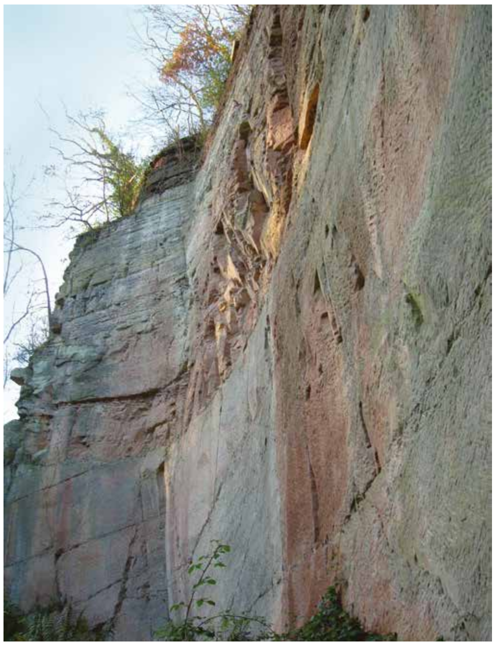
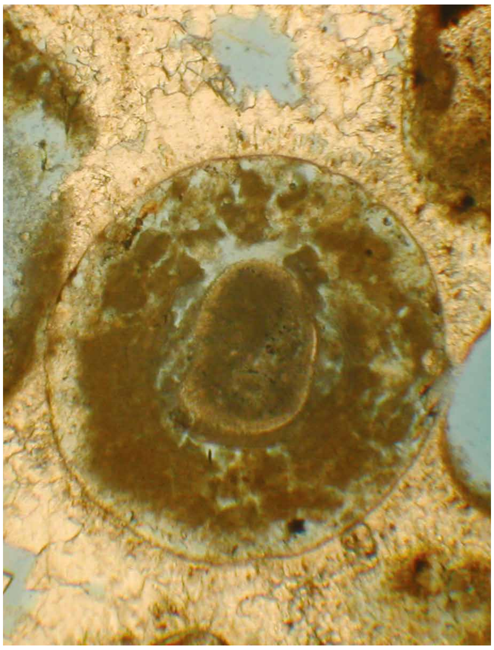
Sourcing Stone for Historic Building Repair





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Front cover

Top left: Truro Cathedral, Cornwall: replacement stone in a decayed frieze
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Top right: Grinshill, Shropshire: a disused quarry face Don Cameron, British Geological Survey.
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Bottom left: Thin section of an oöidal limestone with blue-coloured resin highlighting the porosity
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Bottom right: Howden Minster, East Yorkshire: replacement magnesian limestone on the south doorway arch
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Summary

This Technical Advice Note is aimed at architects, surveyors, engineers, building managers, contractors, conservation officers and owners who need to obtain matching stone for repairing a historic building or monument.

Successful stone replacement requires detailed knowledge of the characteristics of the stone involved and the selection of compatible materials (that is stone that closely replicates the original in terms of its chemical, physical and mineralogical properties). The stone-sourcing process involves several steps:

- Establishing the significance of the building, and the likely impact of intervention
- Understanding why the stone is deteriorating
- Undertaking a survey to determine the need for stone repair or replacement
- Determining the types of stone used, by visual examination *in situ*
- Answering any technical questions arising in the steps above, by detailed analysis of samples taken from the structure
- Obtaining samples of potential replacement stone for analysis, and testing these where necessary
- Sourcing replacement stone from existing quarries, quarries temporarily re-opened for the purpose or by re-using stone salvaged from a demolished structure

Advice on each step is provided, enabling readers to make informed decisions at every stage of the procurement process and thus helping to ensure that any new stone is compatible with the historic fabric.

Historic England supports the need for strategic and sustainable sources of stone for conservation of historic buildings. It is working with partners to ensure that historic sources of important building stones are identified and protected, and that the environmental impact of their extraction is minimised. Addressing the wider issues arising from sourcing and quarrying stone will contribute to the long-term preservation of our rich and diverse stone-built heritage.

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Introduction

Stone has historically been one of the most widely used natural materials for constructing buildings, monuments, sculpture and carved decoration. It is workable and strong and, in many areas, is abundant and can be extracted relatively easily. Through several millennia, extraction, transportation and working of stone have been refined, often with considerable ingenuity. On a local scale, the use by masons of locally available stone has produced distinctive vernacular building styles. In many parts of the world, cultural status is closely related to the number of large stone buildings and public monuments.

Although stone is something of a metaphor for permanence and durability, in reality this is not always the case. Composition varies, even within a single source, and a poorly selected or used building stone may prove unstable, brittle or soft. Timely repair and on-going maintenance may extend its life, but sometimes conservation of the structure can only be achieved by replacing some of the stone. For such intervention to be successful, however, it is imperative that the historic and physical significance of the building, its current condition, and the effect of the proposed intervention are understood before the repair programme is designed.

Planning stone replacement

Stone sourcing should form part of the design and specification stage of any repair project. Identifying suitable sources of replacement stone at this stage will enable the work programme to remain on course and within budget. Stone sourcing for historic building repair must take the following factors into account:

- the replacement stone should be similar in colour, texture, physical, chemical and mineralogical properties to the original
- any intervention must not harm the original building fabric nor the significance of the structure
- the roles and responsibilities of those within the design team must be well understood
- all work must comply, where appropriate, with the Listed Building Consent framework and British and European Standards

For large projects, stone procurement is often part of a sub-contracted masonry package. However, unless a commercially available stone with a common bed height is required, there may not be enough time to identify, select and order the correct stone before work starts (obtaining stone with the correct petrography, texture and colour, or of unusual bed height can take six months or more), and for expediency, this may result in unsuitable stone being used instead. This could have a drastic visual and physical impact and, as the new stone cannot usually be replaced by appropriate stone without great expense, it may, at best, remain as an unfortunate example of bad planning or, at worst, have a long-term disfiguring and damaging effect on the historic building's fabric. Therefore, it is recommended that identification and procurement of stone for repairs is undertaken as a separate contract and is started well in advance of the repair work. For the same reasons, it is suggested that local authorities should require details of stone to be used in any works that require listed building or conservation area consent, together with evidence that sufficient supplies to complete the work are likely to be available within the required time period, to be submitted at the application stage, rather than to reserve approval of stone type as a condition of any consent.

The stone-sourcing team

Matching stone is often not straightforward. Although it may be possible to distinguish common stone types (sandstone from slate, or Bath limestone from Ketton limestone for example) on the basis of colour and texture, there are many subtle colour differences, textural changes and variations, such as striations and sedimentary structures, variable grain sizes, porosities and cementation, and even mineralogical incompatibilities within generic stone types. These fine details may be critical to a successful repair, but their recognition requires considerable expertise.

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 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 to be sourced from a temporary or newly opened quarry, the stone consultant should also be experienced in mineral planning procedures.

Historic-building architects, stone-trade consultants and masonry contractors are often 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. As a member of the project team, an experienced stone consultant can provide vital guidance for client and contractor throughout the procurement process, thus helping to avoid expensive errors. Operating as a link between the project architect or consultant, and the contractor and masonry sub-contractors, the consultant can also control quality when large amounts of stone are being supplied. On occasion, they may work in conjunction with a masonry-trade consultant.

