Identifying and Sourcing Stone for Historic Building Repair

An approach to determining and obtaining compatible replacement stone

Technical advice note
Summary

This Technical Advice Note provides guidance for architects, surveyors, engineers, building managers, contractors, conservation officers and owners on the best way of identifying and sourcing stone for the repair of historic buildings and monuments.

Stone repair must be planned and carried out with care and sensitivity, and requires a sound knowledge of the characteristics of the stone involved. The choice of replacement stone must be both sympathetic and cost-effective. Wherever possible compatible materials should be used – stone that closely replicates the original in its appearance, chemical, physical and mineralogical properties, strength and durability.

The aim should be to retain the maximum amount of original stone, wherever this does not compromise the integrity of the building. Maximum retention is often the preferred option, but for inaccessible structures – such as spires, where the necessary scaffolding is expensive – it may not be the most cost-effective in the long-term. It is therefore acceptable to replace stone selectively to ensure structural stability, or when it has decayed beyond repair. Replacement may also be appropriate when the purity of the building design is considered equally valuable, or more valuable, than the original construction material – for example, a 19th-century classical building. Successful repair also relies on a thorough understanding of the historical context of the building and its surroundings.

The selection process involves several steps:

1 Establishing the historical and physical significance of the building, and the likely impact of any proposed intervention
2 Assessing and understanding weathering and other decay processes affecting the stone
3 Undertaking an initial fabric/masonry survey to determine the need for stone replacement
4 Defining the types of stone used, by visual examination in situ
5 Answering any technical questions in steps 1–4 above, by using the most appropriate analytical techniques on samples taken from the site
6 Obtaining samples of potential replacement stone, and testing these where necessary
7 Sourcing and securing replacement stone from existing quarries or (in certain cases) from quarries temporarily re-opened for the purpose

In all but the smallest of projects, stone selection for historic building repair demands the combined skills and knowledge of a team of people experienced in working with stone. Ideally the team should be led by a stone consultant (usually a geologist or petrographer), who can both identify the stone and find either the most compatible petrographic match from existing or new sources, or the most closely related alternatives. When stone is being sourced from a temporary quarry or from a new quarry, the stone consultant should also be experienced in mineral planning procedures.

English Heritage supports the need for strategic and sustainable sources of stone for the conservation, repair, maintenance and improvement (CRM) of historic buildings, and so is working with other partners to ensure that the environmental impact of quarrying is minimised. Addressing the wider issues arising from sourcing and quarrying stone will contribute as much to the long-term preservation of our rich and diverse heritage as the building repair itself.

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## 1 Introduction

Stone – abundant, readily available, workable and strong – has historically been the most widely used natural material for constructing buildings, monuments, sculpture and carved decoration. Throughout the world, cultural stature is closely related to the number of large stone buildings and public monuments, and through the millennia the extraction, transportation and working of basic rock forms has been refined, often with considerable ingenuity. On a local scale, use of locally available stone and local masons has produced distinctive vernacular building styles.

Although stone is something of a metaphor for permanence and durability, this can prove far from the truth. Composition varies, even within a single source, and a building stone may prove unstable, brittle or soft. Many limestones, for example, are particularly prone to decay. To preserve an historic building, it is often necessary to replace some of its stone and regeneration, repair and maintenance all help the building’s sustainability. For intervention to be successful, however, it is imperative that the historic and physical significance of the building and its current condition be determined before the repair programme is designed.

Stone sourcing forms part of the design and specification stage of repair work, enabling the work programme to remain on course and within budget. Stone sourcing for historic building repair must take the following factors into account:

- the matching stone should be similar in colour, texture and physical properties to the original
- any intervention must not harm the original building fabric
- the roles and responsibilities of those within the design team must be well understood
- all work must comply with the Listed Building Consent framework and British and European Standards

Matching stone is often not straightforward. Although it may be possible to distinguish common stone types on the basis of colour and texture – sandstone from slate, Bath limestone from Ketton limestone – there will be many subtle colour differences, textural changes and variations: striations and sedimentary structures, grain sizes, porosities and cementation, and mineralogical incompatibilities within generic stone types. It is exactly these fine details that may be critical to a successful repair, but their recognition requires expertise and experience.

Historic building architects, stone-trade consultants and masonry contractors will often be able to undertake basic visual identification and sourcing, especially with common stones such as Portland limestone, or where background information is available. However, specialist advice will be needed to identify more complex stone types or to diagnose unusual problems. Stone consultants – geologists or petrographers – can be useful guides for client and contractor throughout the procurement process.

Stone sourcing should be part of the sub-contracted masonry package. If it is left out of the procurement process, there will be insufficient time for selecting and ordering, expediency will replace planning and unsuitable stones or stone supplies may be selected. This could have a drastic visual and physical impact, and as the replacement stone cannot usually be remedied without great expense, it may remain as an uncomfortable example of bad design, or have a possible long-term disfiguring and damaging effect on the historic building’s fabric.

Expensive errors can be avoided by including a stone consultant in the basic project team. Operating as a link between the project architect or consultant, and the contractor and masonry subcontractors, the stone consultant can also control quality when large amounts of stone are being supplied. On occasions they may work in conjunction with a masonry trade consultant.

