. They offer scope to introduce not only dramatic changes in climate but prompt explanations of the huge gaps in geological history.

The role of the building stones as substrates for plants such as lichens further extends the interpretation possibilities.

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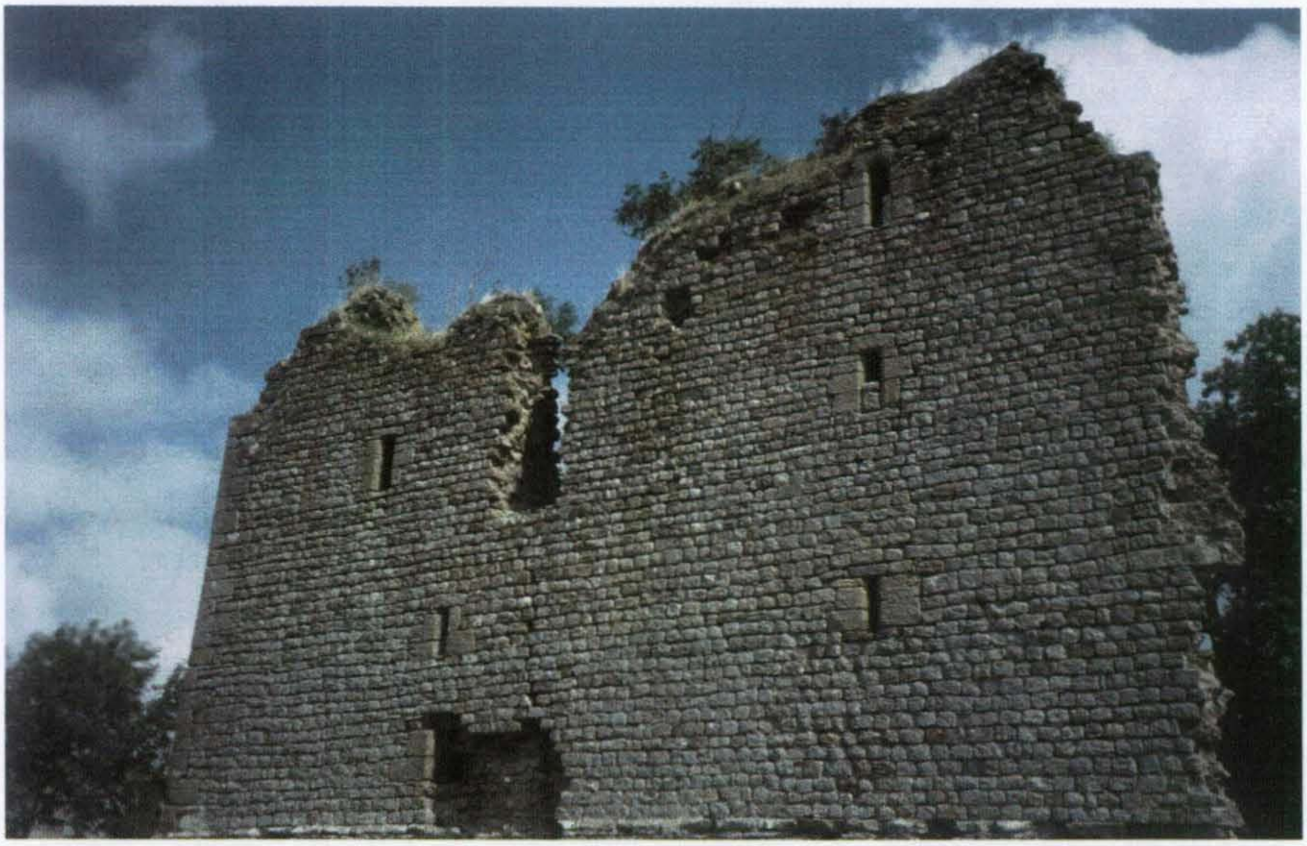


Figure 1.
Thirlwall Castle. General view of south wall prior to restoration work. (Photo. A.Weir)

Figure 2.