1 Existing Stonework

1.1 Understanding the structure and its condition

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 repair and restoration. In most buildings 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, and the flexural strength required for loadbearing 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 been 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.

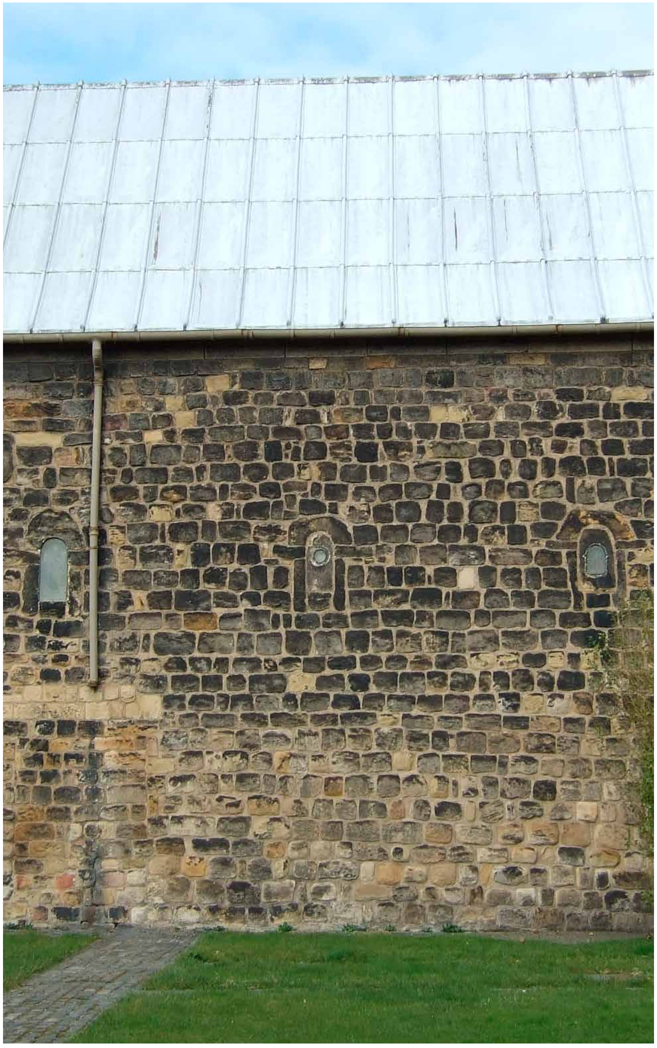


Figure 1
An early example of re-used stone at the Church of St Paul at Jarrow, Tyne & Wear. The chancel of this church is part of the Anglo-Saxon Monastery of St Paul. It was constructed in the 7th century using blocks of Roman masonry looted from nearby Hadrian's Wall. The chancel was later incorporated into the parish church.

Every type of stone has unique properties and a distinct manner of weathering and decay. The rate and type of deterioration is dependent on the composition of the stone, 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 have caused local decay. Even sound stone elements are subject to various chemical and biological processes and mechanical stress that can, over time, lead to internal and superficial deterioration, and eventually may cause complete disintegration. The rate of decay varies, 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; deterioration can accelerate if this is destabilised.

Changes to the fabric, such as the insertion of a different type of stone or the enclosure of an external wall (especially if the enclosed area is heated), can harm the existing stonework. The juxtaposition of two incompatible stones can lead to adverse chemical reactions. For example, placing limestone above certain types of sandstone can lead to decay of the sandstone, since alkaline moisture leaching out of the limestone can react with clay or reactive silica binders in the sandstone.

Natural decay processes are exacerbated by poor design and construction, such as incorrect orientation of bedding planes resulting in blocks that 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. Studying the construction of the original building and the current condition of the stonework and its surroundings is therefore essential when assessing the need for repair and determining the best way of replacing severely decayed elements.

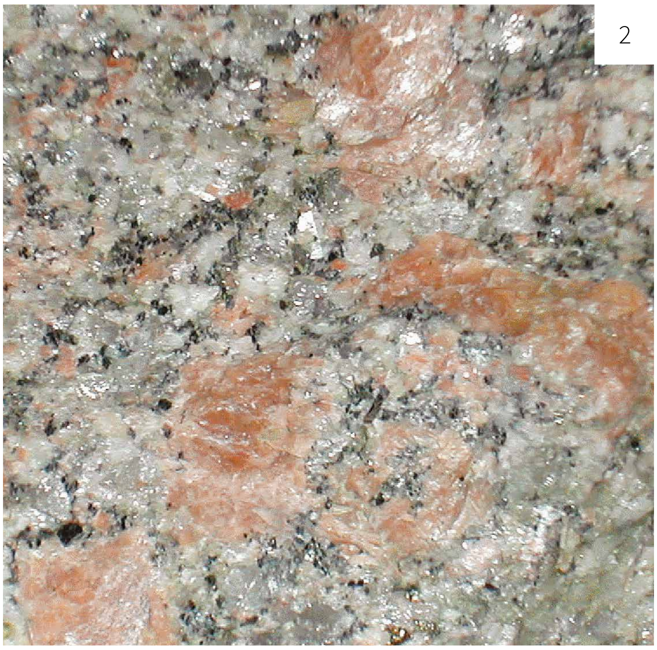
1.2 Preliminary surveys

The initial step in any stone conservation project 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. An extremely important part of the initial survey is the identification, not only of the type of degradation of the stone, but also its cause. There is little point in repairing the fabric of a building if the reasons for the damage to the original stonework still exist, since it is likely that, after a short time, the replacement stone will suffer the same fate as the original.

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 original construction and subsequent repairs, alterations or additions. Such research often provides useful insights into the design, the sources of original and later 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, which may have resulted from similar stones being obtained from different sources, should be recorded.

Features of the stone that should be documented include: banding, inclusions of different-coloured material within igneous or metamorphic rocks (Figure 2) and the orientation of bedding and changes in grain size between layers in sedimentary rocks (Figure 3).