### 2 Evaluation and characterisation of the existing stonework

#### 2.1 Visual and physical properties

Most old buildings have a history of alterations and additions. Often the original fabric incorporated several different kinds of stone, and others may have been introduced during subsequent repairs and restorations.

In most cases the dominant stone is of local origin, but other stone types may have been needed for different elements of the construction – stone suitable for walling may not be sufficiently durable for exposed areas, such as quoins or parapets. The flexural strength required for load-bearing elements such as lintels, and the need for large block sizes for certain design requirements may also have demanded different varieties. Some choices may have been purely aesthetic. At times it may have proved necessary to import suitable stone from outside the local area. The stone used at an earlier stage of building may no longer have been available in subsequent phases: often the remaining stone in the original quarry was not suitable for construction purposes. It is also not unusual to find that stone has been salvaged and re-used (Fig 1).

Every type of stone has unique properties, and a distinct manner of weathering and decay. The rate and manner of deterioration is dependent upon not only on the stone’s composition, but also on the manner in which it was quarried and worked, its final use and the environment in which it is placed. There may be faults in the building design and construction that cause local decay. Even sound stone elements will be subject to the various chemical processes and mechanical stresses that can, over time, lead to internal and superficial deterioration, and eventually may cause complete disintegration.
The rate of decay will vary, especially for exposed stone, depending on the conditions around and within the building: for example, wind, rain, thermal variations, frost action, atmospheric pollution and biological activity. There may be a delicate balance between the stonework and the prevailing climate; if this is destabilised deterioration can accelerate.

Changes to the fabric, such as the insertion of a different type of stone to the enclosure of an external wall (especially in a heated area), can have a harmful effect on the existing stonework. The juxtaposition of two incompatible stones can lead to adverse chemical reactions: for example, placing limestone above certain sandstones can lead to decay as alkaline moisture leaching out of the limestone reacts with clay or reactive silica binders in the sandstone.

Natural decay processes will be accelerated by poor design and construction, such as incorrect orientation of bedding planes (so that blocks are edge- or face-bedded), or permeable stone being used for rain-shedding features such as copings and parapets. The resulting ingress of moisture can lead to deterioration elsewhere in the building.

Studies of the construction of the original building and the current condition of the stonework and its surroundings is therefore essential to determine the need for repair, and for choosing the best manner of replacing severely decayed elements.

### 2.2 Preliminary surveys

The initial step is to survey the fabric of the building in detail, recording the location of the different types of stone, identifying and distinguishing the stones used, and determining whether these are original or later additions.

Condition surveys by architects and surveyors can help identify the factors governing the choices of stone. If possible archival sources should be studied, to collect as much information as possible about the building’s history, from original construction to the present day. Such research often provides useful insights into the design, the sources of original and added materials, the methods of construction and the original workmanship and that of subsequent alterations.

The fundamental fabric/masonry survey and visual inspection must also determine the need for, and extent of, any required repair, identify the most suitable stone types for replacement and decide on what skills and personnel the project will require.

During the initial survey it is not necessary to identify each stone type in a strict geological sense, although variations within a general lithological type – that may have resulted from similar stones being obtained from different sources – should be recorded.

Features to document include: banding, inclusions of different coloured material within igneous or metamorphic rocks (Fig 2) and the orientation of bedding and changes in grain size between layers in sedimentary rocks (Fig 3).

For sedimentary stones, the height of the masonry courses should be recorded. Unless the blocks have been used edge-bedded, course height usually reflects the thickness of the beds in the quarry. The relative proportions of course heights can be invaluable, helping a stone consultant or geologist to identify the original source.

Recordings should be drawn by hand on site as accurate line drawings, for example produced from a photogrammetric survey of the building or documented on to enlarged digital photographs.

### 3 Sampling and identification

#### 3.1 Sampling

Samples can be used to investigate several aspects of the stone and its deterioration. The type of sample preparation, the analysis undertaken and the resulting recommendations will depend on the problem being investigated. **Sampling is invasive, and should not be considered a routine procedure.**

The following is a guide to the type of information needed for different investigations.

![Fig 2 Shap granite showing the scattered large sedimentary phenocrysts of feldspar (field of view 60mm wide). (David Jefferson)](image)

![Fig 3 Whitby Abbey, North Yorkshire: various large-scale features, such as grain size variations and cross-bedding, on 250mm high column drums. (David Jefferson)](image)
Background information required for sampling
The nature of the problem being studied may make it necessary to sample in a specific manner, so the analyst’s advice should always be sought before sampling begins. In many cases – such as studies of rates of weathering or deterioration, the effects of previous treatments or salt contamination – it is imperative to explain the precise nature of the problem when submitting the samples, as this may influence the sample preparation.

If previous treatments are being assessed, it is necessary to gather background information, particularly about the materials used. This should include chemical, physical and ageing properties, weathering and deterioration characteristics of the treatments and potentially harmful effects on both the treated stone and on any surrounding untreated stone.

Choosing sample locations
It is essential to obtain representative samples of the stone to address the relevant problem. For instance, sampling weathered material can lead to misinterpretations of the original nature of the stone. As an example, sandstone cemented with calcite will have completely different properties from sandstone cemented with clay minerals. When weathering occurs, both will eventually consist of sand grains separated by voids from which the cement has been leached and appear remarkably similar.