Outer face of north wall.
Massive pale brown Type 'A' sandstone with faint dark brown Liesegang rings. Note also slight exfoliation due to weathering.

Figure 3.

Outer face of south wall.
Type 'A' stone showing weathered-out traces of original bedding, here laid almost vertically.

Figure 4.

Outer face of north wall.
Several blocks of typical massive Type 'A' stone. Block beneath scale exhibits marked Liesegang rings of iron oxide.

Figure 5.

Rubble core of west wall.
Massive pale brown Type 'A' sandstone with prominent Liesegang rings of iron oxide.

Figure 6.

Outer face of south wall.
'Honey comb' surface of massive Type 'A' sandstone due to differential weathering of hard ferruginous Liesegang rings. Note also abundant lichen growth on this and adjoining blocks.

Figure 7.

Outer face of south wall.
'Honey comb' surface of massive Type 'A' sandstone due to differential weathering of hard ferruginous Liesegang rings. Note also abundant lichen growth on this and adjoining blocks.

Figure 8.

Outer face of south wall.
Roughly spherical nodules of dark brown iron oxide cement in massive Type 'A' sandstone.

Figure 9.

Outer face of west wall.
Very dark brown vein-like concentration of iron oxide cement in Type 'A' stone.

Figure 10.

Outer face of north wall.
Predominantly blocks of pale grey Type 'B' sandstone showing characteristic dull grey colour. Note also sharp, comparatively unweathered outlines of Type 'B' blocks in contrast to slightly in-weathered and slightly crumbling block of pale brown Type 'A' stone at bottom left (adjoining scale).

Figure 11.

Outer face of west wall.
Advanced in-weathering of two blocks of Type 'A' stone, contrasting with much more resistant pale grey Type 'B' stone in overlying course.

Figure 12.
Outer face of south wall.
Conspicuous hollows in Type 'B' stone, marking traces of fossil rootlets.

Figure 13.

Outer face of north wall.
Pale grey Type 'B' stone contrasts conspicuously with dull brown Type 'A' stone.

Figure 14.

Outer face of north wall.
Conspicuous ripple-crosslamination in block of Type 'C' stone (left of scale).

Figure 15.

Plinth at foot of north wall.
Weathered ripple-cross lamination in pale grey Type 'C' stone in block beneath scale.

Figure 16.

Outer face of north wall.
Crude horizontal lamination cut by very faint traces of vertical fossil rootlets in Type 'C' stone block, immediately beneath scale.

Figure 17.

Rubble core of east wall.
Small block of reddened sandstone. Other blocks include grey limestone and pale grey to geenish grey volcanic rocks of Lake District origin.

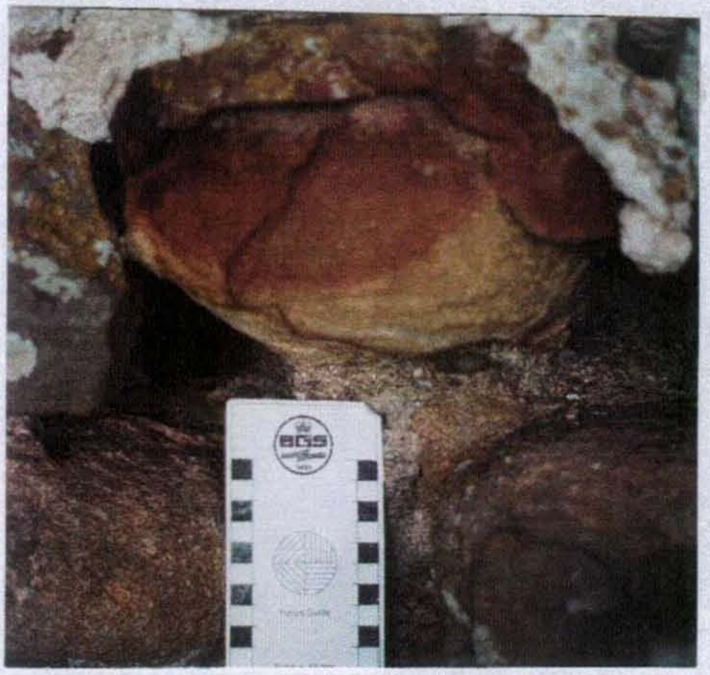


Figure 18.

