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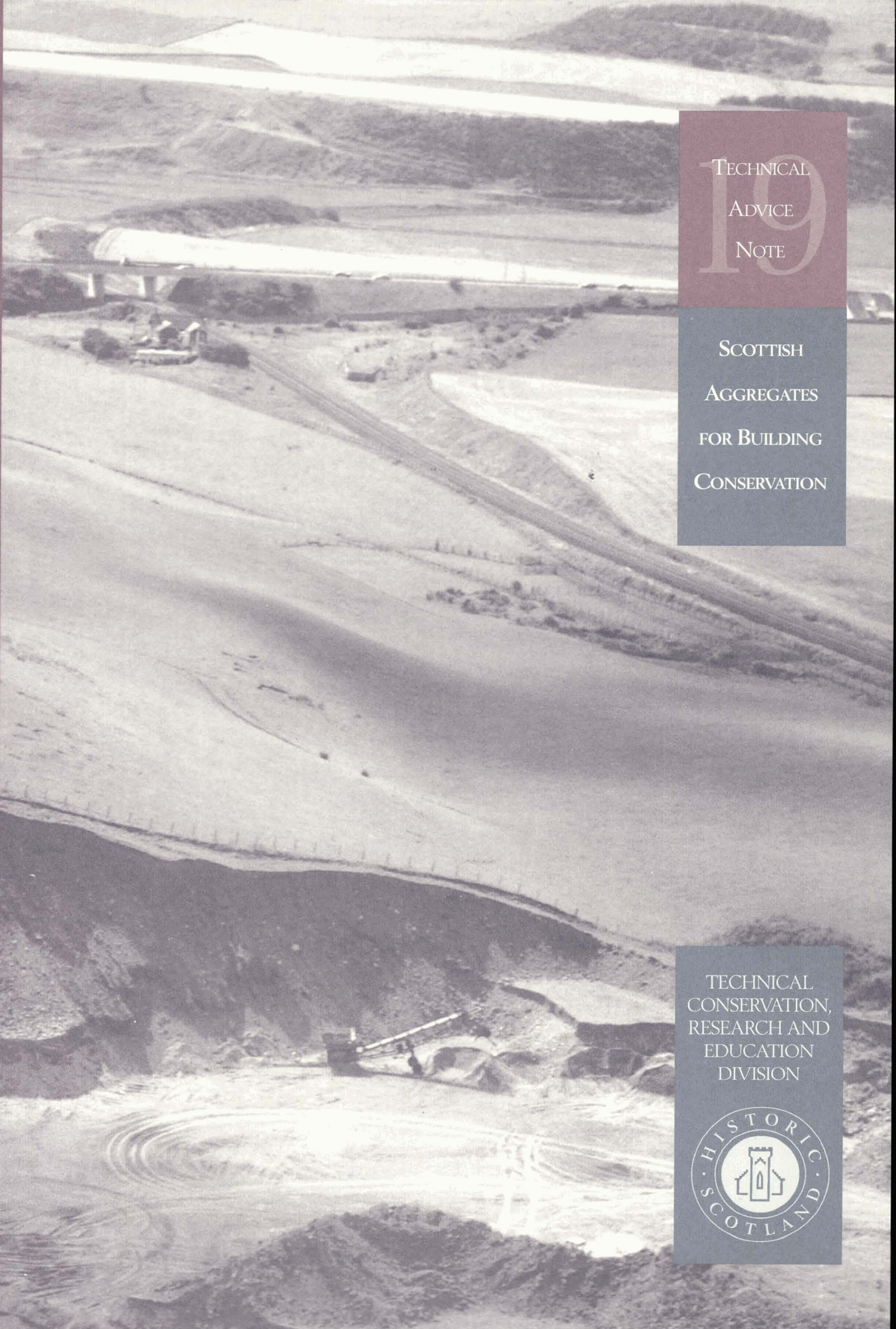
Technical Advice Note 19

Scottish Aggregates for Building Conservation



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SCOTTISH AGGREGATES FOR BUILDING CONSERVATION

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Scottish Aggregates for Building Conservation

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The British Geological Survey are thanked for the loan of a sieve shaker. Grahame Smith of the British Geological Survey assisted the sampling programme of the project by allowing access to the BGS database of quarries. Lawrence Begg and John Knight of Historic Scotland arranged for samples to be collected in the most remote parts of Scotland.

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FOREWORD

This Technical Advice Note, 'Scottish Aggregates for Building Conservation', is based on a survey of Scottish aggregates, carried out in 1996, 1997 and 1998. It forms part of an occasional series of advisory notes related to practical and technical issues which can arise in protecting the nation's built heritage, and is intended to allow informed comparison and choice between a range of materials considered suitable for use as aggregates in traditional lime mortars. In this context the term aggregates includes naturally occurring sands and gravels and crushed rock products.

This publication can be used as a stand-alone guide to the selection of aggregates or in conjunction with the comprehensive range of 'sand profiles' of Scottish aggregates, and supporting data held on the associated database of Scottish Aggregates.

The distinctive local and regional characteristics of Scottish buildings depend not only on the type of stone employed in their construction, as ably described in Historic Scotland Technical Advice Note 12 'Quarries of Scotland', but also on the nature of the mortars. The constituent materials of those mortars influence, in turn, the techniques of their use, their durability and their appearance as they mature and weather. Information on lime mortars generally is available in Historic Scotland Technical Advice Note 1, 'Preparation and Use of Lime Mortars'.

The information concerning aggregates for lime mortars in this Technical Advice Note, and in the database, is concerned with the appearance and other physical characteristics of the products, the matching of modern materials to those used in the past and the selection of aggregates with suitable physical characteristics for use in traditional lime mortars.

Ingval Maxwell
Director TCRE
November 1999

PREFACE

Scottish Aggregates for Building Conservation

This Technical Advice Note is intended to provide those working in the field of conservation with information on the availability and suitability of aggregates for use in mortar. Prior to publication of the Technical Advice Note, a programme of sampling of aggregates from quarries throughout Scotland was carried out. The bulk of the information presented in this publication is also held in the associated database of Scottish Aggregates.

The Database of Scottish Aggregates

The database, containing information on Scottish aggregates and sources of lime for conservation as well as details of research into historic Scottish mortars, is held on behalf of Historic Scotland by the Scottish Lime Centre Trust. Access to the database and matching of currently available aggregates to samples of original aggregate (obtained through mortar analysis - which may be undertaken by the Scottish Lime Centre or by others) is available for a small fee (to offset the administrative costs of operating and maintaining the database).

Research rationale

This survey, carried out for Historic Scotland for the purpose of allowing comparison of aggregates for building conservation, is not intended to provide definitive analyses of each product analysed. The sampling methods are different from those in British Standards document BS 812 which requires a minimum of 10kg of material for aggregates with a maximum grain size of 5mm. This sample size would not be practicable given the constraints of storage space and project time. British Standard analysis also requires regular sampling of products which was not possible in this project. Although it is unlikely that the characteristics of each sample will change significantly in time, it is hoped that the database will be kept as up to date as is practicable in the future, including resampling of quarries where necessary.

The survey is primarily concerned with determining the appearance of the aggregate and the matching of modern materials with those used in historic buildings. The visual aspect of this project, ie the comparison of sand profiles, is therefore the most important part of the database. The analytical data are to be used as a backup for comparative purposes only. If definitive data on void ratio, mineralogy and grain sizes are required then an enquiry should be made to the relevant quarry operators.

1 INTRODUCTION

1.01 Introduction

The re-adoption of traditional building methods, including pointing, harling, rendering and plastering using predominantly lime based (as opposed to the more modern cement based) mortars, has become increasingly popular in the past decade. There is now a better understanding of the need for old buildings to be repaired using indigenous materials, and a growing awareness of the detrimental effects of inappropriate application of cement to old buildings. Lime based mortars, as well as being more aesthetically pleasing than modern cement mortars, were almost invariably the materials used in the original construction of historic buildings and should, therefore, be used in their repair and conservation.

Different specifications for mortars require aggregates with different properties, and mortars used in old buildings can contain shells, crushed rock, brick dust and recycled mortar. It is, therefore, of vital importance to the architectural integrity of buildings to ensure that an appropriate aggregate is identified and specified before repair work begins. In the past buildings were constructed using local materials, many of which would be considered inappropriate in the present day. Most modern construction sites, by contrast, are supplied from quarries which produce large volumes of standardised aggregates for both the building trade and road making. The variety of locally available aggregates used in previous centuries is not necessarily available to the building trade today, and where matching of old and new mortars is required, a special effort should be made to ensure that appropriate materials are used. A short summary of the steps to be followed in selecting a suitable aggregate is given in § 2.04.

Natural sand and gravel products have been sampled from almost all working Scottish sand and gravel quarries, along with sands from a small number of quarries in England where they are located close to the Scottish border, or where the products have a distinctive colour which cannot be found in Scotland. A nominal upper grain size limit of 6mm was adopted in this study since lime-based mortars do not commonly require aggregates with a larger grain size. Aggregates with a coarser grain size were not commonly sampled, although some 10mm grits and 'as dug' materials were taken. A selection of rock quarries, which is representative of the variety of rock types that are commercially available in Scotland, was also visited and samples of fine grained crushed rock taken.