Misinterpretation can lead to incorrect choices of replacement stone, or to inappropriate conservation strategies for the surviving stonework. Similarly, sampling only the non-decayed portions of blocks is of little use if the problem being investigated involves any interaction between the stone and the bedding or pointing mortar.

The sample taken must be truly typical. If there are apparent variations in the stone – for example in colour, texture or type of weathering – wherever possible samples should be collected of each variation.

Samples should always be taken directly from the building and not by collecting fallen stone as its history and whether or not it is representative will always be in doubt. If a piece of stone has detached naturally from the fabric of the building, its weathering may well be more advanced, and so the petrographic characteristics may not be the same as the stone still in situ.

Preparing to take samples
Sampling the stonework of an important historic building or ancient monument is destructive, but the damage incurred by taking a representative sample must be assessed against the potential deterioration and loss if unrepresentative sampling should lead to inappropriate treatment. Large samples can often be sub-sampled for the laboratory analysis and then repaired and placed back in situ during the repair work.

Samples should be selected to have one weathered face, with the remainder non-weathered. The sample’s orientation must be recorded (Fig 4): this can either be indicated in the information supplied with the sample, or if the sample is sufficiently large, and where it would not obscure any useful surface detail, marked directly on the outer face of the stone.

The optimum sample size will depend on the homogeneity and grain size of the stone. For uniform fine-grained stone, samples measuring 75mm × 75mm × 40mm are generally adequate, whereas a coarse-grained stone will require samples 150mm × 150mm × 80mm. Where a sample must be taken from the corner of a block with two weathered faces, it must be large enough to include some of the non-weathered inner core. If samples are required from carved detail, a small-diameter core drill can be used to collect material from concealed surfaces. The resulting holes can then be surface-filled by a specialist conservator.

The site for a sample must be carefully chosen so as not to disfigure the building, although this must not result in the sample being unrepresentative.

Permission to sample must be secured from the relevant authority: a faculty for Church of England buildings, the equivalent for other religious authorities or Scheduled Monument Consent from the Department for Culture, Media and Sports through English Heritage for Scheduled Monuments. For listed buildings, the Local Authority Conservation Officer must be consulted. Ideally an official observer such as a Local Authority Conservation Officer or an English Heritage Historic Buildings Architect or Inspector should be present during sampling, to agree on sample locations and sizes.

It is always preferable that sampling be carried out by an experienced specialist.

Before sampling, the area should be photographed (see below). If large-scale colour banding or grain size variations exist, this should be captured with close-up photographs, and separate samples should be taken of each of the different bands.

European standards for sampling
Although harmonised European Standards (BS ENs) exist to govern and provide uniformity and consistency in sampling, these are designed for quality and process control. The number of samples required to achieve the confidence levels necessary for control purposes would not normally be acceptable for understanding the stone from a historic building, for which invasive investigations must be minimised as far as possible. Where a construction material must be identified or a weathering problem investigated, choosing the number and location of the samples will demand experienced professional judgement.
Sampling fragile stone

If the area to be sampled is deeply fractured or has shear cracks, it may be necessary to apply a temporary facing layer to it to prevent detachment, loss of loose surface material or further fracturing during sampling and removal.

Acid-free tissue should be adhered to the surface with a diluted solution of a suitable reversible consolidant (such as polyvinyl alcohol, or an acrylic emulsion), applied by a qualified conservator engaged by the client or stone specialist. If necessary, fragile samples can be protected in polythene bubble wrap for transportation; the protective layers and consolidant should then be removed prior to the laboratory analysis.

Planning stone sampling

The sampling strategy must be fully planned in advance. Ensure that all sampling locations have been identified, and that each location has been provided with safe access. A range of tools and other equipment should be available, including:

- small hammers
- chisels
- a range of sample bags
- felt-tip permanent markers and pencils
- tape measures
- core-drilling equipment to obtain 25–75mm solid diameter cores (Figs 5 and 6)

Photography

All locations must be photographed before sampling, preferably in colour. A general view of the building is also required, also a context shot of the general location of each sample, as well as several close-up shots of the sample site itself. A colour calibration chart and a scale should be included in the close-up photographs.

Direct lighting, from sunlight or flash, can subdue the surface features, which may assist in the interpretation of the sample. Therefore wherever possible, oblique lighting should be used, creating shadows that can emphasise subtle surface features.

The surface of the sampling area may be soiled, or covered with biological growth. If possible a small sample area in a concealed location should be lightly cleaned to reveal the true colour and texture of the underlying stone. If not, the visible condition of the stone should be recorded in addition to the photography.

Labelling samples

Each sample must be given a unique identifier, and all information regarding the sample and its location must be recorded in a systematic manner. To prevent error, samples should be labelled as soon as they are collected.

Where only a few samples are taken, the identifier can be the name of the building or site, and a sample number. However, where samples will be analysed by an organisation that deals with material from many different sites, the identifying system must be site-specific, and even organisation-specific. Whatever system is used, the identifier should be marked not only on the sample, but also on any accompanying information, and on all photographs taken of the sample location. The date of sampling must be included.