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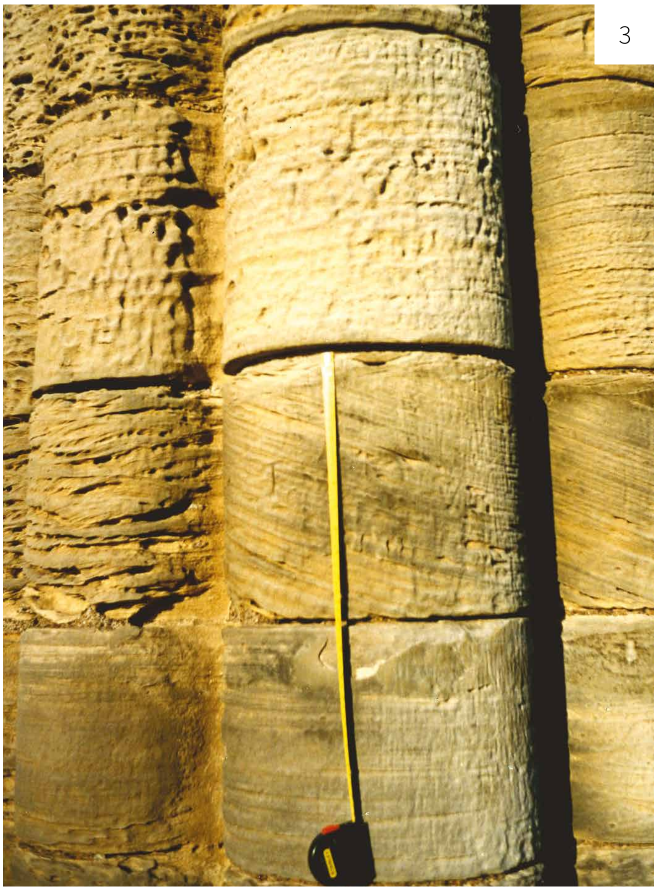

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For sedimentary stones, the height of the masonry courses should be recorded. Unless the blocks have been edge bedded, course height usually reflects the thickness of the beds in the quarry. The relative proportions of course heights can be invaluable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

Findings should be recorded by hand on site onto accurate line drawings, such as those produced from a photogrammetric survey of the building for example, or on to enlarged digital photographs. Information can also be recorded directly onto photographs or drawings stored on a tablet if preferred.

European Standards for Condition Surveys

Although Standards were originally intended as a means of ensuring that manufactured goods conformed to an agreed level of quality, they now apply in areas where professional specialists have to make decisions in non-standard conditions. Standard EN 16096:2012 *Conservation of Cultural property - Condition survey and report of built cultural heritage* falls into this category. Due to the considerable range of historic buildings and monuments throughout Europe, each condition survey will be monument-specific. To ensure that all aspects of deterioration occurring within a building are identified and noted, the Standard should therefore only be used as a guide or *aide-mémoire* for the specialist carrying out the survey.

Figure 2
Shap granite showing scattered large crystals (phenocrysts) of feldspar (field of view 60mm wide).
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Figure 3
Whitby Abbey, North Yorkshire: various large-scale features, such as grain-size variations and cross-bedding, on 250mm-high column drums.
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2 Sampling and Analysis

Reasons for professional analysis

- to identify the type and (ideally) the source of the stone as a guide to the required properties of any replacement stone
- to understand the manner in which a stone is weathering or decaying, and to establish measures to slow the rate of deterioration
- to determine the nature and distribution of contaminants within the pores of the stone, and their possible effect on the stone and on the surrounding building fabric

Information required by the analyst

- the aim of the petrographic analysis, and how the information will be used
- the history, age and condition of the building
- the nature and extent of visible decay mechanisms
- the context and location of specific stones or areas of the building being studied

2.1 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 can be invasive, and should not be considered a routine procedure, but rather a carefully considered operation with a specific purpose.**

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

Background information required for sampling

The nature of the problem being studied may dictate that samples are taken in a specific manner, so the analyst should always be consulted before sampling begins. In many cases, such as studies of weathering or deterioration rates, or the effects of previous treatments or salt contamination, for example, it is imperative to explain the precise nature of the problem when submitting the samples, as this may influence the sample preparation.

If previous conservation treatments are being assessed, it is necessary to gather information about any materials used, including their chemical, physical and ageing properties, their weathering and deterioration characteristics, and any potentially harmful effects they may have had on both the treated stone and 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 only weathered material can lead to misinterpretations of the original nature of the stone. For example, sandstone cemented with calcite has completely different properties from sandstone cemented with clay minerals, but when weathered, both may consist largely of sand grains separated by voids from which the cement has been leached and they can appear remarkably similar. Misinterpretation can lead to an incorrect choice 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.

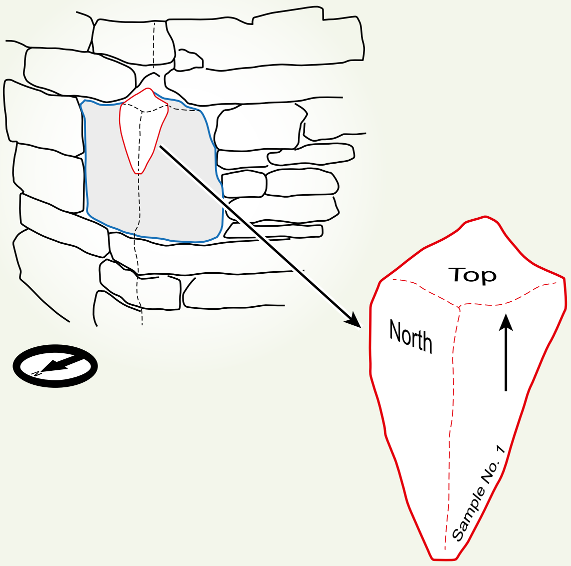
The sample taken must be truly typical. If there are apparent variations in the stone, for example in colour, texture or type of weathering, samples of each variant should be collected whenever possible.

Samples should always be taken directly from the building and not by collecting fallen stone, as the history of such material and whether it is representative will always be in doubt. If a piece of stone has detached naturally from the fabric of the building, it may be more weathered than the *in situ* stone, and therefore have different petrographic characteristics.

Preparing to take samples

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. 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 to the structure if unrepresentative sampling leads to inappropriate treatment. Sometimes a large sample, such as a complete block, can be removed and then sub-sampled for laboratory analysis before being repaired and placed back *in situ* during the repair work.

Ideally, samples should be selected to have one weathered face, with the remainder non-weathered. The sample's orientation must be recorded (Figure 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 with a fine-point felt-tipped pen, wax crayon or pencil.



Orienting a sample.
Having removed the sample from the selected portion of the fabric, replace it in the block and mark the top and orientation of at least one face. If the top is not a flat surface, an upwards pointing arrow on one of the side faces can be used to indicate the top of the piece.

Figure 4
Marking the orientation on a removed stone sample.
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The optimum sample size depends on the homogeneity and grain size of the stone. For uniform fine-grained stone, samples measuring 50mm x 50mm x 30mm are generally adequate, whereas for a coarse-grained stone, larger samples up to 100mm x 100mm x 50mm will be needed. 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, either by replacing part of the core or by using an appropriate mortar.

The appropriate permission to sample must be secured from the relevant authority: for churches in use, this will be a faculty for Church of England buildings or the equivalent for those of other denominations: Scheduled Monument Consent from the Department for Culture, Media and Sports through Historic England for Scheduled Monuments: and for listed buildings the Local Authority Conservation Officer must be consulted. Ideally an official observer, such as a Local Authority Conservation Officer or a Historic Buildings Inspector from Historic England, should be present during sampling, to agree on sample locations and sizes.

It is always preferable that sampling is 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 Standard for sampling

Although harmonised European Standards exist to govern and provide uniformity and consistency in sampling, these have traditionally been 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.
As with other European Standards relating to cultural property, the one on sampling, EN 16085:2012 *Conservation of Cultural property - Methodology for sampling from materials of cultural property - General rules*, should only be used as a guide. The methods of sampling employed and the number of samples taken will depend entirely on the property and the problem being investigated.