Given the dynamic nature of the extractive and construction industries some newly opened quarries will have been overlooked and samples may have been taken from pits which have subsequently closed down. The information in this guide is given in good faith and is as up to date as possible.

If detailed information on sands from England or Wales is required, then conservation agencies such as English Heritage (Barnes, 1996; English Heritage, in press) and the National Trust, who hold similar 'sand libraries' covering parts of England and Wales, should be consulted.

This Technical Advice Note is published to provide guidance so that building professionals and contractors can assess aggregates themselves, and make the best choice of materials for the task. The Technical Advice Note can also be used in conjunction with the database of sands to provide access to detailed information on all Scottish aggregates. This document can also be used as a companion to Historic Scotland Technical Advice Note 12 (1997) 'Quarries of Scotland', which is an illustrated guide to Scottish geology and stone working published in association with the British Geological Survey.

This Technical Advice Note, and the Database of Scottish Aggregates, contain a summary of the total data collected which are held at the offices of the Scottish Lime Centre Trust in Fife. The computer database is accessible through Historic Scotland.

This document does not give guarantees of an aggregate's suitability for use in mortars, or of the conformity of an aggregate to the relevant British and European Standards. The properties of aggregates extracted from natural sedimentary deposits will vary with time and the descriptions given here, of aggregates sampled at various times in 1996, 1997 and 1998, refer to the products as sampled at the time. Although it is not likely that the aggregates will change markedly over a period of a few years, aggregate characteristics and availability should be checked before specifications are finalised.

1.02 Distribution of aggregates in Scotland

The broad range of Scottish rock types and ages, described in detail in Historic Scotland Technical Advice Note 12, is reflected in the varying composition of the aggregates, both sand and gravel and solid rock, that are being exploited by the extractive industry at the present time.

Sand and gravel aggregates

Sand and gravel deposits are found in significant quantities across much of Scotland (Figure 1), mostly as a result of the erosion and transportation of huge volumes of material during glacial ice movements in the past million years, the last episode of which reached a peak roughly 18000 years ago and ended 10000 years ago. The majority of Scottish sand and gravel quarries operating at present are exploiting glacially-derived resources (Figure 1).

The last glacial episode is, in geological terms, very recent and the majority of river valleys still contain glacial sediments. Also currently exploited for sand and gravel aggregate (Figure 1) are a number of raised beach deposits around the coast of Ross-Shire, Argyll, Ayrshire and Dumfries and Galloway, various river gravels on the eastern side of Scotland (Tay, Don, Spey, Lossie, etc) and a small number of beach or dune sand deposits on the western and northern seaboard of Scotland, mostly in the Western Isles. In almost all cases the raised beach, river and wind-blown sediments are themselves reworked from earlier glacial deposits.

Other than wind-blown dune sand formation, all of the processes forming sand and gravel resources involve deposition of sediment from water which flows at progressively slower velocities. The average particle size of the sediment is, therefore, laterally variable and exploitation of natural aggregate deposits will derive a product which changes gradually over time.

The composition of aggregates in Scotland broadly reflects the underlying geology. As a result of this, aggregates in the Highlands derived from different rock types (red sandstone, granite, etc) can be identified and specified for particular jobs. Aggregate composition in the Midland Valley also follows the underlying geology, except where materials have been transported southwards from the Grampian Mountains by river or glacier. In the Southern Uplands, aggregate deposits are composed of sands and gravels containing fragments of grey, sandy sedimentary rocks known as greywacke, mixed with red coloured sands and other locally derived igneous rocks. Sands from the north of England are red (similar to those from Dumfries) in the west and more brown coloured near the east coast.

Most particulate aggregate products can be described by giving the relative proportions of quartz, feldspar and rock fragments, which constitute the three main components in natural sands. In fine grained aggregates quartz is most abundant, whereas coarser sands and gravels contain more rock fragments as well as fine quartz.

In considering the current availability of sand and gravel resources it should be realised that the quarries operating at present are large scale workings used predominantly for roadstone (Figure 2), very few small quarries are still operating. In the past, however, much of the sand and gravel taken for building work will have come from small scale working local to the building site. The range of material currently available will not necessarily correspond to the situation in the past where more numerous sites were producing aggregates, some of which would presently be deemed unsuitable for building work.

Crushed rock aggregates

As well as coarse grained materials for road building and other purposes, rock quarries commonly produce fine grained aggregates which can be used in lime mortars. These crushed rock products are useful in a number of ways:

- such products are commonly angular and well graded, which aids the interlocking and internal adhesion of the mortar,
- crushed rocks of basic igneous and clay-rich, sedimentary types may have some pozzolanic effect, whilst crushed limestones and dolomites can also aid the bonding of the mortar, and
- crushed rock products can provide a natural colour matching with the aggregate in the original mortar, avoiding the need for the addition of pigments.

Crushed rock products are produced throughout Scotland and their distribution reflects the availability of suitably durable rocks in sufficiently large volumes to allow extraction on an economic scale. In the Grampian and Northern highland areas, the Lewisian, Moine and Dalradian metamorphic rocks, and also some igneous rocks, are commonly quarried. In the Midland Valley, hard, fine grained igneous rocks such as basalt and dolerite are most commonly quarried, although some sandstones, including silica sands, and limestones are exploited. In the Southern Uplands muddy sandstones (greywackes) and granites are quarried.

Crushed rock products commonly used in lime mortars are derived from

- limestones and marbles which can help in the setting of a mortar,
- granites which are used in the north east of Scotland and

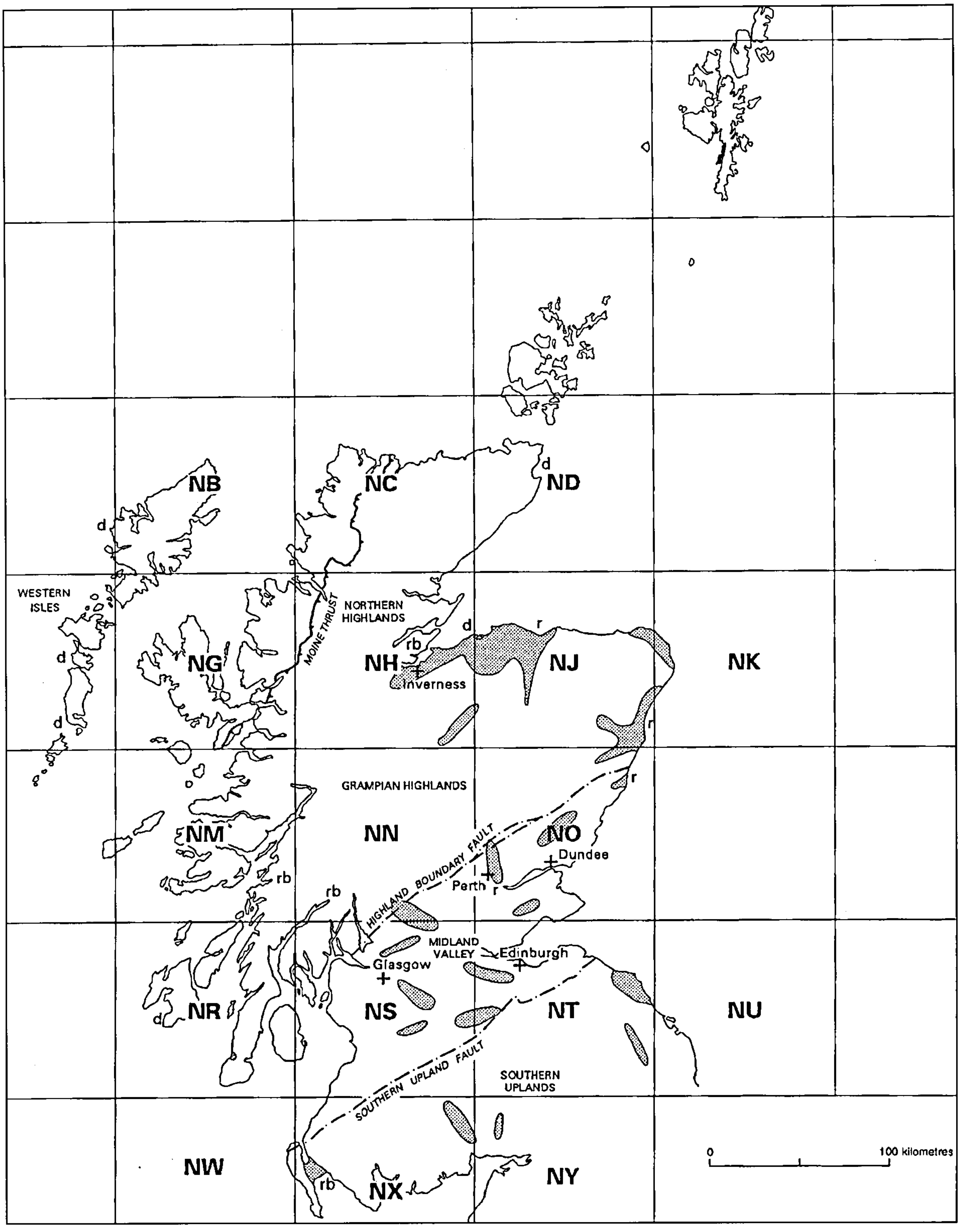


Figure 1 Distribution of major sand and gravel deposits in Scotland. Sediments are glacially derived unless otherwise noted as raised beach (rb), river (r) or dune (d) aggregates. Figure courtesy of the British Geological Survey.