Samples should be placed immediately in a sealable polythene sample bag, with the identifier marked either directly on the sample, or where this is impossible on a manila tag placed inside the sample bag. If there is any concern over chemical pollutants, a non-plastic container should be used instead. When the identifier is written directly on the sample, take care not to damage any features or any surface contamination that may be pertinent to the investigation for which the sample was collected. The outside of the sample bag or container should also be labelled, using a permanent marker.

As most stone is abrasive, if the sample is sent for analysis by post or carrier, it must be packed in a manner that prevents it from moving around within the packaging – especially when more than one sample is included. The detachment of even a small fragment during transit may result in the entire sample being damaged. This risk is particularly high with samples of weathered stone. In this case samples should be tightly bubble-wrapped, before being packed into a padded postal envelope, either with additional soft padding to stop the sample moving around within the envelope, or with the sample taped securely to the inside of the bag.

For samples too large to fit safely into a padded envelope, a card postal pack or a box may be required; any spare space

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For samples too large to fit safely into a padded envelope, a card postal pack or a box may be required; any spare space
should be filled with polystyrene chips, vermiculite or bubble-wrap.

Useful additional information
For cost-effective and efficient analysis it is best to provide as much information as possible about the stone and the building to the analyst along with the sample. Where something is known about the original sources of stone from geographical regions, or better still the specific building, this can be readily compared with the results of the analysis. This information can help to identify potential sources of replacement stone as quickly as possible.

In the study of deterioration mechanisms, it is important to record the precise locations of samples, and the degree to which the original stone was exposed.

3.2 Examination and analysis of stone

Hand samples
The characteristics of many building stones can be readily identified *in situ*; this is especially true of the coarser-grained varieties such as granite, and many of the sandstones and limestones.

Preliminary determination of the general stone type and mineralogy of a stone can often be obtained *in situ* using a hand lens of about ×8 magnification. However, the characterisation of certain other stones – for example basalts, slates, siltstones and fine-grained limestones – will require specialised laboratory techniques. Detailed studies require stereomicroscopy, using magnifications of up to ×40. This helps to interpret the structure and composition of the stone and any physical breakdown.

Petrographic analysis
Petrographic analysis precisely identifies the mineralogical composition of a stone, and the conditions under which it was formed. This allows some assessment of the likely decay processes, especially as the manner in which stone weathers varies according to its petrographic characteristics.

A thin section of the stone is made by mounting a fragment of stone onto a microscope slide and grinding it down to a thickness of 30 microns (1 micron = 1/1000 mm) and is viewed through a polarizing microscope. This enables crystals and grains as small as one micron to be viewed in plane-polarized and cross-polarized light and so determine the type of minerals present and any changes in their composition (Fig 7).

Fig 7 Left side: sample of Devonian sandstone from a medieval corbel, Kilpeck Church, Herefordshire, studied under ordinary. Right side: polarized light microscopy. The width of each picture is 0.72mm. (David Jefferson)

The photomicrograph on the left was taken using ordinary light and shows that most of the mineral grains are transparent, although some can be speckled or slightly cloudy. In the same image on the right viewed under polarized light, the nature of the sand grains is clearly visible. The quartz grains range from clear to black depending upon their crystal orientation relative to the angle of the polarized light. A grain of microcline feldspar, distinguished by its tartan twinning, is located on the bottom left and fragments of rock composed of a number of small grains of quartz are present in the centre, just above the central quartz grain, and in the bottom centre. The bright colours of the elongated grain in the centre top indicate it is muscovite or white mica.

Fig 8 Left side: an oöidal limestone with a coarsely crystalline cement, the oöids have been partially dissolved away to leave a strong, sponge-like stone of high porosity, which is highlighted by the use of blue-coloured resin within the sample. Right side: Ooidal Portland Whitbed under ordinary polarized light with, in this case, the intergranular pore distribution again shown by the blue-coloured resin in the sample. Width of both pictures is 1.4mm. (David Jefferson)
This type of thin section analysis can also provide an assessment of the porosity of a stone, which is not visible to the naked eye (Fig 8). The identification of porosity is important because the size and shape of the pores and whether these are connected to form continuous channels can markedly affect the durability of the stone.

Physical parameters
Although petrographic study can determine the composition and physical properties of stone, very subtle changes in mineralogy can considerably alter its appearance. This is especially true of colour, which is often controlled by the quantity and variety of iron minerals within the rock. In sandstones, for example, the grains are often coated with a thin layer of an iron mineral. This coating can be less than 1 micron thick, and may give the stone a slight pinkish tinge. Should the iron-rich coating be slightly thicker – even by only 1 or 2 microns – the colour may be a deep reddish-brown. There are several common iron minerals that produce colour variations.

The colour of the stone being studied should be recorded using the Munsell® colour code (an internationally recognised standard system used for describing the colour of all types of materials). Geologists and archaeologists use the Munsell system to describe rocks, soils and ceramics, while architects, building surveyors and general contractors will be familiar with its use for classifying and specifying paint colours. Colour is arranged into classes or categories according to three variables: hue, value and chroma. It should be noted that most stones lighten or darken to some extent when wet. The colour of the stone should therefore be recorded both wet and dry.