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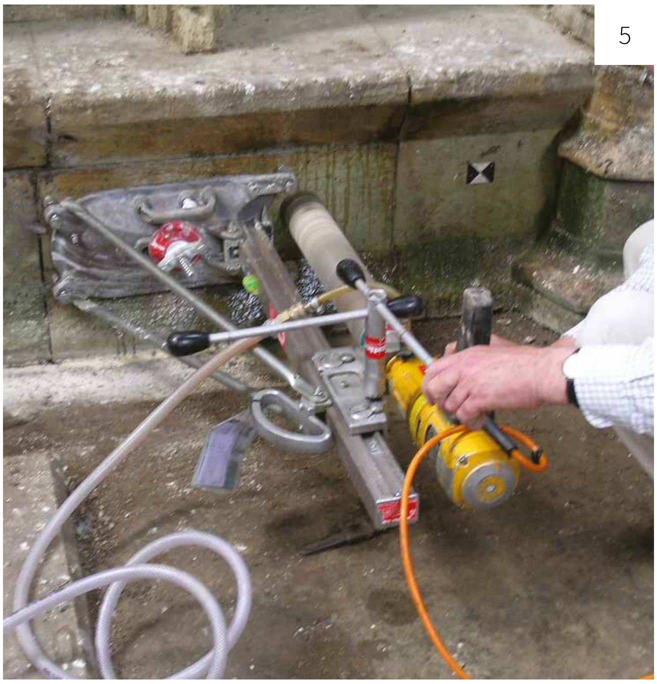

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Figure 5
Core-drilling rig being used to extract a 75mm core-sample of magnesian limestone at Howden Minster, East Yorkshire.

Figure 6
75 mm core drill and extracted core in protective polyethylene tube for safe transportation.

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 removal of the sample. This can be done by 'facing up' the surface with acid-free tissue paper adhered to the stone surface using a diluted solution of a suitable reversible consolidant (such as polyvinyl alcohol, or an acrylic emulsion). This should be done by a qualified conservator engaged by the client or stone specialist. If necessary, fragile samples can be protected in polythene bubble wrap for transportation. It may be necessary to remove the tissue facing and the consolidant 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:

- a small hammer
- chisels
- a range of sample bags
- felt-tipped permanent markers and pencils
- tape measures
- core-drilling equipment to obtain 25–75mm-diameter solid cores may also be required in certain circumstances.

Checklist prior to sampling

Photography

- ❑ Have photographs been taken of the building or monument, and of all the sample areas?

Sampling

- ❑ Is the sample truly representative of the stone being studied?
- ❑ Is the sample being taken directly from the standing structure?
- ❑ Does the sample include both a weathered and a non-weathered side?
- ❑ Is the sample of an appropriate size, for example 50mm x 50mm x 30mm?
- ❑ Has the orientation been marked on the sample?

After sampling

Photography

- ❑ Have the sample locations been photographed after sampling?
- ❑ Has the sample been photographed?

Labelling and packaging

- ❑ Is the sample clearly labelled with a unique identifier?
- ❑ Is the sample accompanied by a statement showing the building or site name, street, town, county, the location on the building or monument and the date of sampling?
- ❑ Is the sample securely wrapped and secured in an appropriate bag, with adequate labelling both inside and out?

Photography

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

Direct lighting from sunlight or flash can subdue the surface features, which may make interpretation of the sample more difficult. Therefore, wherever possible, oblique lighting should be used, as this creates 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 also 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 in a laboratory 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 also be included.

After extraction, samples should be placed immediately in a sealable polythene sample bag, with the identifier marked either directly on the sample with a fine-point felt-tipped pen or a wax crayon, or, where this is impossible, on a manila tag placed inside the sample bag. 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 compromised. 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 cardboard 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, when sending the sample it is best to provide the analyst with as much information as possible about the stone and the building. Where something is known about the original sources of stone in a particular area or, better still, where there is evidence of the actual source of stone used on a 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 to assess the degree of exposure of the fabric at the sampling site. For example, a sample taken from within an open porch or beneath a canopy will have been much less exposed than a sample taken from a parapet. Details of any micro-environments that might exist and of any building defects, such as damaged rainwater goods, that might have contributed to deterioration should also be noted and passed to the analyst.

2.2 Examination and analysis of stone

Hand samples

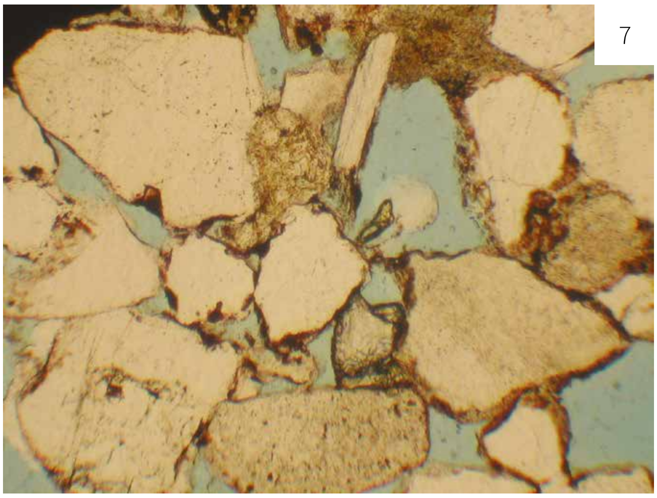
Preliminary determination of the general type and mineralogy of a stone can often be obtained *in situ* using a hand lens of about x8 magnification; this is especially true of the coarser-grained stones such as granite, and many of the sandstones and limestones that have been used for construction. However, the characterisation of certain other stones, for example basalt, slate, siltstone and fine-grained limestone, requires specialised laboratory techniques. Preliminary detailed studies require low-power stereomicroscopy, using magnifications of up to x40. This helps to interpret the structure and composition of the stone and the nature of any physical breakdown.

Petrographic analysis

Petrographic analysis enables precise identification of the mineralogical composition of a stone and the conditions under which it was formed. It also allows some assessment of the likely decay processes, because the way in which stone weathers varies according to its petrographic characteristics.

A thin section of the stone is made by mounting a fragment of the sample onto a microscope slide and grinding it down to a thickness of 30 microns (1 micron = 1/1000 mm). This is then 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 to determine the type of minerals present and any changes in their composition (see Figures 7 and 8).

