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Patrick Murray
Ardrossan Castle Heritage Society
6 Hill Street
Ardrossan
KA22 8HE

Building Stone Assessment of the Ardrossan Sarcophagus

This report describes a visual assessment of the geological character of the stone used to form the Adrossan Sarcophagus, and briefly reviews relevant geological information and analysis techniques which could be used to constrain its provenance.

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Building Stone Assessment of the Ardrossan Sarcophagus

1 Introduction

BGS has been asked by Patrick Murray, acting on behalf of Ardrossan Castle Heritage Society, to examine a stone coffin known as The Ardrossan Sarcophagus (Figure 1). The sarcophagus, which is presently housed at North Ayrshire Heritage Centre in Saltcoats, is believed to date from medieval times. Ardrossan Castle Heritage Society are conducting research to identify the origins of the sarcophagus, and to explore its historical background and significance.

The sarcophagus consists of two pieces of sandstone, one used to form an ornately carved lid and the other used to form a simple base (Figure 1). The lid is approximately 204 x 80 x 18 cm and the base is approximately 200 x 76 x 47 cm.

The objectives of this report are:

- to describe the geological character of the stone used in the sarcophagus, based on a visual examination; and
- to briefly review relevant geological information and analysis techniques which could be used to constrain the provenance of the stone.

In order to achieve these objectives, Paul Everett (BGS) visited the North Ayrshire Heritage Centre on 23rd June 2016 and conducted a brief visual examination of the sarcophagus.

Figure 1 The Ardrossan Sarcophagus

2 Geological description of the Ardrossan Sarcophagus

The top surface of the lid is almost entirely covered in a veneer of limewash, but the stone surfaces on the sides of the lid and the base are fully exposed. Almost all of the sandstone is very strongly cohesive and has experienced little decay (e.g. in the form of granular disintegration); consequently, tooling marks (in the form of droving on the base) are very well preserved.

The stone forming both the lid and base is essentially identical (and therefore likely to share the same provenance). The exposed exterior surfaces are generally buff (close to '10YR 7/3' on a Munsell colour chart), but the colour is slightly variable. The fresh stone, revealed where pieces have (probably relatively recently) broken off one corner of the lid and above a crack which runs through part of one side of the base (Figure 2), is light grey (close to '10YR 7/1' on a Munsell colour chart). The buff colour of the exterior surfaces will have developed gradually since the sarcophagus was created, as a result of tiny particles of iron oxide forming from the chemical alteration (weathering) of other iron-bearing minerals (such as dolomite) as they were exposed to air and moisture.

The stone is dominantly comprised of sand grains of uniform size (in the range 0.25–0.5 mm; i.e. medium-sand-grade). The sand grains consist mainly of the minerals quartz (which appears clear grey/white), feldspar (a white mineral which has experienced partial dissolution and appears 'powdery'), and iron oxide (black to brown and orange particles). These constituents are uniformly distributed on the surface of the stone (Figure 3). A small proportion of muscovite (a member of the mica family of minerals, which forms shiny, silvery flakes) is also present.

Texturally, the stone is essentially uniform; however, two small, dark grey mud flakes up to 3 cm across were observed (Figure 4), and several dark grey/brown laminae (thin layers <1mm thick consisting of concentrations of iron oxide minerals), which reveal cross-bedding, are faintly visible on one side of the base.

Figure 2 A piece of stone has broken off the base of the sarcophagus above a crack, revealing the light grey colour of the fresh stone

Figure 3 Detail of grain-scale characteristics in the stone. The black division on the scale bar at left is 1cm from top to bottom

Figure 4 A mud flake in the sandstone. Each division on the scale bar is 1cm

Figure 5 Faintly visible laminae (thin, dark grey/brown layers) are developed in gently curved sets (cross-bedding). Each division on the scale bar is 1cm.

3 Constraining the provenance of the Ardrossan Sarcophagus

The mineral and textural character of the stone used to form the Ardrossan Sarcophagus is typical of sandstones deposited during the Carboniferous Period (299-359 million years ago) in what is now the Central Belt of Scotland. Figure 6 shows the distribution of sandstone-bearing Carboniferous strata in this part of Ayrshire. The considerable size and weight of the two stone blocks forming the sarcophagus suggests they are unlikely to have been transported a long distance from the site at which they were quarried. These two lines of evidence suggest the stone is likely to have been sourced reasonably close to Ardrossan Castle Hill, where the sarcophagus was found.