Rubble core of east wall.
Block of partially reddened sandstone.

Figure 19.

Window casings, south wall.
Massive pale brown sandstone showing cross-bedding.

Figure 20.

Quoins at west corner of south wall.
Massive pale brown sandstone showing traces of lamination. A single iron oxide concretion is conspicuous in the large block beneath the pencil.

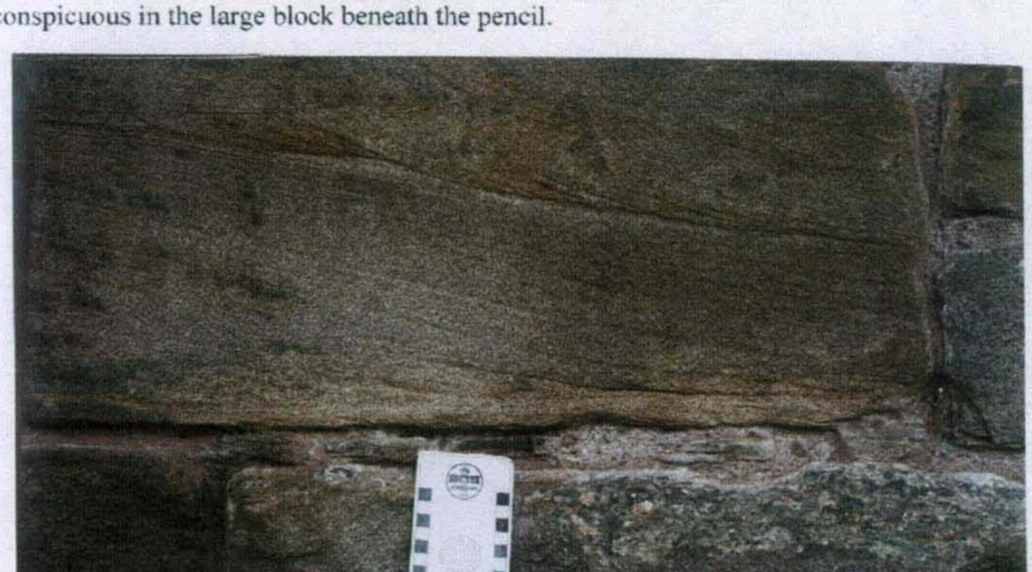


Figure 21.

Quoin in west wall.
Conspicuous cross-bedding in massive sandstone.

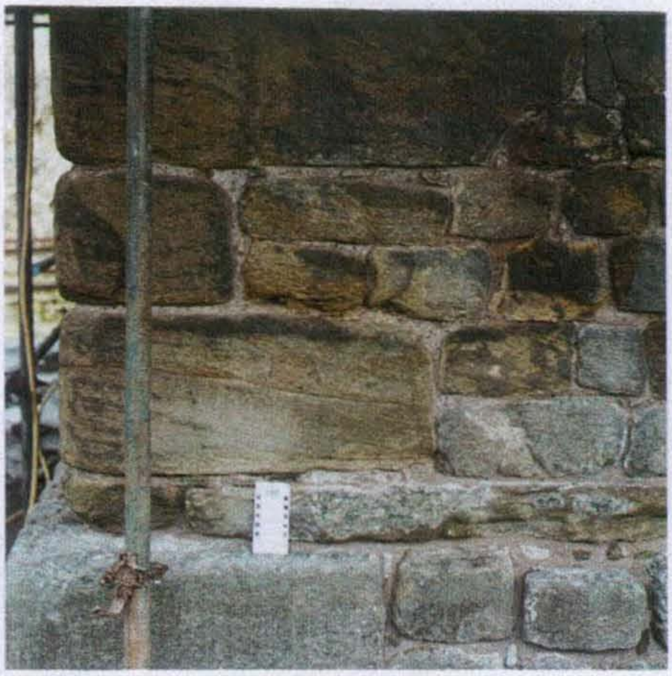


Figure 22.