This type of thin-section analysis can also be used to assess the porosity of a stone, which is not visible to the naked eye (see Figures 9 and 10). The identification of porosity is important because the size and shape of the pores and whether they are connected to form continuous channels can markedly affect the durability of the stone.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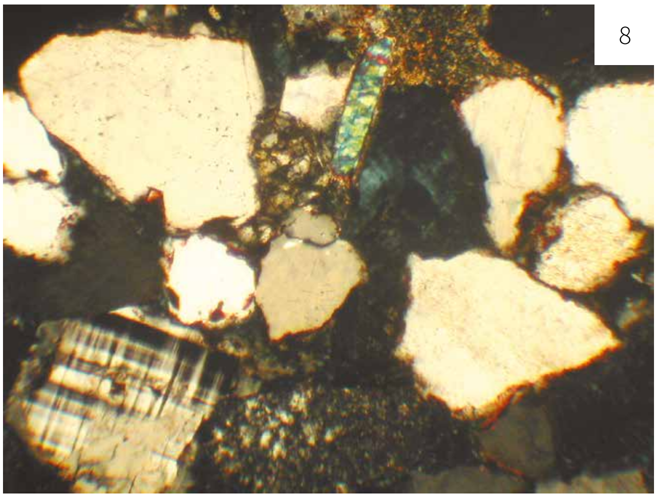
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Figures 7-8 Thin sections

7 Sample of Devonian sandstone from a medieval corbel at Kilpeck Church, Herefordshire, studied under plane-polarized light. This shows that most of the mineral grains are transparent, although some can be speckled or slightly cloudy. Field of view: 0.72mm.

8 The same view under cross-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 plane of vibration of the polarized light. A grain of microcline feldspar, distinguished by its tartan twinning, is located on the bottom left. 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 lower centre of the image. The bright colours of the elongated grain in the upper centre of the image indicate that it is muscovite mica. Field of view: 0.72mm.

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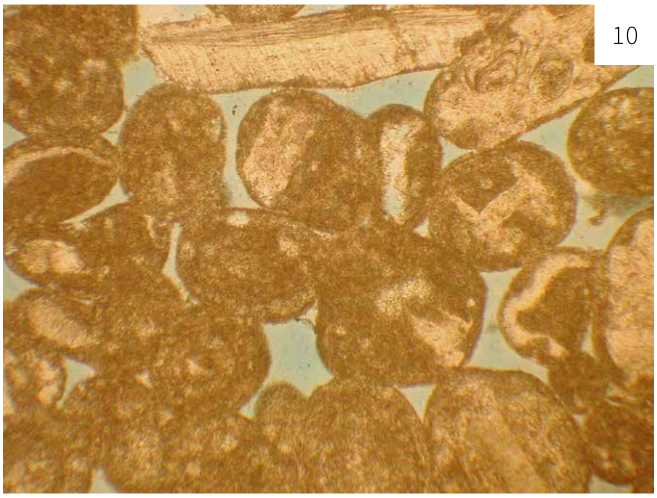

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The European Standard EN 12407:2000 *Natural stone test methods – Petrographic examination*

This Standard is intended for the petrographic classification of stone and as such is unnecessarily exhaustive for characterising stone for historic building repair. More importantly, the procedures specified for slide preparation may be inappropriate for the studies required on weathered or soiled materials. Thin sections should be prepared in the context of the investigation being undertaken. This may require different thicknesses to be prepared (for example in limestone), non-aqueous fluids to be used in grinding (if soluble salts are present), or alternative pre-preparation or staining techniques. There should therefore be no requirement to use EN 12407:2000 in every case.

Figure 9- 10 Thin sections

9 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. The pores are highlighted by the use of blue-coloured resin within the sample. Field of view: 1.4mm.
© David Jefferson

10 Oöidal Portland Whitbed under plane-polarized light. The inter-granular pore distribution is shown by the blue-coloured resin in the sample. Field of view: 1.4mm.
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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 1or 2 microns – the colour may be 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® Rock Colour Chart. The Munsell® system is an internationally recognised standard system used for describing the colour of all types of materials, in which colour is arranged into classes or categories according to three variables; hue, value and chroma. Geologists and archaeologists use it 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. It should be noted that most stones lighten or darken to some extent when wet, so the colour should be recorded both wet and dry.

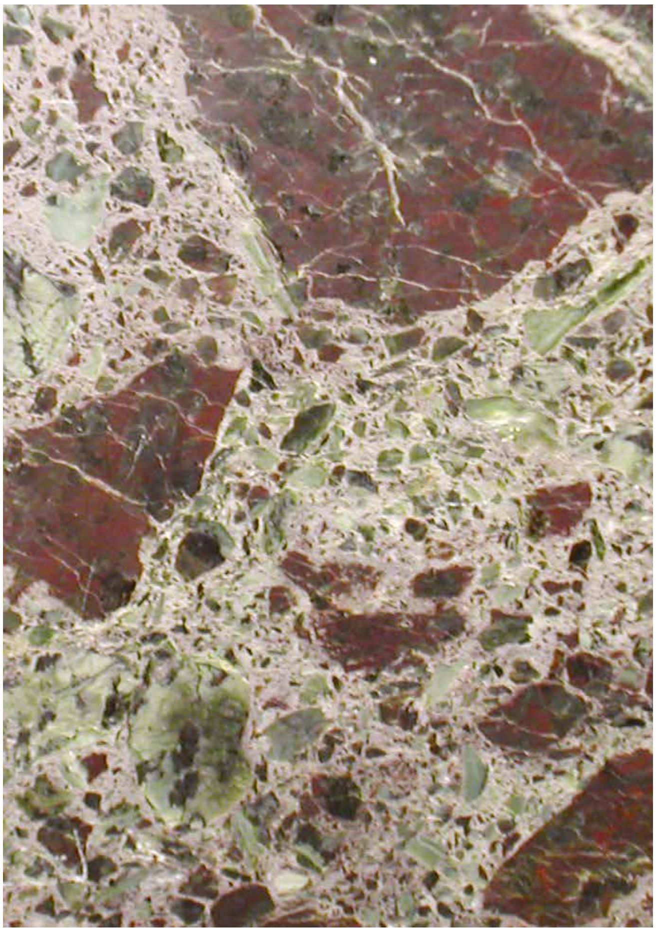
Although a European Standard for measuring colour (EN 15886:2010 Conservation of cultural property - Test methods - Colour measurement of surfaces) has been produced, it involves the use of sophisticated instruments, such as a reflectance spectrophotometer or a tristimulus colorimeter, to determine the colour of the object being studied. Furthermore, the surfaces used for the measurements must be smooth, flat and dry. Inhomogeneous areas, such as veins in marble, must be avoided. Although potentially suitable for works of art or studying changes in colour of surface coatings, the method is of little value for most stones in an external environment where they are weathered, often highly variable in colour and texture, and frequently damp.

Many stones that superficially look very alike, such as some sandstones, may 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 help to identify unstable minerals or ones likely to react with other building materials, such as mortar. For example, cryptocrystalline silica in a sandstone may react with solutions leached from uncarbonated lime mortar, resulting in the degradation of the stone. Identifying such minerals is 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 that was 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 (see Figure 11) is not a marble but a hard polishable serpentinised stone. Purbeck Marble is just one of the many so-called marbles available that are not in fact true metamorphic marbles, but are hard polishable limestones. Similarly, some commercially available slates are actually highly compacted mudstones and siltstones that have not been subjected to the metamorphic forces necessary to produce true slate. The European Standards that have been adopted for many stone products, ranging from rough blocks to cladding and flooring, include a requirement for the denomination of the stone to be determined. However, this only includes the traditional name of the stone (for example Purbeck Marble), the petrological family (which in this instance would be limestone), the typical colour, and the place of origin. Although providing the information that this ‘marble’ is actually a ‘limestone’, the Standards would provide little additional information of value in conservation work. In fact the variation in many building stone quarries would make it completely impractical to produce data sheets for each available variant. Data sheets supplied by quarries, whether they be descriptive or conforming to a Standard, are therefore of little use when selecting replacement stone for conservation and do not obviate the need for a petrographic analysis of potentially suitable stone.