The good condition, uniform character and size of the pieces of stone forming the sarcophagus suggest that it would have been sourced from a quarry which could provide high quality stone in large block sizes. It seems reasonable to expect that such a quarry would have supplied stone for other carvings and high quality masonry.

Taking these points into consideration, further work to constrain the provenance of the stone used to form the Ardrossan Sarcophagus could involve one or both of the following approaches.

1) Comparing the stone in the sarcophagus to the stone in potential source bedrock units

The aim of this approach would be to determine which (if any) of the Carboniferous sandstone units in Ayrshire have geological properties (e.g. colour, grain-size, fabric, mineral constituents, textural character, geological history) that match those of the sandstone used to form the sarcophagus; any that do might be the source bedrock unit. The provenance of the sarcophagus stone would be well constrained if just one bedrock unit was a good match.

The BGS rock collections are likely to contain some samples that are representative of Carboniferous sandstone units in Ayrshire, but it probably would be necessary to collect new samples from quarries and outcrops to provide sufficient ‘baseline’ data for this exercise.

2) Comparing the stone in the sarcophagus to other carved stone artefacts and/or masonry

The aim of this approach would be to determine whether any other historical sandstone artefacts from the local area (or further afield) have geological properties that match those of the sandstone used to form the sarcophagus; any that do might have come from the same source bedrock unit. This exercise might identify groups of artefacts made of the same stone, which could shed new light on their history (for example, aspects of the work of medieval masons). This approach, and its results, might be of interest to other local or national heritage organisations, but on its own it would not constrain the bedrock or quarry source of the Ardrossan Sarcophagus stone. Medieval carvings found at Kilwinning Abbey would be obvious artefacts to include in a study using this approach. Medieval (and later) sandstone masonry could be targeted, in addition to sandstone artefacts.

For either approach, one or more of the following techniques could be used to characterise and compare the geological properties of sandstone.

- *Unaided visual examination* - this would involve no damage to artefacts or masonry, and is likely to be less expensive than other techniques; however, it would yield less useful data and therefore is less likely to produce a definitive result.
- *High magnification examination using a microscope* - this technique would require the collection of a small sample of stone from each artefact, from which a thin section (a slice of the stone cut thin enough to be transparent) would be prepared; some damage to historical artefacts would therefore be involved, and the additional analytical work means this technique could be relatively expensive, but it probably would yield the most useful data of any technique and therefore is most likely to produce a definitive result. The thin sections could be examined using various instruments (including optical microscope, Scanning Electron Microscope [SEM], and cathodoluminescence [CL] microscope).
- *Handheld X-Ray Fluorescence (XRF) analysis* – this technique would involve the use of a small hand-held instrument to determine the concentration in the stone of selected chemical elements, which can be diagnostic; the technique would not damage the stone in any way, and has the potential to allow different stone samples to be matched or distinguished from each other. However, it requires clean (unweathered) stone surfaces for analysis, and relies on effective statistical treatment of the data which can in some cases be limited by analytical accuracy. This approach is likely to be more expensive than unaided visual examination, but less expensive than high magnification examination.

A phased project would reduce risks related to costs and would allow the most effective approach to be developed in stages. Any study should be preceded by a review of historical records and other relevant information, and an assessment of available artefacts, samples, quarry sites etc. Subsequently, a 'scoping study' could be conducted to determine the most suitable approach (e.g. 1 or 2 above, or a combination of these), analytical technique(s), and stone artefacts/samples, following which (if deemed appropriate) a more detailed analytical study could be conducted with a well-planned work programme and clear objectives.