Many stones that superficially look very alike, such as sandstones, can be seen under high magnification to be significantly different. The microscope may disclose that the natural cement in one sample is calcite, in another a clay mineral, and in a third silica. The weathering properties of all three stones would be very different, no matter how similar they appeared to the naked eye. Petrography can also identify minerals known to be unstable in the built environment, or likely to react with other materials, such as mortars. For example, cryptocrystalline silica in a sandstone may react with highly alkaline lime mortar, resulting in the degradation of the stone. Such features are important not only when determining the reasons for the breakdown of a historic stone, but also when selecting its replacement.

The geology of the British Isles is well characterised, so petrographic study can be very useful for locating quarries and sources of compatible stone within the United Kingdom. Matching historic stone imported from Europe and other parts of the world, however, demands both specific knowledge of the stone and careful reference to standard samples.

Petrographic analysis is essential when using commercially available stone, as the trade names can be misleading. For example, Rosso Levanto Marble (Fig 9) is not a marble but a hard, polished serpentinised stone. Purbeck marble is just one of the many so-called marbles available that are not in fact true metamorphic marble, but are hard, polished limestone. Similarly, some slates are actually highly compacted mudstones and siltstones that have not been subjected to the metamorphic forces necessary to produce true slate.

Other analytical techniques

X-ray diffraction analysis
The diffraction of x-rays passing through a crystalline material produces patterns characteristic of the crystal, and determines the mineralogy of a particular stone.

Scanning electron microscopy
Many of the reactions that damage building stone occur at sub-microscopic level. A scanning electron microscope permits magnifications well in excess of \(\times 1000\), and with the addition of an EDX (Energy-Dispersive X-ray Spectrometer) can determine aspects of chemical composition (Fig 10).

A simple chemical test for carbonates
Limestone and calcareous sandstone can be distinguished from other forms of sandstone and from other stone types by applying a 5% solution of dilute hydrochloric acid to a small area of surface. Any calcium carbonate present within the stone will vigorously effervesc as carbon dioxide is liberated by reaction with the acid.

Sandstones are commonly composed of quartz sand grains, but the cement binding these together can vary in composition. If effervescence is observed between the grains, the cement is likely to be calcite. If there is no reaction, the binder...
If the mineralogy of the replacement stone is similar to the original, then the chemistry of the stone will effectively be the same. The constituent grains should be of the same type, size, angularity and order of importance – should be used for finding replacement stone:

**Petrography**
The constituent grains should be of the same type, size, angularity and proportions as in the original stone. The binding material must also be similar. The ratio of binding material to constituent fragments or mineral grains and the porosity must also be alike.

**Porosity**
Both the overall value of the porosity and the pore-size distribution should be as close as possible to those of the original stone. If a stone with the same porosity and permeability cannot be found, use one with a higher rather than lower porosity. Any subsequent degradation is then more likely to occur in the new stone rather than in the original fabric.

**Compressive strength**
Where it is not possible to match the compressive strength of the replacement with the original stone, the replacement stone should be weaker rather than stronger, so that it is the more likely to fail.

Satisfying all these criteria would ideally require the replacement stone to be from the original quarry, or at least a source in very close proximity to the original quarry. Failing this, the new stone should meet as many of the above criteria as possible, with the first three being the most critical.

### 5 Sources of stone

#### 5.1 Active quarries
There are approximately 220 quarries producing building stone in England listed in a biennial publication *The Natural Stone Directory*. Other quarries supplying building stone can be found in the *Directory of Quarries & Quarry Equipment* and in the *Directory of Mines and Quarries*. The British Geological Survey and freelance stone consultants can also help locate appropriate current sources of stone.

Some quarries have been working the same strata in the same location for centuries, for example, the Portland quarries have been producing relatively consistent limestone since the 18th century. Some smaller quarries are also working long-established building-stone beds, but for others the output has changed over the years. The modern stone available from a particular quarry may retain the identifiable visual features of the original, but be petrographically different from the stone extracted in the past. Such differences could prove significant when a stone is inserted in the existing fabric of an historic building (Fig 11).

#### 5.2 Disused quarries
If the source of stone has been traced to a particular quarry but the quarry is now closed, it may be possible to obtain the stone by reopening the workings for a short time. Land and mineral-rights owners are frequently amenable to extracting stone from an old quarry on their land, especially if the building or monument being conserved is a local feature. Mineral Planning Authorities are also normally sympathetic to proposals to obtain supplies of the correct stone from original sources, especially for the repair of historic buildings.

To determine whether the stone from a closed quarry can be economically extracted, it must be thoroughly sampled *in situ*. If any lithological variation is suspected, representative samples must be obtained from all the beds of rock, and from different parts of every bed. The thickness of the different beds, any lateral variation in thickness, and the distribution and angle of joint patterns within the rock must be recorded, as these features determine the sizes of the blocks that can be
6 Obtaining stone for historic building repair

6.1 Specifying stone

Replacement stone should be specified to meet the criteria defined in Section 4, with samples of potential replacements carefully matching the original material.

All stone varies to some extent, but the variation in the replacement stone should not be greater than the variation in the original fabric of the building, to avoid differences in petrography, porosity and colour of the repair stone. For example, limestone taken from a single quarry can range from very fine-grained to coarse and shelly, depending on which beds are being worked. If some of the stone produced by the quarry is not suitable, the exact stone

extracted. Possible block sizes must be carefully compared to the masonry sizes required for the repair.