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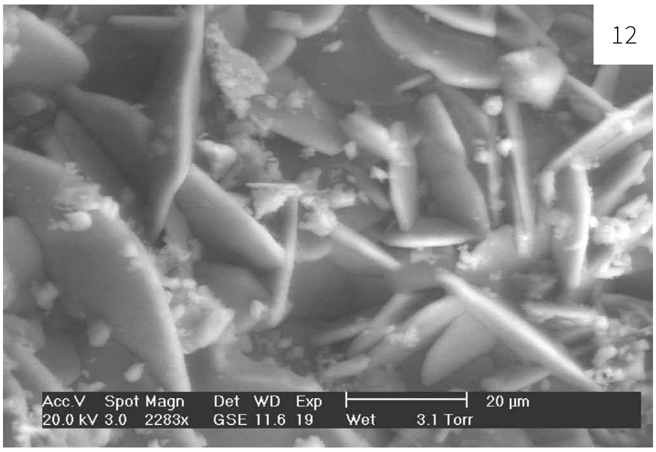

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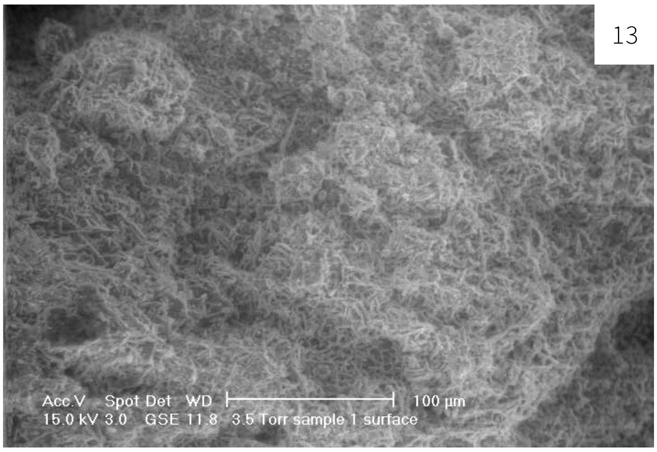

Figure 11
Rosso Levanto Marble. Field of view: 95mm.
© David Jefferson

Figures 12-13 ESEM images
12 Pure gypsum on the surface of dolomitic sandstone (White Mansfield stone).
© David Jefferson

13 Individual oöids (rounded shapes) in this sample of Portland Stone have developed a crust of gypsum. This secondary mineral also occurs in the surrounding pore spaces.
© David Jefferson

Other analytical techniques

X-ray diffraction analysis

The diffraction of X-rays passing through a crystalline material produces patterns characteristic of the different crystals that are present. The mineralogy of a particular stone can therefore be investigated using this technique on a powdered sample of the material. The method is also useful when investigating mineral salts, such as gypsum and epsomite, which may be present due to weathering of stone or mortar.

Electron microscopy

Many of the reactions that damage building stone occur at sub-microscopic level. An environmental scanning electron microscope (ESEM) (that is, one which operates at low vacuum and does not require the sample to be coated with a conductive layer such as gold, thereby allowing the true surface of the sample to be investigated), permits magnifications well in excess of x1000 (see Figures 12 and 13). In addition, an energy-dispersive X-ray spectrometer (EDX) can be used to determine aspects of chemical composition.

A simple chemical test for carbonates

Limestone and calcareous sandstone can be distinguished from other sandstones and from other stone types by applying a droplet of 5% solution of dilute hydrochloric acid to the surface. Any calcium carbonate present in the stone will react with the acid, which will vigorously effervesce as carbon dioxide is liberated by the reaction.

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 is probably silica, iron oxide or a clay mineral. Granite and most other igneous rocks will not effervesce in the presence of the dilute acid, as they do not contain carbonates. The majority of metamorphic slate is siliceous, but certain slates (for example some from the Lake District) do contain some calcium carbonate, and will therefore effervesce slightly.

Testing stone with hydrochloric acid

The acid should be diluted to an approximately 5% solution by volume (1 part concentrated hydrochloric acid to 19 parts water).To avoid the acid spitting violently, the acid must always be added to the water rather than the water to the acid. Appropriate safety precautions must be taken when preparing the solution.

To carry out the test, the stone is viewed through a binocular microscope as a small amount of the solution is dropped on the surface with a pipette. Effervescence indicates that calcium carbonate is present in the stone.

3 Selection Criteria

The following criteria, in descending order of importance, should be used when selecting replacement stone.

- **Petrography**

  The constituent grains of the replacement stone should be of the same type, size, angularity and proportions as those 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 of the stone must also match the original stone.

  If the mineralogy of the replacement stone is similar to the original, then the chemistry of the stone will probably be similar.

- **Chemical characteristics**

  The chemistry of replacement stone must be similar to that of the original, particularly the concentrations of silica, magnesium and iron. The iron content and the form in which it occurs are particularly important, as these largely determine the final colour of the exterior surface, especially after weathering. The composition of moisture moving through the building fabric is conditioned by the chemistry of the stone through which it passes, so stones of different types contain pore fluids of different composition. If these fluids move from one stone into an adjacent one of a different type they can generate adverse reactions.

- **Porosity & permeability**

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

- **Appearance**

  The appearance of the stone viewed in block form must be a good match for the original. If the petrography and chemistry are similar, then the small-scale appearance should also be the same, but large-scale features such as bedding and veining must also be considered. The bed depth within the quarry must be sufficient to allow extraction of suitably sized blocks for the intended purpose. It should be remembered that stone changes colour to a variable degree when weathered. New stone may, for a short time after it has been installed, look different to the original fabric. The potential change in colour can be assessed by viewing buildings where stone supplied from the same quarry has been used in the past.

Geological age and setting

Even after their original formation, rocks continue to alter due to earth movements, which result in continuing changes in temperature and pressure. In very general terms, the geologically older a stone is the more lithified, less permeable and more durable it becomes. For example, the Carboniferous building stones in the Pennines tend to be harder and more durable than those in the south-east and south of England, which are geologically younger. Sedimentary building stones should be repaired or replaced with stone formed in a similar sedimentary environment, preferably of the same age and which has a similar geological history to the original stone.Metamorphic building stones should be of a grade corresponding to the original and igneous rocks should be from the same family. The geological history of such materials should reflect that of the original stone.

Compressive strength

Where it is not possible to find replacement stone that matches the compressive strength of the original stone, the replacement should be weaker rather than stronger, so that it will be likely to deteriorate sacrificially, in preference to the host fabric.

Satisfying all these criteria in replacement stone can usually be achieved only by using stone from the same quarry as the original stone, or at least a source very close to it. Failing this, the new stone should meet as many of the above criteria as possible, with the first four being the most critical.