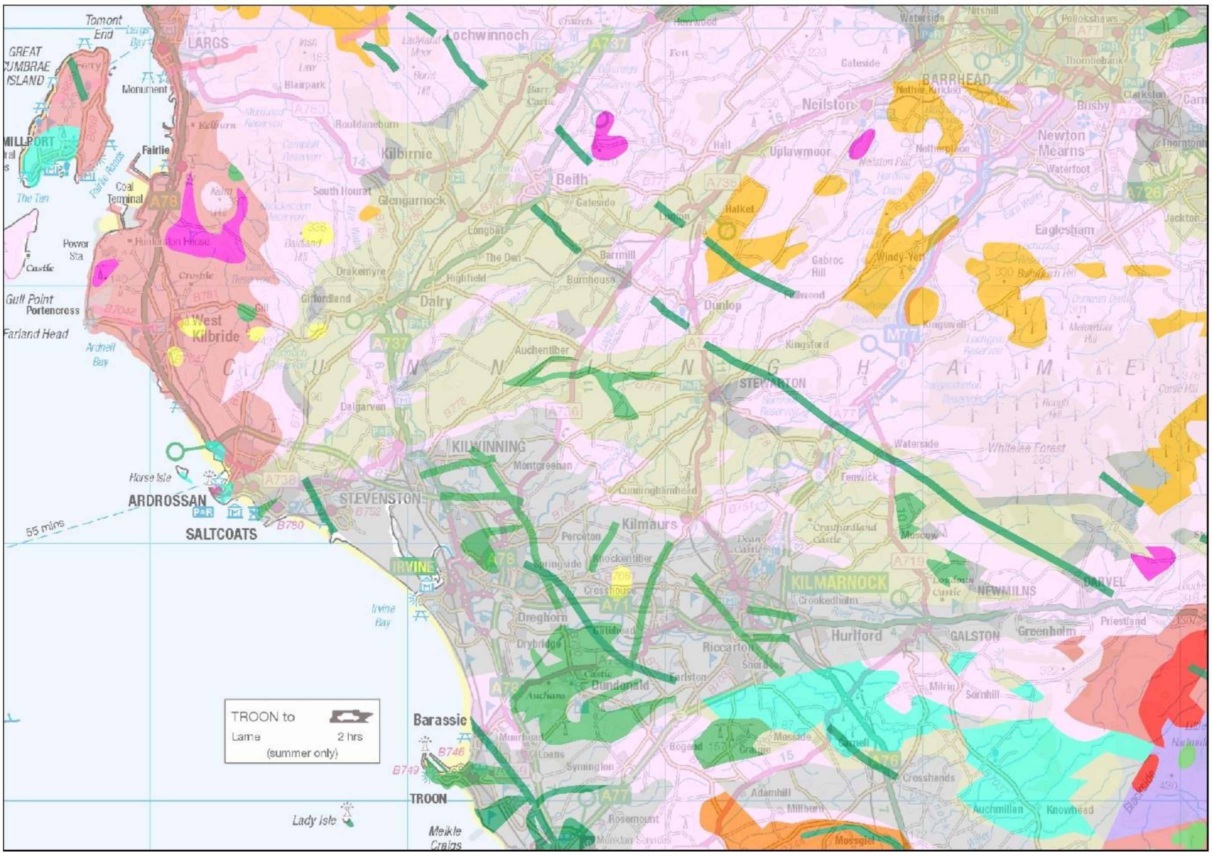

Figure 6 Map of bedrock geology around Ardrossan

Each colour on the map represents a different bedrock geological unit. Units of sandstone-bearing Carboniferous strata, which may have produced the stone used in the Ardrossan Sarcophagus, are shown in grey (e.g. around Stevenston), bright blue (south of Hurlford) and light olive brown (e.g. around Dalry).

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Compiled by: **Paul Everett**

Checked by: **Dr Martin Gillespie**

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British Geological Survey

The Lyell Centre, Research Avenue South, Edinburgh EH14 4AP

Appendix 1 Background to a BGS Building Stone Assessment of sandstone

Sandstone consists of adhering sand grains with unfilled gaps (pore spaces) and/or a mineral ‘cement’ between the grains. Sand grains are small – between 2 and 0.064 millimetres in diameter – so many of the intrinsic properties of a sandstone, including the relative proportions of the various constituent minerals, the grain-size and textural arrangement of the constituents, and the porosity (pore space) characteristics, can only be determined accurately by microscope examination. Some properties, including the colour and fabric of the stone, can be determined adequately with the unaided eye. Still others, including the cohesiveness and permeability of the stone, require a simple test to make an adequate evaluation. Each property can vary considerably from one sandstone to another, and no two sandstones are identical.