Most building stone tends to be rectangular, but if the joints in the natural block of stone are not at right angles there will be a high level of wastage when the stone is cut, and the resulting blocks will be considerably smaller blocks than those extracted from the quarry (Figs 12 and 13).

5.3 Recycled stone

Where no suitable replacement stone is commercially available, but only small quantities of material are required, for example, minor repairs to window mullions, it may be acceptable to recycle stone. The provenance of stone being re-used must be established and must have been obtained from a lawful dismantling of a building or other structure to prevent unlisted vernacular buildings being robbed for their stone.

Great care must be taken when selecting stone for re-use. Avoid weathered or damaged material, and ensure that the blocks are large enough to accommodate the dressing-back necessary to remove the original exposed surfaces.

Fig 11 Grinshill Quarry, Shropshire: left side, old disused quarry; right side, modern working quarry. (Don Cameron, British Geological Survey. © NERC. All rights reserved IPR/74-54C)

Fig 12 Clipsham, Lincolnshire, irregular-shaped stone prior to being sawn into rectangular blocks. (David Jefferson)

Fig 13 Grinshill, Shropshire, waste stone after cutting, and the range of colours within one quarry source. (Don Cameron, British Geological Survey. © NERC. All rights reserved IPR/74-54C)

Fig 13 Grinshill, Shropshire, waste stone after cutting, and the range of colours within one quarry source. (Don Cameron, British Geological Survey. © NERC. All rights reserved IPR/74-54C)
required must be clearly specified. The grain size of sandstones can also vary widely, so the acceptable range should be specified, along with the acceptable porosity. This is especially important if the stone is to be inserted into the existing fabric of a building. Experienced quarry managers and their staff can assist the specifier with these aspects.

Finding blocks of the correct size for a particular purpose may require contractors to pre-order and pay a deposit, as it may take the quarry some time to locate and earmark the appropriate blocks. The lead-in time the quarry requires to source and supply blocks must be taken into account when designing the repair programme. The logistics should be planned well in advance of when the stone will be needed on site.

6.2 Samples of new stone
All quarries producing building stone will supply samples on request. These typically measure 100mm by 100mm, and are about 10mm thick.

As stone is a natural and variable material, a single sample cannot completely represent the variations that probably occur within the stone. This is often indicated in the supplier’s literature, but it should be remembered that stone naturally changes colour as it weathers. New or replacement stone should therefore never be selected on the basis of supplier’s samples alone, and these samples should not be sent for analytical comparison with samples of existing stonework.

If a supplier’s sample appears suitable for a particular project, the quarry itself should be visited. There the likely variation in the stone can be determined by examining the quarry faces, and blocks extracted and stored at the quarry.

Samples from varying blocks can be collected in the same manner as for in situ sampling (Section 3.1), and these should be analysed to determine the suitability of the stone for its intended purpose.

6.3 Testing replacement stone
Many of the established tests for building stone are designed to investigate their performance in the context of modern building practices, for example, the breaking load of a fixing used in stone cladding.

Other tests – salt crystallisation, saturation coefficient, porosity, and freeze/thaw cycles – were originally designed to give an indication of durability. As these tests tend to be carried out on small cubes of stone within a laboratory, they take into account neither the environment within and around the building, nor the effect of the mortar between the blocks. Thus it can be difficult to relate the test results to the behaviour of stone in situ. Such tests may, however, be useful for comparing the behaviour of the potential replacement with that of the original stone, or with that of a stone whose properties in a similar environment are well understood.

6.4 Obtaining stone from new or temporary sources
In recent years a number of small, disused quarries have been temporarily re-opened to supply walling stone, stone roofing slates and even stone for crushing (to help replicate medieval mortar mixes). Opening up quarries requires professional assistance from a stone consultant or an existing quarrying company.

The first step is to identify the landowner and, if they are not the same, the mineral-rights owner. The Mineral Planning Authority (MPA) should be approached to determine whether planning consent is required. This may be dependent upon the scale of the proposed operation; if the quantity of stone required is relatively small, the MPA will frequently waive planning consent and permit temporary works in a manner agreed in detail with them.

Once the necessary consent has been obtained, the overburden and topsoil is carefully removed and stockpiled. After stone extraction is completed, the excavation is backfilled with any waste stone, and the stored overburden and topsoil is used to restore the site. The vegetation usually regenerates rapidly from the natural seed bank in the soil.

7 Sources of further information and assistance

7.1 Stone collections
There are a number of sample collections of historical and contemporary building stone, which are useful for understanding...
different stone types or for comparing stones. Some collections are open to the public, although admission may be charged.

The National Collection of Building and Decorative Stones, Natural History Museum, London: reference collections may be inspected by appointment.

The John Watson Building Stone Collection, Sedgwick Museum Building, University of Cambridge: assembled at the beginning of the 20th century, this collection includes building stone, stone roofing slates, flagstones and road stone.

The British Geological Survey (BGS), Keyworth, Nottinghamshire: this collection of more than 50,000 stones is available for public consultation, and details of the collection are accessible through a computer database.

Contact details can be found below under Useful contacts.