4 Sources of Stone

4.1 Active quarries

The Natural Stone Directory (published biennially) currently lists about 275 quarries producing building stone in the UK. 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 for use throughout southern England since the 18th century. Other sources have been producing stone for even longer; the quarries at Grinshill in Shropshire (see figures 14 and 15) have been extracting sandstone for building since at least the 12th century. Some smaller quarries also work long-established

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Figures 14-15 Grinshill Quarry, Shropshire

14 A disused quarry face.
Don Cameron, British Geological Survey. © NERC.

15 The modern working quarry.
Don Cameron, British Geological Survey. © NERC.

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 into the existing fabric of an historic building. There also appear to be differences in the potential durability of stones from some quarries when, due to the exhaustion of the surface deposits, the strata is followed underground and extracted from a mine.

4.2 Disused quarries

If the original source of stone used in a historic building has been traced to a particular quarry that 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 for which it is needed is a local feature. Mineral Planning Authorities are also often sympathetic to proposals to obtain supplies of the correct stone from original sources, especially for the repair of historic buildings, although their approach can vary.

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 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 than those extracted from the quarry. In commercial quarries the removal of the irregular portions of the blocks is undertaken using large saws (Figure 16). The use of diamond wires and chain saws is now becoming common in building stone quarries, resulting in reduced wastage, as well as blocks that have sawn sides thereby allowing immediate inspection of any variation or irregularities within the stone (Figure 17).

4.3 Recycled stone

In cases when no suitable new replacement stone is commercially available, and only small quantities of material are required (for example, minor repairs to window mullions), it may be acceptable to recycle stone salvaged from another building or structure. The provenance of such stone must be established and it must have been obtained from lawful dismantling of a building or other structure to discourage other 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.

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Figure 16
Clipsham, Lincolnshire, irregular-shaped stone prior to being sawn into slabs.
© David Jefferson

Figure 17
Ancaster Hardwhite and Weatherbed stones have been worked on Wilsford Heath north of Grantham since Roman times. Extraction at Glebe quarry, the present source of the stones, uses the latest technology, cutting out the stone using chain saws.
© David Jefferson

5 Stone for Repairs

5.1 Specifying stone

Replacement stone should be specified to meet the criteria defined in Section 3, with samples of potential replacements carefully matching the original material.

All stone varies to some extent, and it is important that the variations in the new stone reflect those in the original fabric of the building. This will not only ensure that extreme differences in petrography, porosity and colour are avoided, but also that blocks of comparatively uniform stone are not inserted into a wall that displays more variety of colours and textures, as this would result in a visually obvious and unpleasant patch of stonework. 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 currently produced by the quarry is not suitable, the exact stone required must be clearly specified. The grain size of sandstones can also vary widely, so the acceptable range should be specified. The specification for all stones should include the acceptable minimum and maximum value for both porosity and permeability. 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 specified by the quarry for sourcing and supplying the correct blocks must be taken into account when designing the repair programme. The scheme for obtaining the block stone, its transport to a masonry yard for cutting into blocks, and the moving of these blocks to the mason's yard for cutting or carving should be planned well in advance of when the stone will be needed on site, as the lead-in time is often six months or more.

5.2 Samples of new stone

All quarries producing building stone 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 might 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 a supplier's samples alone, and care should be taken that any samples sent for analytical comparison with samples of historic stone are truly representative of what is available from a particular source .

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 any extracted blocks that have not been dispatched. Samples from varying blocks can be collected in the same manner as for *in situ* sampling (Section 2.1), and these should be analysed to determine the suitability of the stone for its intended purpose.

Since the colour and texture of the stone may vary in both the quarry and the building being repaired, it is often necessary to assemble a small reference panel of stones on site. This panel will include the full range of stones that are acceptable for use in the repairs. Any delivered stone that is not within this range should be rejected.

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Figures 18-19

Stone testing chamber at Sheffield Hallam University, for testing new stone for repairs at Truro Cathedral

18 Stone test wall being built
© Chris Wood

19 Testing in progress
© Chris Wood

5.3 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, such as salt-crystallisation resistance, saturation coefficient, porosity, and resistance to 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 extremely difficult to relate the test results to the behaviour of stone *in situ*. Such tests may, however, be useful for comparing the behaviour of potential replacement material with that of the original stone, or with that of a stone whose properties in a similar environment are well understood.

Large-scale environmental testing

Where major repairs are required and it is impossible to obtain stone that is petrographically identical to the original, large-scale environmental testing of alternative replacement stones can be useful, if costs permit.

Walls constructed in a test chamber can be exposed to simulated weathering conditions, based upon real meteorological data, including wetting, drying, and driving rain. Large chambers can accommodate mortar-bonded masonry units up to 2m long and 2m high. Smaller freeze-thaw chambers used for testing bricks can also be useful for testing stone. Environmental testing is relatively expensive, but for major repair or replacement projects it can prove cost effective (see Figures 18 and 19).

5.4 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 on the scale of the proposed operation. If the quantity of stone required is relatively small, the MPA may waive planning consent and permit temporary works in a manner agreed in detail with them, although the approach can vary from one authority to another.

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

6 Mortar for Repairs

When replacing decayed stone in historic masonry, the choice of mortar for bedding and re-pointing should also be compatible with the fabric, both existing and new. As indicated in Section 1.1, different types of stone can react with each other, and a similar chemical reaction can occur between stone and mortar. Some sandstones, for example, contain forms of silica that react with alkaline fluids in un-carbonated lime mortar, resulting in breakdown of the stone.

In most cases, mortar used for repair should match that used in the original fabric, unless it seems that the mortar may have contributed to deterioration of the stone, in which case, detailed assessment of both mortar and stone may be necessary to confirm this. Specifiers should consult further advice on selecting appropriate mortars for conservation work, published elsewhere by Historic England (see Bibliography).


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Figure 20
This new Blue Lias stone has been bedded and pointed in a cement mortar. Not only is this a poor visual match for the original lime mortar, it risks accelerating deterioration of the new stone

Figure 21
In traditional stone buildings, lime mortars act sacrificially, decaying in preference to the masonry units. Hard cement mortars are more durable but can increase the rate of deterioration of some stone types. Here, the cement mortar is left standing proud as the Blue Lias stone has decayed and eroded in preference to the mortar

7 Further Information

7.1 The Strategic Stone Study

The Strategic Stone Study, initiated by Historic England (working with the British Geological Survey, local geologists and historic-buildings experts), uses a combination of fieldwork, historic records and maps, together with a representative range of historic structures, to identify the most significant building stones in each English county. All the northern, western, and midland counties have been surveyed, and work is continuing to complete the southern counties. This information is published on the freely available Strategic Stone Study website, hosted by the British Geological Survey (BGS). This contains links to the stone sources and stone buildings datasets as well as to a set of atlases covering the building stones of each county, which can be downloaded. There is also a link to a GIS-based search tool that can be used to identify underlying geology, the stone produced from different quarries, and representative buildings in which different stone types are used.