Each of the intrinsic properties of sandstone plays a role in determining how any one stone responds to the complex physical and chemical processes associated with weathering. The result is that no two sandstones respond to weathering in exactly the same way and at the same rate. If more than one type of sandstone is used in a stone structure, obvious contrasts in the appearance and condition of masonry blocks commonly become apparent over time. Furthermore, placing two sandstones of contrasting permeability next to each other in masonry can lead one (usually the more permeable stone) to suffer accelerated decay. For these reasons, it is generally considered good practice to repair or replace ‘original’ sandstone masonry with sandstone that is the closest achievable match in terms of the properties that govern how the stone responds to weathering (‘weathering properties’). This maximises the likelihood that the replacement stone will co-exist harmoniously with the original stone and will weather sympathetically. The poorer the match between the weathering properties of the replacement stone and the original stone, the greater is the likelihood that the condition and appearance of the two stones will diverge over time.

The purpose of a Building Stone Assessment is to identify which stones from the range currently being supplied by quarries in the UK most closely match the stone requiring repair or replacement. Special requirements of the replacement stone - for example, load-bearing capacity, suitability for carving or tooling, and salt resistance - are taken into consideration if requested.

Appendix 2 Methodology

A BGS Building Stone Assessment is usually performed in three stages.

(i) The sample of ‘original’ stone (usually supplied by the client) is first subjected to a detailed petrographic examination, to establish the range and character of its intrinsic properties.

(ii) The range of properties is then compared with those of stone samples held in the BGS Collection of UK Building Stones, to constrain the source of the stone. Historical records (if available), and the likelihood that the stone was sourced locally or imported, are also taken into account.

(iii) Finally, the closest-matching currently available stones are identified. If the quarry from which the stone was sourced originally has been identified and is still open, it will usually provide the closest-matching stone. If the quarry from which the stone was sourced originally has not been identified, or is closed, the closest-matching currently available stones are identified by comparing the properties of the original stone with those of samples of currently available stones held in the BGS Collection of UK Building Stones.

Comparing stone properties to identify the source and/or the closest-matching stones is known as stone matching.

Petrographic examination

A macroscopic examination of the sample of ‘original’ stone is performed with the unaided eye and using a binocular microscope. A microscope examination is performed on a thin section (a slice of the stone sample cut thin enough to be transparent), using a polarizing microscope. Before preparing the thin section, the stone is impregnated with blue resin to highlight pore spaces. The thin section is cut perpendicular to the bedding fabric of the stone (where this is visible), and is positioned to be as representative as possible of the sample. The thin section is typically cut to include the freshest part of the supplied stone sample, and also any weathered part and/or exposed (exterior) surface where these are present.

Observations from these examinations are recorded on a Petrographic Description Form designed for building stones, to ensure the description is systematic and consistent with the procedures set out in British Standard BS EN 12407:2000 (*Natural stone test methods – Petrographic examination*). The completed Petrographic Description Form is included in this report, with a set of accompanying notes describing each of the recorded properties. The description is accompanied by one or more photographs illustrating the typical character of the stone as it appears in the thin section.

Stone matching

Where possible, the source (quarry and bedrock unit) of the original stone is determined by comparing it with samples held in the BGS Collection of UK Building Stones; historical records (if available), and the likelihood that the stone was sourced locally or imported, are also taken into account, if appropriate. Many thousands of quarries in the UK have supplied building stone in the past, and in many instances it is not possible to relate a stone sample back to one particular quarry or bedrock unit.

Where the source cannot be identified unambiguously, the closest-matching currently available stones are identified by comparing the intrinsic properties of the original stone with those of similar stones that are currently being supplied by quarries in the UK.

The following factors are taken into account when comparing an original stone with a potential replacement stone.

1) *Mineral and textural features* – ideally, these should be as similar as possible in the replacement stone and original stone, to increase the likelihood that the two stones will respond in similar ways and at similar rates to the various physical and chemical processes associated with weathering, and will therefore co-exist harmoniously. Replacement stones are selected to match the original stone in its fresh (rather than weathered/decayed) state, unless otherwise requested. Particular attention is paid to those minerals and textural features that are known to play a significant role in sandstone decay and discolouration.

2) *Permeability* – ideally, the replacement stone and original stone should have similar permeability characteristics, thereby minimising the degree to which fluid (water and air) migration between adjacent blocks of original and replacement stone might be impeded. Accelerated stone decay can occur where fluid migration is impeded.