7.2 Other sources of help
Local Planning Authorities and their Conservation Officers can often help with technical advice on local natural building materials.

The BGS can also provide information on the geology of building stones, including the location of both active and disused quarries.

Independent consultants who specialise in the identification, selection and assessment of stone for the repair of historic buildings can be located through the Natural Stone Directory, the Geological Society or the Institute of Quarrying (see Useful contacts).

Bibliography


Clifton Taylor, A 1972 The Pattern of English Building, 3 edn. London: Faber and Faber


Shore, B C G 1957 Stones of Britain. London: Leonard Hill (Books) Limited


Warnes, A R 1926 Building Stones: Their Properties, Decay, and Preservation. London: Ernest Benn Limited

Watson, J 1911 British and Foreign Building Stones. Cambridge: University Press


Useful contacts

British Geological Survey (BGS)
Kingsley Dunham Centre
Keyworth
Nottingham NG12 5GG
tel: 0115 936 3100
fax: 0115 936 3200
e-mail: enquiries@bgs.ac.uk
website: www.bgs.ac.uk

British Standards Institution (BSI)
389 Chiswick High Road
London W4 4AL
tel: 020 8996 9001
fax: 020 8996 7001
e-mail: orders@bsi-global.com
website: www.bsi-global.com

Building Research Establishment (BRE)
Bucknalls Lane
Garston
Watford WD25 9XX
tel: 01923 664000
e-mail: enquiries@bre.co.uk
website: www.bre.co.uk

Directory of Quarries and Quarry Equipment
QMJ Publishing Limited
7 Regent Street
Nottingham NG1 5BS
tel: 0115 941 1315
fax: 0115 948 4035
e-mail: mail@qmj.co.uk
website: www.qmj.co.uk

English Heritage
Customer Services
PO Box 569
Swindon SN2 2YP
tel: 0870 333 1181
fax: 01793 414926
e-mail: customers@english-heritage.org.uk
website: www.english-heritage.org.uk

Geologist's Directory
available from The Geological Society,
address below

Geological Society of America Rock Colour Chart
Geo Supplies, Limited
49 Station Road
Chapeltown
Sheffield S35 2XE
tel: 0114 245 5746
fax: 0114 240 3405
e-mail: sales@geosupplies.co.uk
website: www.geosupplies.co.uk

Institute of Quarrying
7 Regent Street
Nottingham NG1 5BS
tel: 0115 945 3880
fax: 0115 948 4035
e-mail: mail@quarrying.org
website: www.quarrying.org

John Watson Building Stone Collection
Sedgwick Museum of Earth Sciences
University of Cambridge
Downing Street
Cambridge CB2 3EQ
tel: 01223 333456
fax: 01223 333450
e-mail: sedgwickmuseum@esc.cam.ac.uk
website: www.sedgwickmuseum.org

National Stone Centre
Porter Lane
Middelton by Wirksworth
Derbyshire DE4 4LS
tel/fax: 01629 824833
e-mail: nsc@nationalstonecentre.org.uk
website: www.nationalstonecentre.org.uk

Natural History Museum
Cromwell Road
London SW7 5BD
tel: 020 7942 5839 (Customer Services)
website: www.nhm.ac.uk

Natural Stone Directory
QMJ Publishing Limited
7 Regent Street
Nottingham NG1 5BS
tel: 0115 941 1315
fax: 0115 948 4035
e-mail: mail@qmj.co.uk
website: www.qmj.co.uk

The Geological Society
Burlington House
Piccadilly
London W1J 0BG
tel: 020 7434 9944
fax: 020 7439 8975
e-mail: enquiries@geolsoc.org.uk
website: www.geolsoc.org.uk
### Annex: A system for the field identification of the more common building stones used in England (based on a scheme developed by the Division of Physical Research, Bureau of Public Roads, U.S. Department of Commerce by D O Woolf)