Figure 2 Glacial drumlin deposit being quarried as a source of sand and gravel. Newton Hill, Fife. Grid reference NO 405 247. In the past, much smaller deposits were exploited for building aggregates. Photograph courtesy of the British Geological Survey.

- silica sands which have no natural colour, allowing the colour of the binder to predominate. They can also be mixed with coloured aggregates to create a matching mortar.

Although crushed rock products are not commonly produced or marketed as constituents in mortars, they are sufficiently useful, particularly in aiding the colour matching of original aggregates, to be included in the database.

1.03 Processing of aggregates

Aggregates, both sands and gravels and crushed rocks, need to be processed to standardise the size characteristics of the products and to remove materials which are undesirable. The raw, unprocessed product, which is commonly known by the term 'as dug' in the case of sands and gravels, can contain particles with varying sizes from clay to cobbles (Figure 3).

As-dug sands and gravels are sorted by screening (passing the aggregate through sieves) or classifying (using gravitational methods - coarse grained sediments settle downwards more rapidly than fine material) into suitable sizes and are stored in stockpiles (Figure 4). Blasting in rock quarries is followed by crushing, grinding and then sorting of the rock until a suitable size distribution is achieved.

1.04 Environmental considerations

The quarrying industry in general has become much more aware of its environmental responsibilities in the past few decades. All quarries must satisfy basic statutory requirements for levels of noise, dust, etc., which have become more stringent following the Environmental Protection Act (1990). Further measures have been taken by the Quarry Products Association (formerly the British Aggregate Construction Materials Industry Federation) who have published an environmental code (BACMI, 1994). Restoration of quarry sites is also a priority (Figure 5). At present approximately ninety per cent of sand and gravel sites are returned to agricultural use after quarrying is completed (BACMI, 1994), other afteruses such as forestry, amenity and nature conservation are being encouraged.

Of more direct relevance to this project is the cost of transportation of aggregates. The cost of aggregates approximately doubles for every 50km of transportation. This, combined with the problems associated with frequent movement of heavy traffic, makes the use of local aggregates particularly desirable. In most cases, when dealing with historic buildings, a local aggregate (commonly the nearest river or sand bank) is likely to have been used in the original construction (the '400 yard rule' where in the past materials were transported for as short a distance

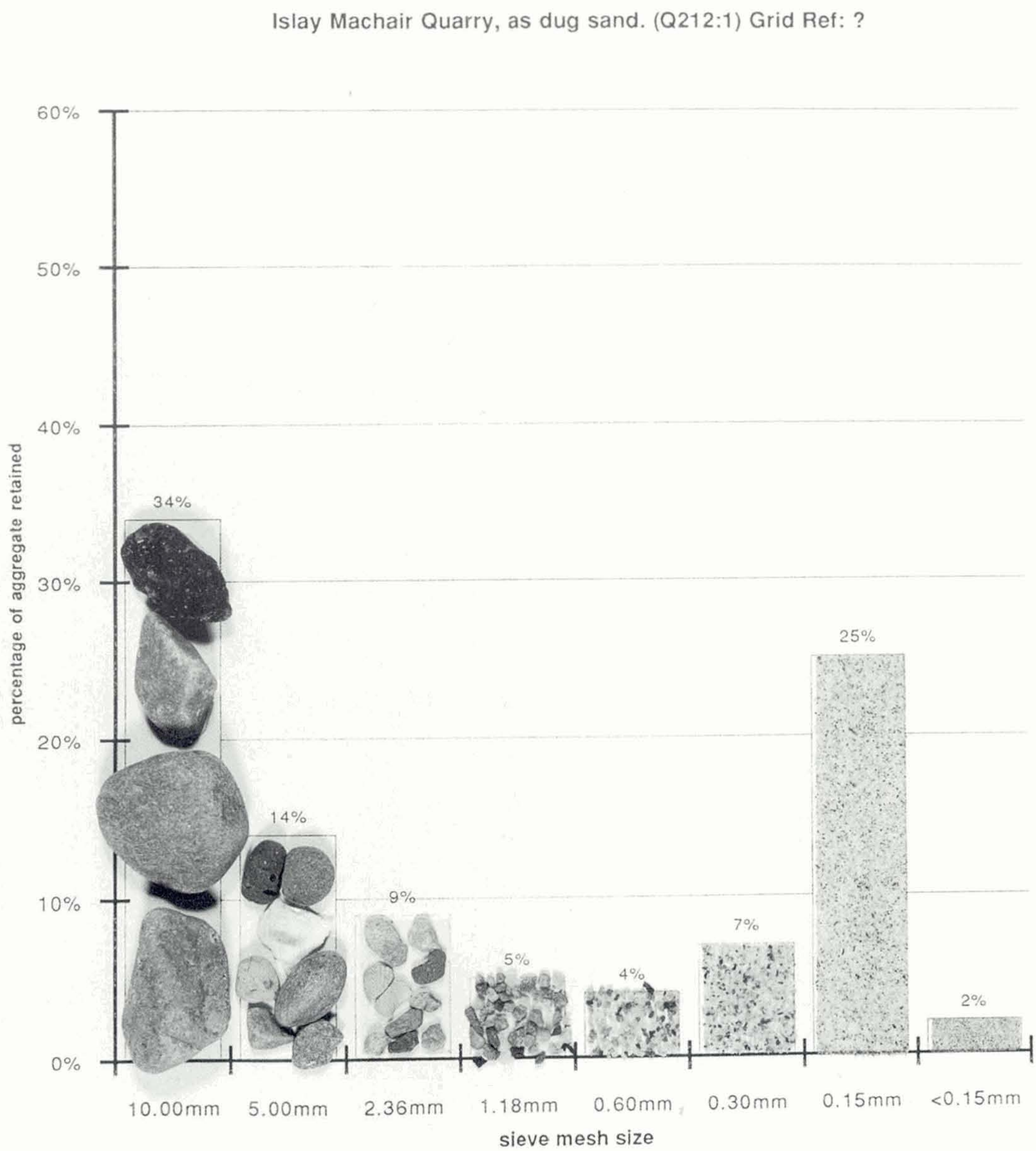


Figure 3 *Sample sand profile with grain size distribution of an unsorted, 'as dug' aggregate.*

as was practical). As part of a mortar analysis service, if the best match for the sand in the mortar is from a distant quarry, an alternative locally available aggregate should also be considered.

1.05 Function of aggregates in mortars

Since the aggregate forms, on average, seventy five per cent of the total volume of a modern mortar, the correct choice of aggregate to be added to the binder is crucial to both the performance and the appearance of the finished product. Aggregates should have the following attributes which make them suitable for use in lime mortars:

- they act as a filler, reducing the volume of binder required and therefore reducing the shrinkage of the mortar during drying,
- they contribute to the compressive strength of the mortar,
- porous aggregates may entrap air within their structure, which both reduces the possibility of frost damage, and aids the carbonation and hardening of the mortar,
- aggregates containing pozzolans (reactive, fine grained silica and/or alumina) may chemically enhance the setting of a lime mortar, and
- they add a natural colour and texture to a mortar, which can be aesthetically more pleasing than the use of pigment, as well as being more in keeping with the original appearance of the building.

The aggregate is commonly required, for conservation purposes, to be a good match both visually and compositionally to that used in the original mortar.