3) *Appearance* – for aesthetic reasons, the replacement stone and original stone ideally should look similar to the unaided eye in terms of colour and stone fabric at the time the repair is made. However, the closest-matching stones in terms of the properties that govern weathering performance (mineral-textural features and permeability) are not necessarily the closest match in terms of appearance. A repair using stone selected primarily because it is the closest match in terms of appearance may look good initially but could quickly show signs of decay or of being incompatible with the original stone. For that reason, priority is generally given to the properties that govern weathering performance, thereby maximising the likelihood of long-term compatibility of the original stone and replacement stone. A degree of compromise may in some cases be desirable and acceptable if the closest-matching stones in terms of 'weathering properties' are not a close match in terms of appearance. Immediately following repair, the fresh surfaces of a stone insert or indent will usually contrast in appearance with the soiled or discoloured surfaces of adjacent original masonry, but if the 'weathering properties' of the two stones are a good match the new stone should blend in over time and the contrast should become less obvious.

4) *Functional and performance requirements* – specific functional and performance requirements of a replacement stone are taken into account if requested. For example, if the original stone performed a load-bearing role, the choice of matching stones should include only those that are at least as strong; and if the original stone was carved or shaped in a particular way, the choice of matching stones ideally should include only those that can be carved or shaped in a similar way, with a similar level of detail and quality of finish.

One or more replacement stone types are proposed taking these factors into account. A brief description and a thin section photograph are provided for each.

Appendix 3 Supporting notes for the petrographic description

Each numbered note below relates to a superscript number in the Petrographic Description Form (Section 2).

1 The determination of stone type follows the classification and nomenclature of the BGS Rock Classification Scheme.

2 The 'visual' determination of stone colour is based on a simple assessment with the unaided eye in natural light. The 'Munsell' determination is obtained by matching the stone colour to one of the coloured patches in a Munsell Rock Colour Chart; each patch has a unique colour and a unique code (the 'Munsell code'), which incorporates values for hue and chroma. In stones displaying variable colour, both the 'visual' and 'Munsell' determinations record the colour deemed by the geologist to be most representative. The determination of stone colour is made on a broken (not sawn), dry surface.

3 A simple, non-quantitative assessment of the degree to which the stone is cohesive. This property is recorded in terms of four conditions, each representing one segment of a continuum: *strongly cohesive*, *moderately cohesive*, *moderately friable*, and *very friable*. The grains in a *strongly cohesive* stone cannot be disaggregated by hand, whereas the grains in a *very friable* stone can be readily disaggregated by hand.

4 A record of whether the distribution of granular (detrital) constituents in the sample is essentially isotropic (uniform) or anisotropic (non-uniform). The type of anisotropic fabric is recorded.

5 A record of the identity and relative proportions of all granular (detrital) and intergranular (authigenic materials and pore space) constituents currently in the stone. The proportions are estimates, expressed in %, which are based on a visual assessment of the whole thin section area.

6 The terms are those used for grain-size divisions in the BGS Rock Classification Scheme.

7 A simple, non-quantitative assessment of the degree to which detrital constituents display similarity in terms of physical characteristics (in particular the size and shape of grains).

8 A simple, non-quantitative assessment of the degree to which detrital constituents are abraded.

9 A simple, non-quantitative assessment of stone permeability, presented as one of five conditions (*very low*, *low*, *moderate*, *high*, *very high*) expressed relative to a nominal 'average' permeability in building stone sandstones. The assessment is based on: (i) a water bead test; (ii) the proportion of pore space in the stone; (iii) a visual assessment of the degree to which pore spaces appear connected in the thin section.

10 A record of the type and extent of authigenic mineral cement that acts to bind detrital grains, as observed in thin section. *Isolated* means the cement occurs in discrete locations (e.g. as overgrowths on individual detrital grains) that are typically not connected in the plane of the thin section. *Discontinuous* means the cement is formed in patches, each of which typically encloses several to many detrital grains. *Continuous* means the cement is more-or-less connected across the thin section.

11 A record of the evidence observed in thin section for mineral alteration that occurs in the stone when it is near the ground surface. Such alteration processes typically begin before stone is quarried, but some may continue, or be initiated, after stone is extracted from the ground.

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