#### Preliminary classification groups

<table>
<thead>
<tr>
<th>Group 1</th>
<th>Glassy rocks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>glassy lustre, hard, conchoidal fracture, colourless to white or smoky grey, generally brittle</td>
</tr>
<tr>
<td></td>
<td>cellular or frothy glass</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group 2</th>
<th>Very fine-grained rocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-group 2A</td>
<td>not scratched by a fingernail, but readily scratched with a knife</td>
</tr>
<tr>
<td></td>
<td>particles almost imperceptible, dull lustre, homogeneous, clay odour, little if any effervescence with dilute acid, laminated structure, breaks into flakes</td>
</tr>
<tr>
<td></td>
<td>brisk effervescence with dilute acid, little if any clay odour although a bituminous odour may be discharged if the stone is struck; may contain fossil fragments</td>
</tr>
<tr>
<td></td>
<td>brisk effervescence with dilute acid, no clay odour, soft, normally white in colour, can leave white powder on the hands</td>
</tr>
<tr>
<td></td>
<td>little if any clay odour, brisk effervescence with dilute acid only when the rock is powdered or the acid is hot</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sub-group 2B</th>
<th>not scratched by a knife, or scratched only with difficulty, no effervescence with dilute acid</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>very hard, pale colours to black, no clay odour, conchoidal fracture, waxy or horn-like appearance</td>
</tr>
<tr>
<td></td>
<td>heavy, dark colour, may be finely crystalline when viewed with a hand lens, may contain small cavities which can be open or filled with crystalline mineral</td>
</tr>
<tr>
<td></td>
<td>chert</td>
</tr>
<tr>
<td></td>
<td>basalt</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group 3</th>
<th>Granular rocks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-group 3A</td>
<td>easily scratched with a knife</td>
</tr>
<tr>
<td></td>
<td>brisk effervescence with dilute acid; granular material may be broken fossil fragments, angular material or small spherical grains, the granular material may be mixed with fine-grained material</td>
</tr>
<tr>
<td></td>
<td>brisk effervescence with dilute acid; grains may be large and interlocking, compact, colour may be white, cloudy grey or coloured, often banded or variable</td>
</tr>
<tr>
<td></td>
<td>grains are deep red or brown, embedded in a similarly coloured material; may be slight effervescence with dilute acid; hard bands or patches of very fine-grained red or brown mineral may occur; may stain hands red</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sub-group 3B</th>
<th>hard, not scratched with a knife or scratched with difficulty, grains normal of approximately equal size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mainly quartz and feldspar in relatively large crystals, although mica commonly present, usually grey, pink or red</td>
</tr>
<tr>
<td></td>
<td>mainly quartz in distinct grains often clearly set in a matrix, can fracture round the grains; no distinct red colouration, can be buff, grey or greenish grey</td>
</tr>
<tr>
<td></td>
<td>mainly quartz in distinct grains often clearly set in a reddish coloured matrix, can fracture round the grains; may stain hands red</td>
</tr>
<tr>
<td></td>
<td>mainly red-stained quartz, embedded in a relatively large quantity of red or brown coloured material; hard bands or patches of very fine-grained red or brown mineral may occur; may stain hands red</td>
</tr>
<tr>
<td></td>
<td>mainly quartz in distinct grains often clearly set in a pale-coloured matrix which effervesces with dilute acid, can fracture round the grains</td>
</tr>
<tr>
<td></td>
<td>mainly quartz in distinct grains in a hard siliceous matrix, stone fractures through an appreciable quantity of the grains</td>
</tr>
</tbody>
</table>

#### Group 4 | Foliated rocks |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>medium to coarse grain; roughly foliated</td>
</tr>
<tr>
<td></td>
<td>very fine grain, splits easily into thin slabs, usually dark grey, green or black in colour</td>
</tr>
</tbody>
</table>

#### Group 5 | Fragmental |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>rounded pebbles embedded in a cementing medium which can be reddish in colour</td>
</tr>
<tr>
<td></td>
<td>angular fragments of rock embedded in a cementing medium which can be reddish in colour</td>
</tr>
<tr>
<td></td>
<td>fragments of volcanic (fine-grained or glassy) rocks embedded in compacted volcanic ash</td>
</tr>
<tr>
<td></td>
<td>quartz grains, possibly together with fragments of rock and mica, rounded or angular, less than about 1mm in diameter, cemented together</td>
</tr>
<tr>
<td></td>
<td>quartz grains, possibly together with fragments of rock and mica, rounded or angular, between about 1mm and 4mm in diameter, cemented together</td>
</tr>
</tbody>
</table>

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1. Glassy (wholly or partially)
2. Not glassy, dull, homogeneous, so fine-grained that the grains cannot be recognised
3. Distinctly granular
4. Distinct foliation, no effervescence with dilute acid
5. Clearly fragmental in composition, rounded or angular pieces or grains cemented together

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1. Glassy lustre, hard, conchoidal fracture, colourless to white or smoky grey, generally brittle
2. Cellular or frothy glass
3. Shale
4. Limestone
5. Chalk
6. Magnesian limestone
7. Chert
8. Basalt
9. Limestone
10. Marble
11. Ironstone
12. Granite
13. Sandstone
14. Ferruginous sandstone
15. Ironstone
16. Calcareous sandstone
17. Quartzite
18. Gneiss
19. Slate
20. Conglomerate
21. Breccia
22. Volcanic tuff
23. Sandstone
24. Gritstone
Notes for Annex opposite

1 Although quartz is a mineral rather than a rock, it is included as a building stone because quartz cobbles from rivers and beaches have been used in rubble stone buildings.

2 Chert includes flint, which is the traditional name given to the chert bands and nodules found in some Cretaceous chalk.

3 Ironstone is a term traditionally used for both calcareous stones rich in iron minerals, which effervesce with dilute acid, and extremely iron-rich sandstones that do not react with acid.

Acknowledgements

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Cover figure:
(top left) Grinshill, Shropshire: disused quarry. (Don Cameron, British Geological Survey. © NERC. All rights reserved IPR/74-54C)
(top centre) Howden Minster, East Yorkshire: new magnesian limestone replacement on the south doorway arch. (Seamus Hanna)
(top right) Clipsham, Lincolnshire: modern working quarry. (David Jefferson)
(bottom left) Thin section of an oöidal limestone with blue coloured resin highlighting the porosity. (David Jefferson)
(bottom centre) Truro Cathedral, Cornwall: replacement stone in a decayed frieze. (Seamus Hanna)
(bottom right) Rosso Levanto marble: a hard polishable serpentinised stone. (David Jefferson)