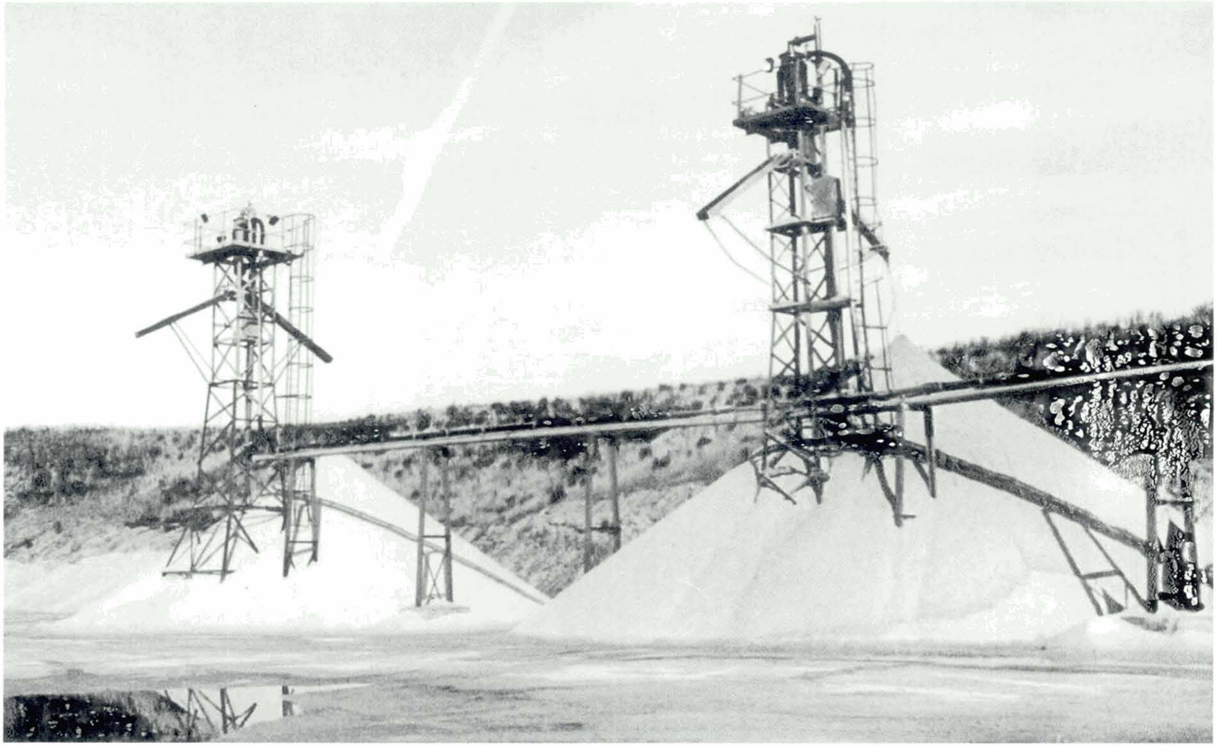


Figure 4 *Stockpiles of sorted silica sands in a quarry. Burrowine Moor Quarry, Fife. Grid reference NS 966 901.*

In cases where rock fragments contained minerals which are chemically unstable and have dissolved, the resulting small pores on the rock surface may form a 'key' which strengthens the bond between binder and aggregate. If, however, such unstable grains are still present when the mortar is made, then chemical reactions when mineral dissolution takes place may cause degradation of the mortar. In most cases mineral grains which are chemically unstable on a time scale of relevance to building maintenance have been dissolved long before the aggregate is extracted and used in construction.

It should be noted that the above functions of an aggregate are also relevant to cement based mortars. The choice of aggregate when repairing or replacing a cement mortar is also an important consideration when dealing with a building of historical value.

1.06 Use of lime mortars

Lime is a binder in a mortar; other binders used in traditional Scottish mortars include clay or earth and, to a lesser extent, gypsum. In buildings of traditional construction, the most common binding material used in a mortar was lime, which was used throughout Scotland until the beginning to middle of the C20 when the use of modern cements became widespread. Cementitious binders were developed throughout the C19 (the patent for 'Portland Cement' was taken out in 1824 by Joseph Aspdin) and modern cement is the most common binder used in present day construction. A binder is mixed with an aggregate to form mortar.

Lime (calcium hydroxide, $Ca(OH)_2$) is formed by firstly burning limestone or other forms of calcium carbonate, ($CaCO_3$). Burning drives off carbon dioxide (CO_2) to form quicklime (calcium oxide, CaO). Lime is formed by combining water (H_2O) and quicklime (known as slaking). Care must be taken as this process produces considerable heat. Lime can be produced in the form of a dry hydrate powder or, if excess water is added during slaking, putty.

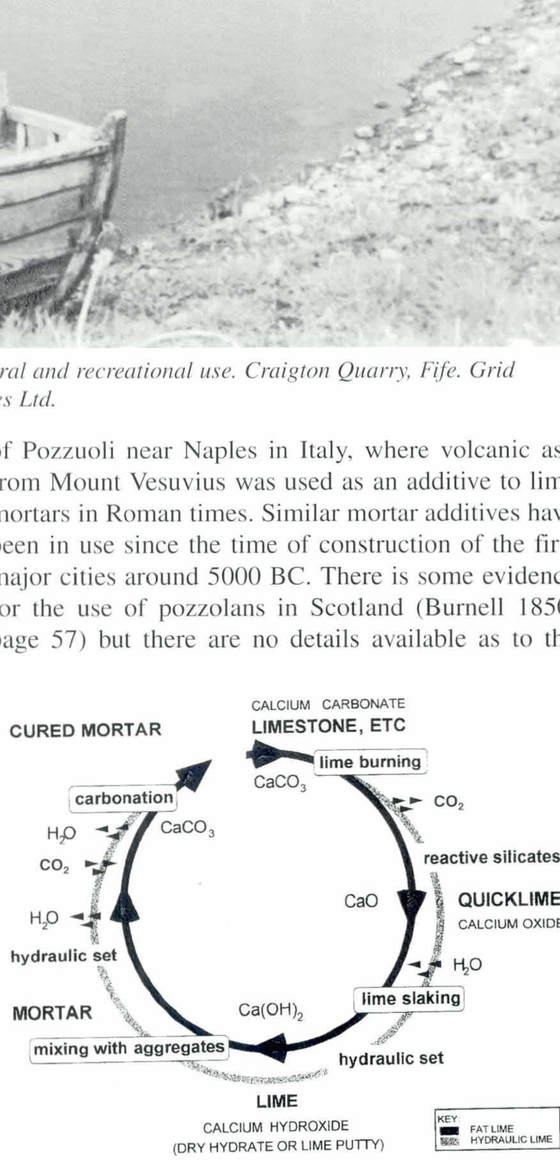
Lime mortars are produced by mixing an aggregate (and water if appropriate) with quicklime, lime hydrate or putty. When exposed to air the lime naturally loses water through evaporation and absorbs carbon dioxide to become calcium carbonate (CaCO3) which is mineralogically the same as limestone. This process, which results in a set mortar, is known as carbonation. The process as a whole, which has the same material at the start and finish, is known as the lime cycle (Figure 6). Further information can be found in Historic Scotland Technical Advice Note 1 (1995) 'Preparation and Use of Lime Mortars'

If an impure limestone is burnt the resulting lime may contain reactive silica derived from burning of clays or

Figure 5 Site of sand and gravel quarry restored to agricultural and recreational use. Craigton Quarry, Fife. Grid reference NT 090 990. Photograph courtesy of Bardon Aggregates Ltd.

siliceous minerals. This reactive silica (and also reactive alumina) gives the mortar a chemical set (Figure 6) in addition to the natural carbonation process, which results in faster setting, greater water resistance and a harder final product. The amount of reactive silica/alumina can be controlled by both the temperature and duration of burning. Lime mortars containing reactive silica/alumina are known as hydraulic limes, and these are traditionally classified as feebly, moderately or eminently hydraulic according to their reactive content. The equivalent modern classifications for natural hydraulic limes are NHL 2.0, NHL 3.5 and NHL 5.0 respectively. At present both schemes of classification are in use. Hydraulic lime production and use does not strictly form a cycle, since the hydraulic materials have a different chemistry before burning and after setting.

As well as natural hydraulic limes, material (clay and/or siliceous minerals) can be added to give a pure, non-hydraulic lime mortar a chemical set. If these materials are added to limestone before burning, the resultant binder is an artificial hydraulic lime. The production of artificial hydraulic limes was refined through the late C18 and C19, the final product being modern cement. Reactive material (such as naturally occurring volcanic ash or manufactured crushed brick) can also be added to lime and sand when the mortar is mixed; these materials are known as pozzolans (Gibbons 1997). Pozzolans are named after the village of Pozzuoli near Naples in Italy, where volcanic ash from Mount Vesuvius was used as an additive to lime mortars in Roman times. Similar mortar additives have been in use since the time of construction of the first major cities around 5000 BC. There is some evidence for the use of pozzolans in Scotland (Burnell 1850, page 57) but there are no details available as to the



SIMPLIFIED LIME CYCLE AND HYDRAULIC SET

Figure 6 The lime cycle showing the minerals formed during processing of a pure limestone (black) and during processing of an impure limestone (grey) which forms a hydraulic lime.