Quoins in west wall.
Conspicuous cross-bedding in massive sandstone.

Figure 23.

Window casing in south wall.
Fossilised cast of plant stem in massive sandstone (immediately above 2p coin).

Figure 24.

Rubble core at top of west wall.
Greywacke sandstone boulder (below 2p coin).

Figure 25.

Outer face of north wall.
Thin fillets of sandstone and slate used to pack space beneath sandstone quoin.

Figure 26.

Quoins on outer face of west wall.
Very thin slate fillets used to pack space beneath quoins (below pencil).

Figure 27.

Inner core of north wall.
Ovoid boulder of coarse-grained granite (beneath scale).

Figure 28.

Rubble core at top of south wall.
Ovoid boulder of coarse-grained granite.

Figure 29.

Rubble core at top of west wall.
Block of pinkish buff porphyritic dacite (arrowed).

Figure 30.

Rubble core at northern end of east walls.
Small black fragments of coal within mortar.

Figure 31.

Rubble core at northern end of east walls.
Small pebbles of grey to greenish grey Lake District rocks in mortar.

Figure 32.

Rubble core at northern end of east walls.
Small fragment of brick within mortar.

Figure 33.

Arching in north west turret.
Wedge-shaped blocks of ? Type 'A' sandstone used in arching.

Figure 34.

Quoins in west wall.
Thin slabs of sandstone used to level courses of quoins.

Figure 35.

Top of walls at north east corner.
Advanced deterioration of masonry due to growth of vegetation.

Figure 36.

Outer face of north wall.
Rounding of blocks of Type 'A' stone due to weathering.

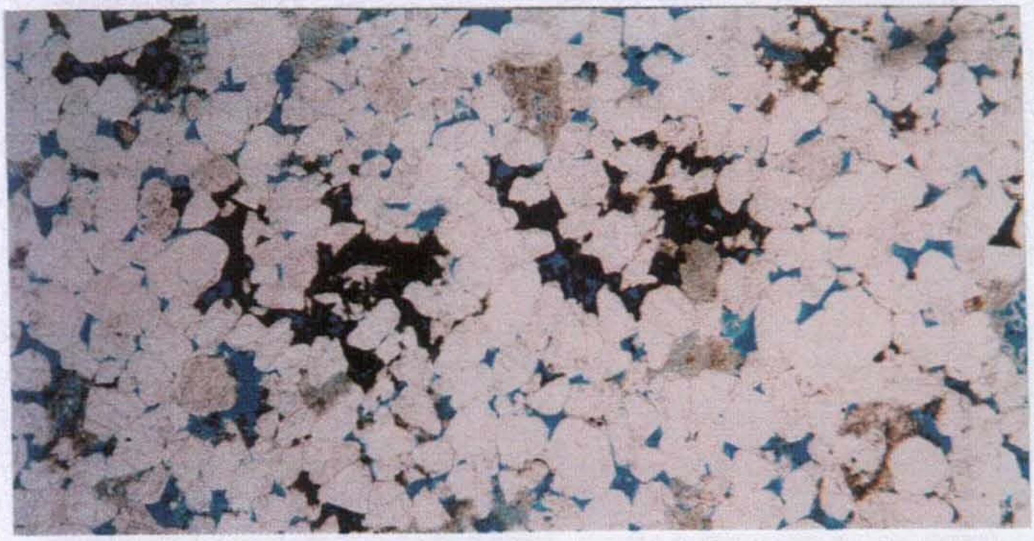
Figure 37.