7.2 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,** Department of Earth Sciences, 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 Where to get advice.

7.3 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, and offers a stone-matching service. 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 Where to get advice).

8 Bibliography

Ashurst, J. and Dimes, F. J. (1990); *Conservation of Building and Decorative Stones*; London: Butterworth Heinemann

Brereton, C. (1995); *The Repair of Historic Buildings: Advice on Principles and Methods* (2nd edition); London: English Heritage

British Geological Survey and Natural Environment Research Council (2001); *Building Stone Resources Map of Britain*; Nottingham: British Geological Survey

British Geological Survey and Natural Environment Research Council (2014); *Directory of Mines and Quarries*; Nottingham: British Geological Survey

Clifton Taylor, A. (1972); *The Pattern of English Building* (3rd edition); London: Faber and Faber

Hart, D. (1988); *The Building Magnesium Limestones of the British Isles: Building Research Establishment Report*; Watford: BRE

Hart, D. (1991); *The Building Slates of the British Isles: Building Research Establishment Report*; Watford: BRE

Henry, A., Stewart, J. (eds.) (2011); *Practical Building Conservation: Mortars, Renders & Plasters*; London: Routledge

Howe, J. A. (1910); *The Geology of Building Stones* (Reprinted 2001); Shaftesbury: Donhead

Leary, E. (1983); *The Building Limestones of the British Isles*: Building Research Establishment Report; Watford: BRE

Leary, E. (1986); *The Building Sandstones of the British Isles. Building Research Establishment Report*; Watford: BRE

Odgers, D., Henry, A. (eds.) (2012); *Practical Building Conservation: Stone*; London: Routledge

QMJ Publishing (2016); *Directory of Quarries & Quarry Equipment* (35th edition, 2016/17); Nottingham: QMJ Publishing Ltd

QMJ Publishing (2016); *Natural Stone Directory* (No19, 2016-17); Nottingham: QMJ Publishing Ltd

Rock-Color Chart Committee (2009); *Rock-Color Chart*; Grand Rapids, Michigan: Munsell Color

Schaffer, R. J. (1932); *The Weathering of Natural Building Stones*. (Reprinted 2006); Shaftesbury: Donhead

Sierakowski, A. *Stone slate delphs: A guide to making a mineral planning application for a stone slate quarry or delph*; Tisbury: Institute of Historic Building Conservation

Smith, M. R. (ed.) (1999) *Stone: Building Stone, Rock Fill and Armourstone in Construction*: Geological Society Engineering Geology Special Publication 16; London: Geological Society

Whitten, D. G. A., and Brooks, J. R. V. (1972); *The Penguin Dictionary of Geology*; London: Penguin

Wood, C (ed) 2003 ‘Stone roofing: conserving the materials and practice of traditional stone slate roofing in England’. *English Heritage Research Transactions 9*. London: James and James

Woolf, D. O. (1960); *The Identification of Rock Types* (revised edition); Washington, DC: United States Government Printing Office

9 Appendix

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

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

Group 1 Glassy rocks		Glassy lustre, hard, conchoidal fracture, colourless to white or smoky grey, generally brittle	Quartz[1]
		Cellular or frothy glass	Pumice
Group 2 Very fine-grained rocks	**Sub-group 2A** Not scratched by a fingernail, but readily scratched with a knife	Particles almost imperceptible, dull lustre, homogenous, clay odour, little if any effervescence with dilute acid, laminated structure, breaks into flakes	Shale
		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	Limestone
		Brisk effervescence with dilute acid, no clay odour, normally white in colour, can leave white powder on the hands	Chalk
		Little if any clay odour, brisk effervescence with dilute acid only when the rock is powdered or the acid is hot	Magnesian limestone
	Sub-group 2B Not scratched by a knife, or scratched only with difficulty, no effervescence with dilute acid	Very hard, pale colours to black, no clay odour, conchoidal fracture, waxy or horn-like appearance	Chert[2]
		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	Basalt

Group 3 Granular rocks	Sub-group 3A Easily scratched with a knife	Brisk effervescence with dilute acid; granular materials may be broken fossil fragments, angular material or small spherical grains; the granular material may be mixed with fine-grained material	Limestone
		Brisk effervescence with dilute acid; grains may be large and interlocking, compact, colour may be white, cloudy grey or coloured, often banded or variable	Marble
		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	Ironstone[3]
	Sub-group 3b Hard, not scratched with a knife or scratched with difficulty, grains normally of approximately equal size	Mainly quartz and feldspar in relatively large crystals, although mica commonly present, usually grey, pink or red	Granite
		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	Sandstone
		Mainly quartz in distinct grains often clearly set in a reddish coloured matrix, can fracture round the grains; may stain hands red	Ferruginous sandstone
		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	Ironstone
		Mainly quartz in distinct grains often clearly set in a pale-coloured matrix which effervesces with dilute acid, can fracture round the grains	Calcareous sandstone
		Mainly quartz in distinct grains in a hard siliceous matrix, stone fractures through an appreciable quantity of the grains	Quartzite
Group 4 Foliated rocks		Medium to coarse grain; roughly foliated	Gneiss
		Very fine grain, splits easily into thin slabs, usually dark grey, green or black in colour	Slate
Group 5 Fragmental		Rounded pebbles embedded in a cementing medium which can be reddish in colour	Conglomerate
		Angular fragments of rock embedded in a cementing medium which can be reddish in colour	Breccia
		Fragments of volcanic (fine-grained or glassy) rocks embedded in compacted volcanic ash	Volcanic tuff or breccia
		Rounded quartz grains, possibly together with fragments of rock and mica, between about 1mm and 4mm in diameter, cemented together	Sandstone
		Angular quartz grains, possibly together with fragments of rock and mica, between about 1mm and 4mm in diameter, cemented together	Gritstone

Notes for Annex

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.

10 Where to Get Advice

British Geological Survey (BGS)
Environmental Science Centre
Nicker Hill
Keyworth
Nottingham NG12 5GG
Tel: 0115 936 3100
Email: enquiries@bgs.ac.uk
Website: www.bgs.ac.uk

BRE
Bucknalls Lane
Garston
Watford WD25 9XX
Tel: 0333 321 8811
Email: 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
Email: mail@qmj.co.uk
Website: www.qmj.co.uk

English Stone Forum
Channel Business Centre
Ingles Manor
Castle Hill Avenue
Folkestone CT20 2RD
Website: www.englishstone.org.uk

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

Institute of Quarrying
8a Regan Way
Beeston
Nottingham NG9 6RZ
Tel: 0115 972 9995
Email: mail@quarrying.org
Website: www.quarrying.org

Munsell Rock Colour Chart
Geo Supplies Limited
49 Station Road
Chapeltown
Sheffield S35 2XE
Tel: 0114 245 5746
Email: sales@geosupplies.co.uk
Website: www.geosupplies.co.uk

National Stone Centre
Porter Lane
Middelton by Wirksworth
Derbyshire DE4 4LS
Tel: 01629 824833
Email: nsc@nationalstonecentre.org.uk
Website: www.nationalstonecentre.org.uk

Natural Stone Directory
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