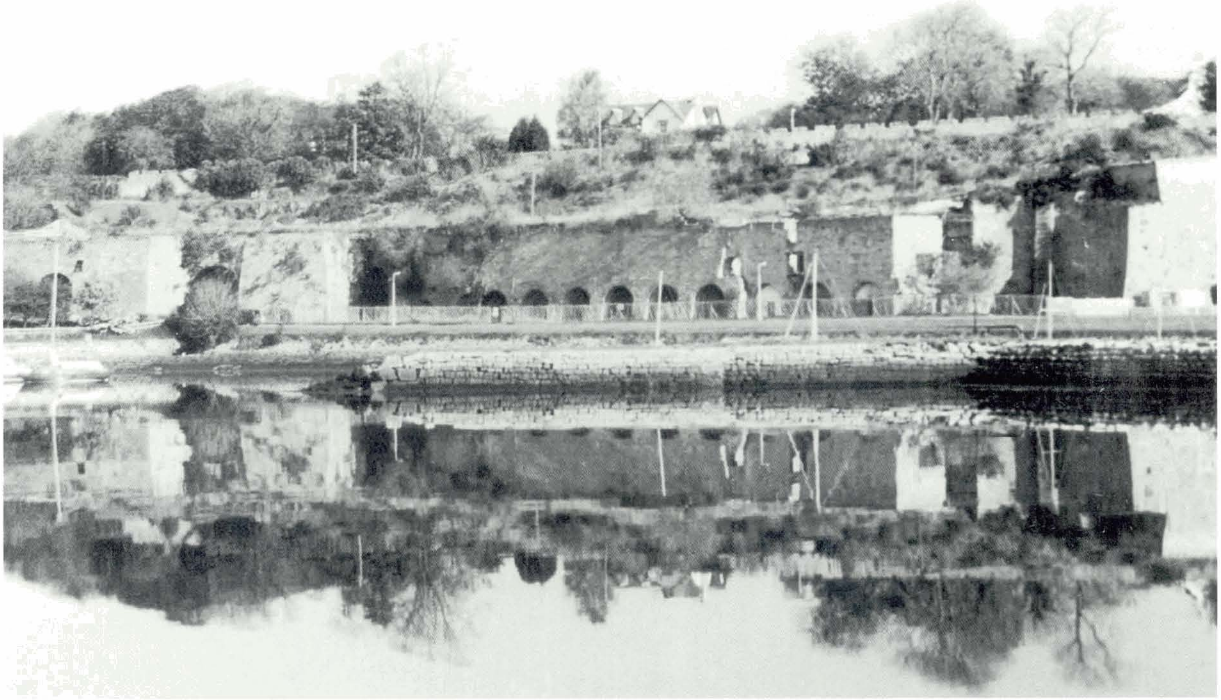


Figure 7 Abandoned lime kilns at Charlestown on the south coast of Fife.

actual localities where the material was found. Neither hydraulic lime mortars nor pozzolanic mortars have the same strength as modern cements, which are burnt at higher temperatures and contain a different mineral assemblage.

Until the beginning to middle of the C20, lime was used both in mortars for building construction and also in plasters, renders and harling as a finishing material. When repairing traditional buildings, it is usually best to replace like with like and so the use of matching lime mortars is the most effective means of ensuring a durable and aesthetically pleasing repair. At present there is no production of lime for building construction in Scotland, supplies are imported from England or, in the case of most hydraulic limes, Europe. In the past, since transportation of materials was costly and impractical, lime was produced in Scotland in great quantity. The lime works at Charlestown in Fife (Figure 7) produced over a third of Scotland's lime for a period.

1.07 Defects which may occur with inappropriate cement based repairs to historic buildings

There are a number of specific problems associated with cement based mortars which do not apply to lime mortars.

Stone decay

Impermeable cements concentrate water movement in the adjacent stone, and can also introduce soluble salts into the stone while setting. Both mechanisms can lead to accelerated decay of the stone, particularly if a soft or porous building stone has been used (Figure 8).

If water movement through a porous stone is increased as a result of use of impermeable cement mortars then the associated erosion of the stone through salt and acid attack and frost damage is also intensified. In a similar fashion, setting of cements produces soluble salts which can crystallise within porous stones and increase the surface erosion of the stone.

Erosion is often concentrated at the contact between mortar and building stone, where the contrast in properties between the two materials is greatest. This leads to enhanced stone erosion and, over a small area of the structure, failure of mortar and increases both the speed of decay and the unsightly aspect of the weathering.

Lime based mortars are permeable and do not produce the same soluble salts during setting, and therefore cause less damage to the stone. Lime mortars can also, however, react with atmospheric pollutants to form gypsum (calcium sulphate) which might be damaging to stone work.

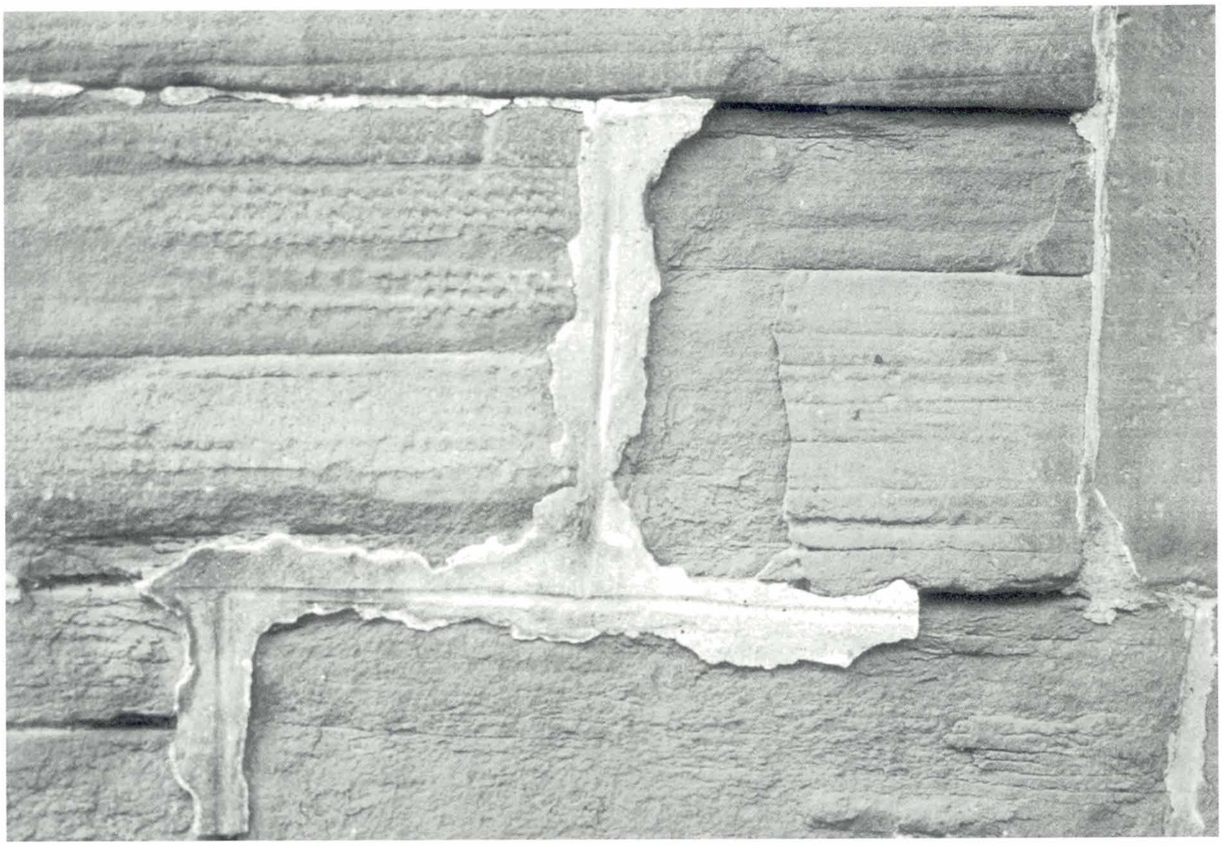


Figure 8 Example of accelerated stone decay caused by inappropriate use of cement mortar.

Weatherproofing

Whether used for building and pointing or for harling, rendering and plastering, lime mortars and harlings are more permeable than cement based mortars and allow moisture to pass through. More importantly, they allow water within the structure to evaporate more efficiently from the building. This is particularly important when the masonry is composed of an impervious stone such as granite.

Cement mortars, on the other hand, tend to trap and collect moisture, leading to loss of thermal insulation, excess condensation, timber decay and other problems. Trapping of water behind an impermeable coating also leads, through the action of repeated freeze / thaw cycles, both to the detachment of the coat from the wall (boss), and to the formation of salt crystals at the interface, which accelerate decay of the structure.

Structural and seasonal movements in buildings

Most buildings expand and contract with the seasons and tend to settle over the years. In a traditional building which has been repointed or covered using a cement based mortar, this movement will lead to cracking of the new mortar and penetration of water which, once trapped in the structure, cannot evaporate. Lime based mortars respond to structural movement by the formation of numerous microscopic cracks which are then sealed by the reprecipitation of lime in solution. This 'flexibility' or, more accurately, micro movement maintains the waterproof nature of the structure while still allowing vapour and moisture permeability.

Environmental advantages of lime

Lime manufacture requires less energy (burning temperatures are lower) than the production of cement. Lime mortars also re-absorb CO_2 during setting (Figure 6), whereas during cement production CO_2 is driven off and remains in the atmosphere.

Lime based mortars are also ideal for repair of old buildings where the principles of reversible repair and 'sacrificial' materials are of importance. In this way the surviving historic fabric of a building can be protected from further decay.

Appearance

Lime mortars are aesthetically more pleasing than grey cement coatings and also develop an attractive patina with time. Lime based materials, being the materials used in the original construction of old buildings, are also more in keeping with traditional building practices.