Outer face of west wall.
Rather 'blocky' surface deterioration of Type 'C' stone (arrowed).

Figure 38.

Outer face of north wall.
Face-bedded block of Type 'C' stone.

a



b

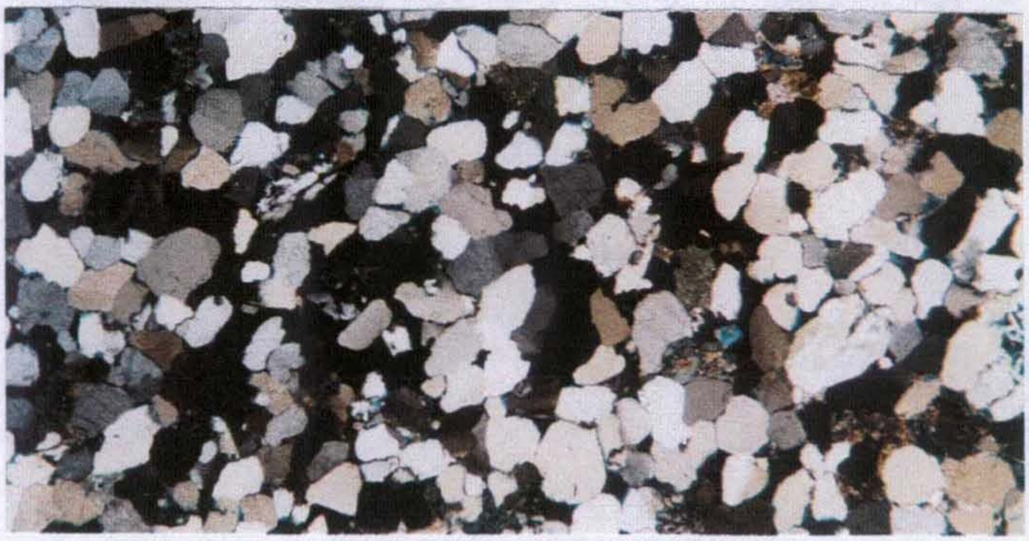


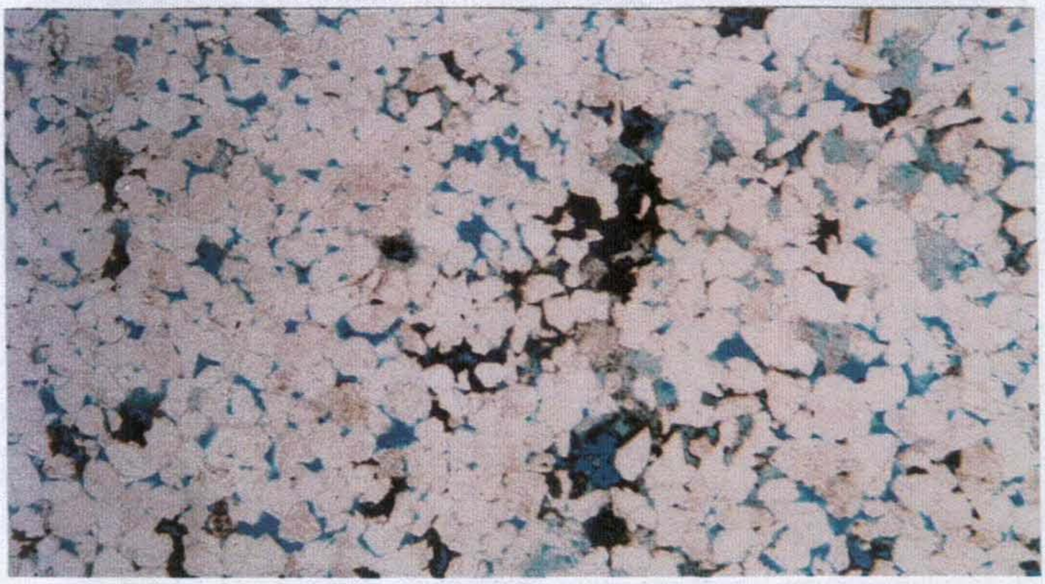
Figure 39a & b.