If colour is of importance then the choice of correct aggregate can be particularly useful in determining the appearance of the mortar.

1.08 Lime mortar working practice

The use of lime mortars, renders and harls in building conservation has significant advantages over cement based products. Working with lime mortars requires different skills and knowledge than use of cements. Damage can be done to a building, however, if lime based materials are applied incorrectly. It is recommended that contractors employed in building conservation, where the use of lime based materials is involved, are fully conversant with the appropriate techniques, which are described in detail in Historic Scotland Technical Advice Note 1.

In all cases it is recommended that where necessary initial practical experience of working with lime is gained through workshops or training seminars before work is carried out.

2 THE PROPERTIES AND REQUIREMENTS FOR AGGREGATES IN MORTARS

2.01 General requirements for modern building practice using lime mortars

To be suitable for use in lime mortars, aggregates should conform generally to a number of requirements. Aggregates should contain little or no fine-grained materials such as silts and clays, and should not contain salts or organic (plant) material. Other materials which should not normally be included in an aggregate, as specified by the British Standards documents, are

- excessive fine grained material,
- salts,
- organic materials,
- rock fragments containing abundant clays or micas,
- wood fragments,
- coal,
- gypsum or
- other sulphates and iron sulphides such as pyrite.

The need for a mortar mix which is acceptable to modern building practice must be balanced with the desire to use a mortar which matches that used originally.

In cases where there is uncertainty as to the suitability of an aggregate, it is recommended that test panels are created before work commences to assess the short to medium term performance, and visual suitability, of the mortar.

Grading

Grading describes the grain size distribution of an aggregate in terms of how close the spread of sizes is to a statistical 'normal' distribution pattern. The geological term 'sorting' refers to the same grain size characteristics, but a well-graded sand containing particles of several sizes would be termed moderately sorted. Both well-sorted (consisting of one grain size) and poorly sorted (consisting of an equal amount of all grain sizes) sands are therefore poorly graded in terms of materials for use in mortar production (Figure 9).

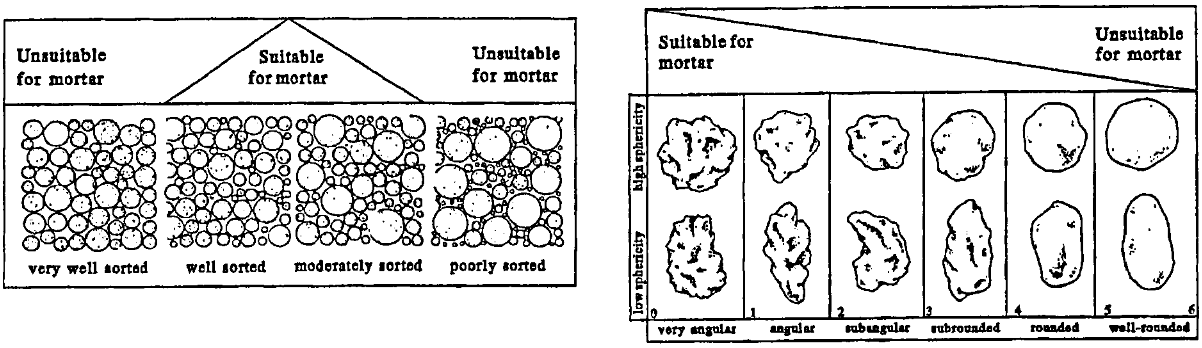


Figure 9 Diagrams showing the suitability of sands in mortars according to: a. the sorting (grading) of the sand and b. the roundness or grain shape. Adapted from Historic Scotland Technical Advice Note 12 (1997, Tables 4 & 5). Figure courtesy of the British Geological Survey.

Of these 'undesirable materials' only micaceous rock fragments and coal are found in significant quantities in Scottish aggregates.

For replacement mortars specified to match those used in traditional buildings, however, modern (British Standards Institution and the European Committee for Standardisation) specifications may not always be relevant. Aggregate in mortars from old buildings can contain clays, coal and other materials which are regarded as unsuitable in modern building practice.

For use in lime mortars a well-graded coarse grained aggregate has a 'normal' distribution of particle sizes with most particles lying within the very coarse sand to medium sand range (between 2.00mm and 0.30mm grain diameter, Figure 10). Aggregates with a large proportion of particles outwith this range may not be suitable for use in lime mortars. Fine grained or building sands commonly have a range of grain sizes between 1.00mm and 0.15mm. A simple description of grading is given for individual aggregates in the database.

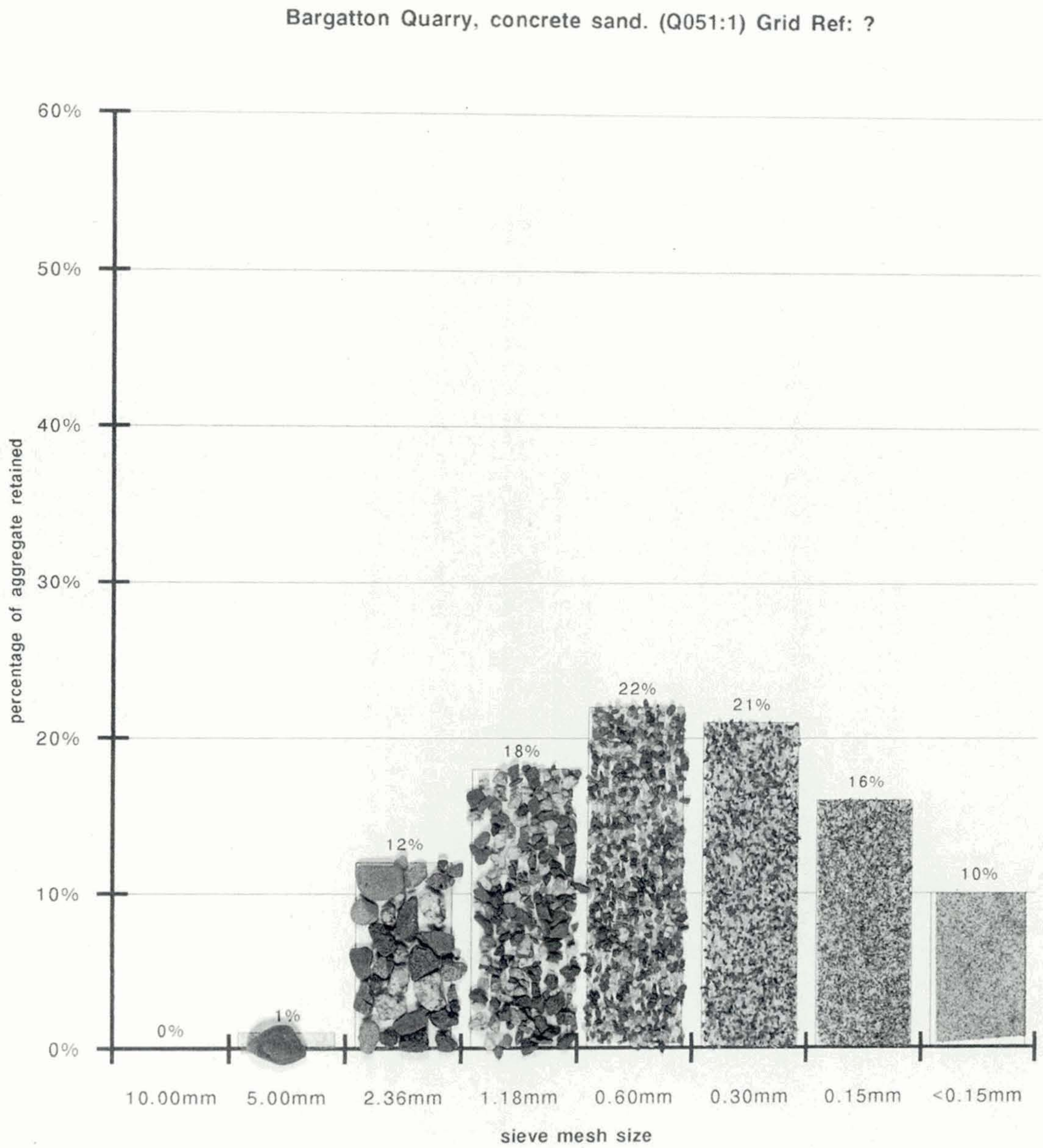


Figure 10 Sand profile showing grain size distribution of a well graded (or moderately sorted) sand.

The definition of grading with respect to sorting as given in Table 5 in Historic Scotland Technical Advice Note 12 is not strictly correct (although the text on page 20 gives the correct relationship). The Figure shows an unsorted or poorly sorted material as being most suitable for use as a mortar sand, whereas in practice a moderately sorted material is preferred. The correct relationship, with a moderately to well sorted (well graded) sand being most suitable for mortars, is given in Figure 9.

The British Standards Institution provides a number of grading curves for sands to which aggregates should conform if they are to be used in mortars (see § 2.03). As has already been discussed, where a match with an aggregate in an old mortar is required the matching material may not conform exactly to the British Standard specifications. In this case it should be ensured that the aggregate forms a workable mortar before beginning the repair.

Particle or grain shape

The shape of the particles in an aggregate is also important to the suitability for use in a lime mortar (Figure 9). Individual grains can be angular, leading to a 'sharp' sand, or may be rounded, forming a 'soft' sand. For use in mortars, a sharp sand is preferred since angular, non-spherical particles fit closely together

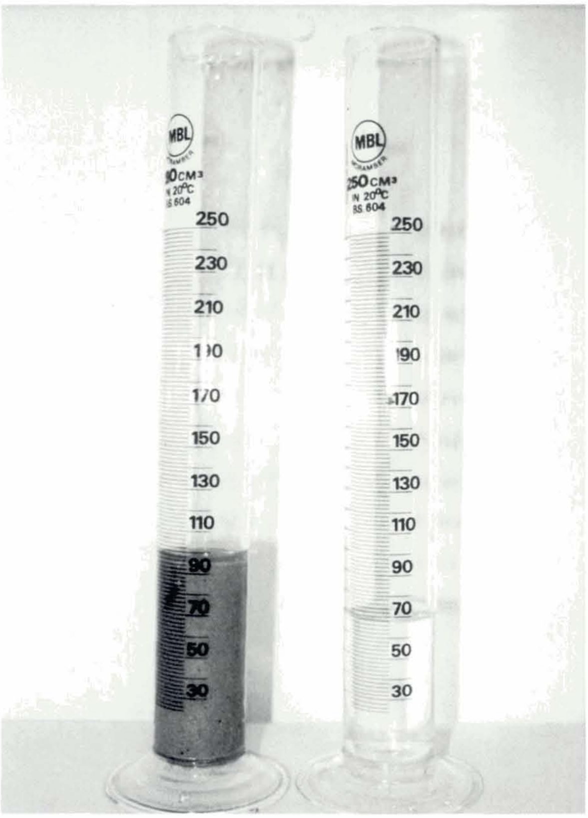


Figure 11 Void ratio equipment showing a sample of 100ml of dry sand, to which 33ml of water has been added to fill the space between grains, giving a void ratio of thirty three per cent.

whereas rounded, spherical grains tend to roll over one another like ball bearings, which although easier to work, ultimately leads to a poorly bonded mortar.

Mineralogy

Sand is derived from the weathering of rocks and the minerals present within a sand and gravel aggregate are, therefore, dependent upon the geology of the underlying land and the effects of glacial, river, wave and wind erosion and transportation (Figure 1). Most aggregates consist of a mixture of the minerals quartz and feldspar as well as rock fragments, with minor amounts of mica, coal, plant fragments and other impurities. Aggregates containing large proportions of mica or metamorphic schist may be unsuitable for use in mortars in exposed locations.

Materials such as coal or some clays may be pozzolanic and aid setting of the mortar. In some cases, however, coal and clays can expand and cause a disruption of the mortar and the presence of such materials in an aggregate should be noted. A quick inspection of an aggregate can, if necessary, be carried out on site either by eye or using a small hand lens or magnifying glass.

Descriptions of common mineral and rock types are given in Chapter 3 and the Glossary. Crushed rock aggregates are usually composed of one rock type, and so are used in more specialised jobs where a distinct colour or grain size is required.

Void ratio

Void ratio describes the proportion of space between particles in a dry aggregate, and is expressed as a percentage of the volume of the aggregate (Figure 11). The void ratio is ideally the proportion of binder, by volume, which should be added to the aggregate to make a good mortar. When a binder is added to the aggregate it should fill completely the spaces (voids) between the grains. Lack of binder will lead to a less cohesive mortar.

In almost all aggregates the void ratio is close to thirty three per cent, thus approximating to a 1 part binder to 3 parts aggregate specification in a mortar mix. The 1 : 3 by volume ratio assumes that the voids in an aggregate are filled by binder, thus from the combination of 1 unit of binder and 3 of aggregate, 3 units of mortar are formed. Some aggregates have a different void ratio (between thirty and forty five per cent) and are suitable for use provided the appropriate quantity of binder is used. (See also Chapter 3)

2.02 Specific requirements

All aggregates used in building repair and conservation must meet the requirements given in § 2.01, and a wide range of commercially available aggregates in Scotland are suitable for the purpose. In the conservation of old buildings, the appearance of the replacement mortar should generally be as close as possible to that of the original. Factors such as overall colour, colour of the fine grained (<0.15mm) fraction and whether or not the local aggregate used in the original construction is still available should therefore be considered.

Of primary importance when considering the choice of aggregate and mortar is a knowledge of the building and details such as provision of rain water goods, stone treatments, etc. This information is vital when carrying out repairs, as the performance of a mortar can be severely impaired if attention is not paid to the condition of the surrounding parts of the building.

These specific requirements, which are dependent on the individual job, should ensure that the aggregate, lime and resultant mortar match the original materials as closely as possible.

Sieve diameter	BS 882	BS 1199		BS 1200	
	Sand	Sand type A	Type B	Type S	Type G
5.00mm	0 - 11%	0 - 5%	0 - 5%	0 - 2%	0 - 2%
2.36mm	0 - 40	0 - 40	0 - 20	0 - 10	0 - 10
1.18mm	0 - 70	0 - 70	0 - 30	0 - 30	0 - 30
0.60mm	0 - 85	20 - 85	0 - 45	0 - 60	0 - 60
0.30mm	30 - 95	50 - 95	25 - 95	30 - 95	10 - 80
0.15mm	85 - 100	85 - 100	80 - 100	85 - 100	75 - 100
0.07mm (sand)	-	95 - 100	95 - 100	95 - 100	92 - 100
0.07mm (rock)	-	95 - 100	95 - 100	90 - 100	88 - 100

Note: in the 0.07mm rows, sand = natural sand and gravel aggregate, rock = crushed rock aggregate.

Table 1 Aggregate grading curve limits as defined by British Standards documents BS 882, BS 1199 and 1200, adapted to show percentage by weight retained on each individual sieve (as shown on the sand profiles, Figure 3, 10 & 16), not percentage by weight passing.

2.03 British Standards specifications

Several of the British Standards Institute documents contain information regarding acceptable standards for working with mortars. British Standards document BS 812 specifies the appropriate methods of testing both grain size and other characteristics and British Standards BS 882, BS 1199 and BS 1200 specify the particle size ranges (grading curves) for aggregates in mortars, renders, harls and cements. It should be borne in mind that these specifications are in almost all cases relevant to cement mortars.

While these recommendations are generally adhered to, it must be appreciated that in the conservation and repair of historic buildings, which is commonly concerned with the replacement of old lime mortars with matching materials, there may be a requirement for an aggregate which does not conform to modern specifications. Furthermore, the following statement gives the impression that evidence of acceptable performance in use is one of the main considerations when specifying an aggregate:

'Much of the sand used for the production of mortar in the UK, particularly that used for internal rendering, does not conform to the appropriate limits prescribed by the current British Standards. Nor is reference made to the quantitative limits on 'impurities' in the existing UK standards, there being a considerable difference of opinion by both producers and users on the acceptability of sands containing impurities such as mica, lignite or high salts content.' (Smith & Collis, 1993, § 9.9, page 246)

Table 1 shows the range of particle sizes specified by BS 882, 1199 & BS 1200, overall limits for sand for concrete, aggregate types A and B for external renderings, internal cement plastering, internal lime undercoats and floor screeds and types S and G for mortar for plain and reinforced brickwork, blockwalling and masonry. Other than the recommended grading characteristics, BS 1199 & BS 1200 specify that sands (aggregates mainly passing through a 5mm sieve) should not contain 'harmful' materials such as iron pyrites, salts, coal and organic impurities. Sands should also be free from excess clay material and from elongated or 'flaky' particles.

The British Standards documents are currently being replaced by European standards which cover the same subject. Many of the new European Committee for Standardisation (CEN) documents, including the document covering aggregate specifications (EN 932), are at the draft stage. It is not likely that the testing methods and recommended grading curves will be significantly different in the new document.

2.04 The selection of aggregates for mortars

The selection of the correct aggregate for any conservation work is dependant upon a number of factors. Most important are a good knowledge of the work to be carried out and an understanding of what function the mortar is to perform.

In many conservation projects, a sample of old mortar should be available for study and this provides a basis for the choice of an aggregate for repair work. From mortar analysis, the grading and colour of the original aggregate should be apparent, and void ratio can also be measured if necessary. Analysis methods are given in detail in Chapter 3.

Grading and colour are the two most important factors to consider if an exact match of the original aggregate is required. In most cases, however, other considerations, such as the function of the mortar, stone type, etc. have equal importance in choosing an aggregate (table 2).

The colour of the aggregate plays a large part in determining the colour of the mortar and if patch repairs are to be carried out or if colour is of particular importance, using a replacement aggregate with a similar colour is recommended. Since coloured aggregate gives different effects in a mortar depending on grain size, the grading should also be close to the original if a match is required. The fine grained fraction (<0.15 mm) influences the overall colour of a mortar in the same way as a pigment, while coarse grained material can give materials such as harling a distinctive appearance.