Photomicrograph of Type 'A' stone.
Field of view 5mm.

a. photographed in plane polarised light.
The blue areas are resin used to impregnate and stabilise the stone to allow thin sectioning and to identify the areas of primary intergranular porosity.

b. the same view under crossed polars.

a



b

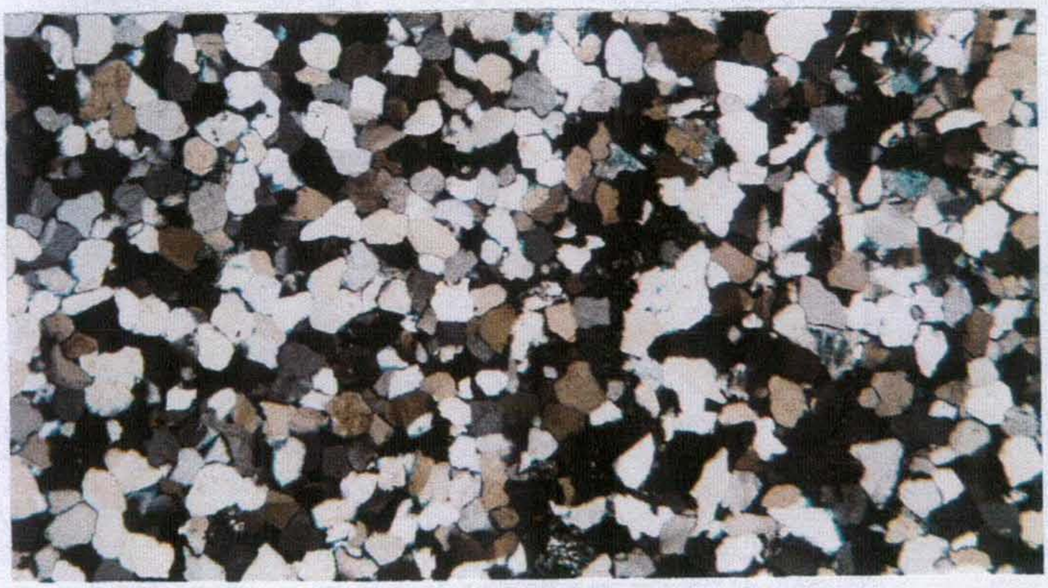


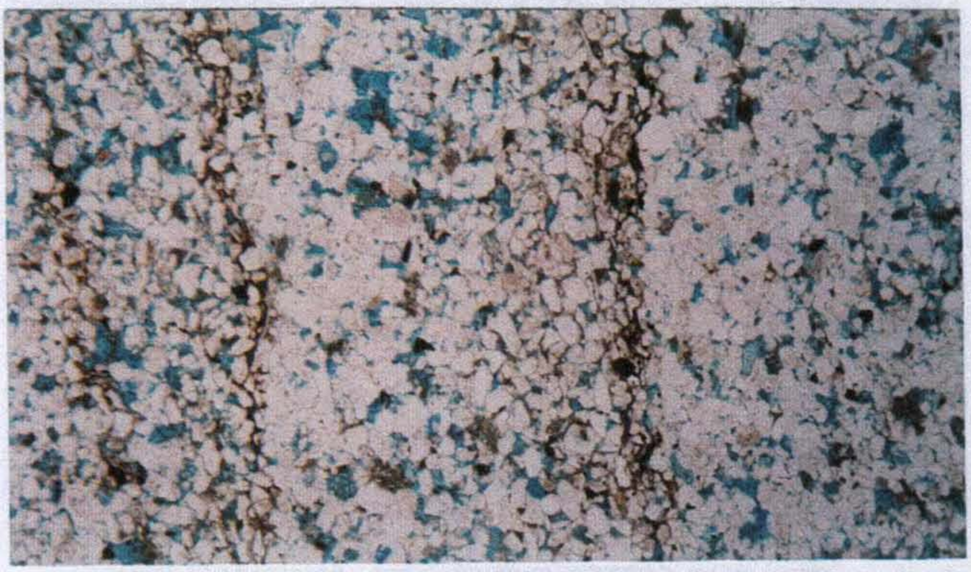
Figure 40a & b.

Photomicrograph of Type 'B' stone.
Field of view 5mm.

a. photographed in plane polarised light.
The blue areas are resin used to impregnate and stabilise the stone to allow thin sectioning and to identify the areas of primary intergranular porosity.

b. the same view under crossed polars.

a



b

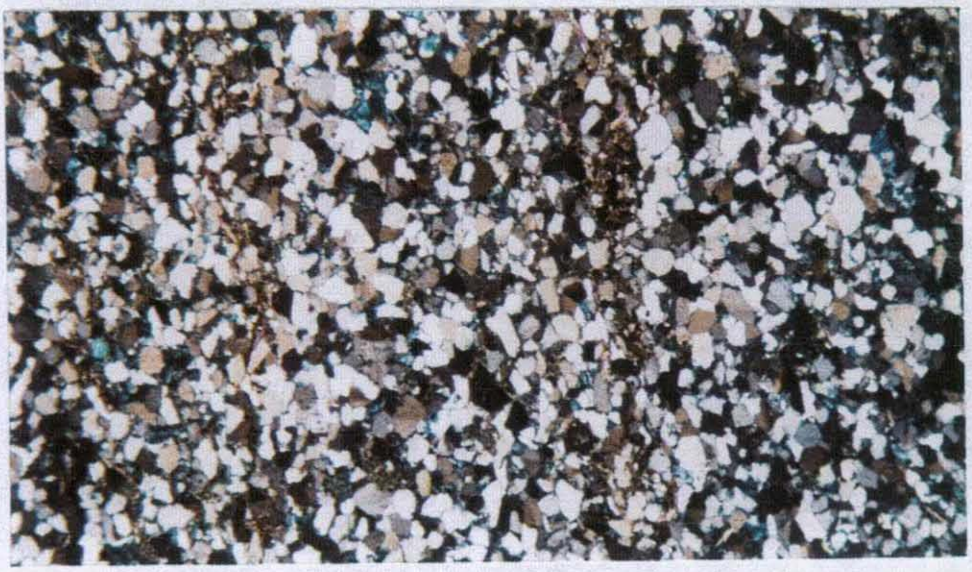


Figure 41 a & b.

Photomicrograph of Type 'C' stone.
Field of view 5mm.

a. photographed in plane polarised light.
The blue areas are resin used to impregnate and stabilise the stone to allow thin sectioning and to identify the areas of primary intergranular porosity.

b. the same view under crossed polars.

a

b

Figure 42 a & b.

Photomicrograph of sandstone from quoin.
Field of view 5mm.

a. photographed in plane polarised light.
The blue areas are resin used to impregnate and stabilise the stone to allow thin sectioning and to identify the areas of primary intergranular porosity.

b. the same view under crossed polars.

a

b

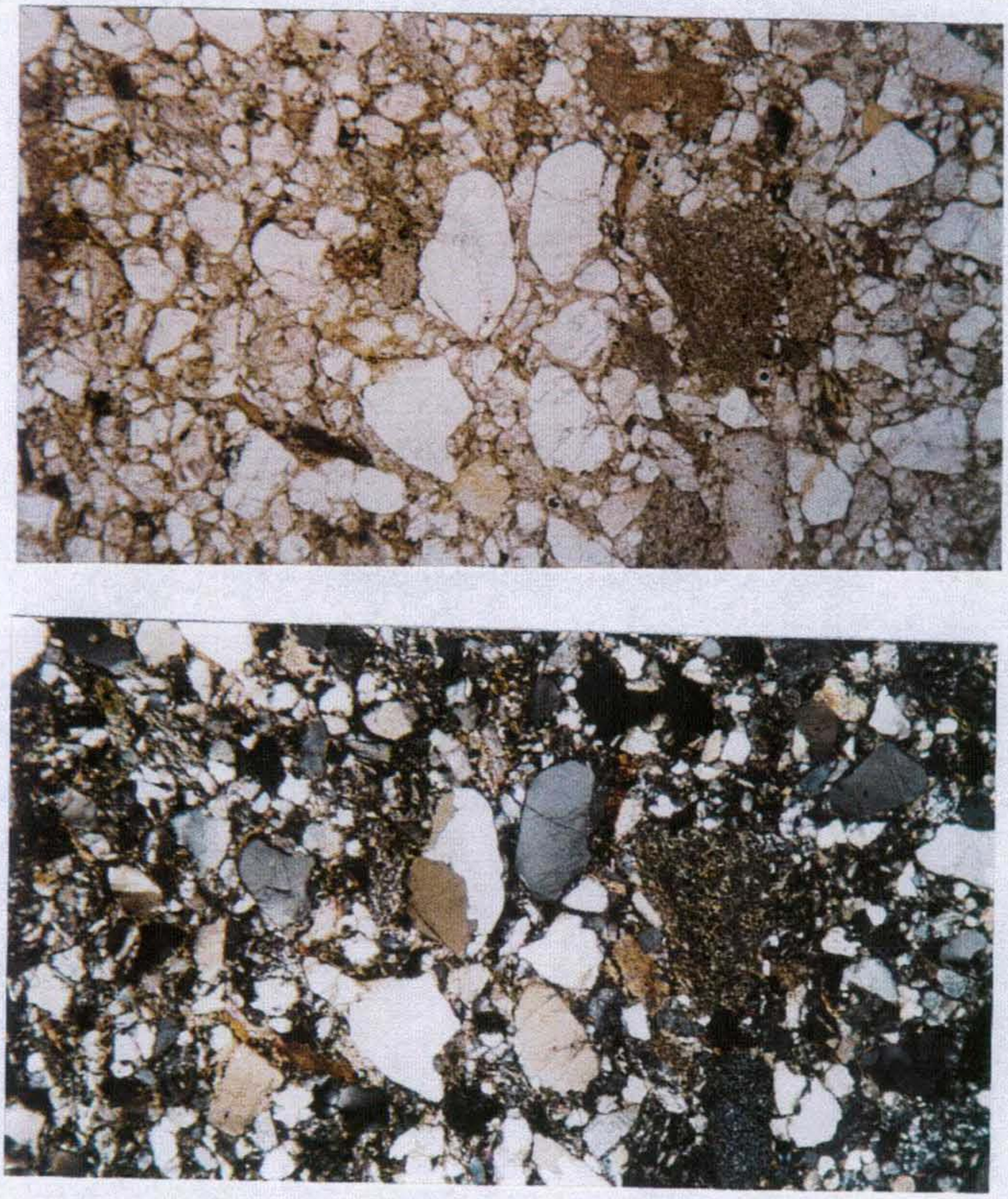


Figure 43 a & b.

Photomicrograph of greywacke sandstone.
Field of view 5mm.

a. photographed in plane polarised light.

b. photographed under crossed polars.

a

b

Figure 44 a & b.

Photomicrograph of feldspar-biotite-quartz-microporphyritic dacite.
Field of view 5mm.

a. photographed in plane polarised light.

b. photographed under crossed polars.

a

b

Figure 45 a & b.

Photomicrograph of slate.
Field of view 5mm.

a. photographed in plane polarised light.

b. photographed under crossed polars.