If analysis cannot be carried out, then a qualitative impression of the aggregate grading and colour can be derived from simple visual inspection. Visual assessment is commonly sufficient to assess the match for grading and colour of a replacement aggregate.

When mixing mortar to be used for pointing or bedding work, an aggregate should have a maximum grain size of one-third the width of the joint being filled.

It should be noted that a newly applied lime mortar will commonly be much lighter than the original material even if the mortar composition is the same. This effect fades with time, but it may take several years for a new mortar to weather to the desired tone. It is not possible to create a quick match for a mortar which has been interacting with a building and influenced by climatic variations for several hundred years, by using modern materials.

•	Assess building repair task.	
•	Take representative sample of original mortar, or inspect mortar if sampling is not possible.	
•	Analyse original mortar to assess	- binder type
		- binder : aggregate ratio
		- aggregate grading
		- aggregate colour
•	Other considerations	- binder type
		- stone type
		- function of mortar
		- joint size
		- building setting (climate, aspect, etc.)
•	Choose aggregate.	
•	Choose binder and mortar mix.	
•	Decide on methods of mortar application and aftercare.	

Note: Aggregates are usually chosen, as part of the project specification, in association with other mortar materials. Details are given in Historic Scotland Technical Advice Note 1.

Table 2 Summary of methods of choosing suitable materials for conservation work. Factors of direct relevance to the selection of an appropriate aggregate are shown in bold.

3 METHODS OF ANALYSIS AND CHARACTERISATION OF AGGREGATES AND MORTARS

3.01 Methods and equipment for aggregate sampling and analysis

Introduction

As part of the work associated with the writing of this Technical Advice Note, a survey of working sand and gravel quarries in Scotland was carried out by the Scottish Lime Centre on behalf of Historic Scotland. As the survey developed, the scope was widened to include quarries within 50km of the Scottish border and also a number of crushed rock quarries representative of the range of rock types available in Scotland.

The information collected in this survey is summarised in Appendix A and included in the database of Scottish aggregates.

Sampling methods and equipment

Sampling of sands, gravels and crushed rock products was carried out roughly in accordance with the techniques set out in BS 812: part 102.

The small size (1.0 - 1.5kg) of the sample taken is less than that recommended by BS 812 (a minimum of 10kg for aggregates with average grain sizes under 5mm in diameter); products with a coarser grain size could not be collected, analysed and stored efficiently given the total number of samples to be processed and the scale of the project, and are not commonly used in lime mortars.

It is apparent from discussions with quarry managers, and given the nature of geological deposits, that the characteristics of aggregates are variable through time and that the materials collected may not be representative of quarry products in future years. This cannot be avoided and could be partially resolved by a resampling of certain quarries at a fixed period. Alternatively, the quarry operators could be asked to provide grain size information if necessary. All of the samples in the original database were collected and analysed at various times between 1996 and 1998. If it becomes necessary to resample products from a quarry, or if a new sample is sent to the Scottish Lime Centre, then the month and year of the sampling is indicated.

Aggregate analysis can be carried out using a minimum of specialist equipment. Visual inspection to determine grain shape and mineralogy of the aggregate can be carried out without any equipment. Visual inspection can be greatly helped by use of a hand lens with a magnification of times ten. It is also beneficial to have access to a rock and mineral identification guide such as the Observer or Hamlyn series to aid identification of mineral types. Samples should be thoroughly dried before analysis.

To obtain data on grain size distribution, a set of analytical scales with a minimum resolution of ±0.05g and a stack of British Standard approved sieves is required. Both can be obtained from specialist laboratory equipment suppliers, although most quarries analyse their own products and can supply the relevant information on request.

Void ratio analysis can be carried out using any container which has volume gradations marked on the side. Ideally, a mark every 1 ml is required, such as is seen on volumetric measuring cylinders, but rough estimates of void ratio can be made using other straight sided containers.

Sample sieving

In order to establish the range and relative proportions of grain size within an aggregate sample each of the samples is dry sieved. This process allows separation of the different size fractions and measurement of the grading of the aggregate with respect to the appropriate British Standards.

Dry sieving of samples is carried out in accordance with BS 812: part 103.1 using sieves as specified in BS 410 (Figure 12). A sieve shaker is used for fifteen to twenty minutes to separate particles, using samples with a total weight of 100.0 ±0.05g. This time is sufficient to separate the different size fractions although additional shaking and brushing can be employed where necessary. A stack of sieves with meshes of the following diameters is used:

10.00mm (for very coarse grained materials only)
5.00mm
2.36mm
1.18mm
0.60mm
0.30mm
0.15mm

Figure 12 Sieve stack including sieve shaker (sieve shaker courtesy of the British Geological Survey).

The fraction retained on each sieve is weighed to the nearest ±0.05g and each weight expressed as a percentage of the whole.

In most aggregates the fine (under 0.15mm) grained fraction is composed of fine sand and coarse silt, coarser than 0.016mm. This can be classified in more detail by a simple test (Figure 13) using a small amount of damp fine grained material.

The average grain size and approximate grading of an aggregate can be estimated visually on site. A small grain size card can greatly help in the determination of grain size, but any scale such as a simple ruler can also be of use.

Sand profile construction

After sieving, a sand profile (histogram of grain size, expressed as a percentage as retained by each sieve) is created for each sample and the bars were covered by particles from the separated size fractions using adhesive tape (Figure 3, 10 & 16). This simple method provides an immediate and effective visual impression of sample colour along with grain size information.

Grading and grain shape

As described in Chapter 2, good grading tends to give a sand a particular profile which is close to a 'normal' distribution. Sands also contain grains with a variety of shapes; typical grain shapes are shown in Figure 9. The less common shapes (irregular, flaky and elongate as described in BS 812) are not used. Since almost all samples contain both rounded and angular grains the

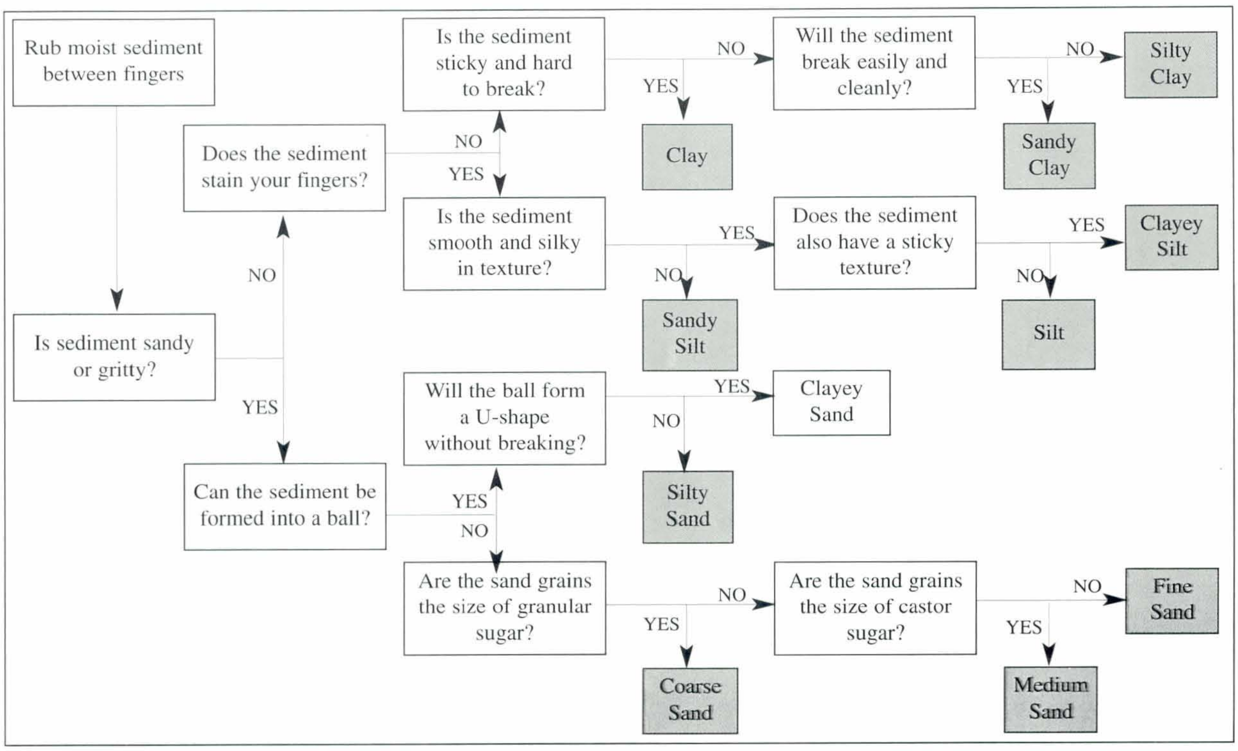


Figure 13 Test procedure for identification of the grain size of the fine fraction. Taken from Westman (1994, Section 3.1.2, Figure 14).

estimate of roundness or angularity is an 'average' based on the general appearance of the aggregate under the binocular microscope. This visual estimate also takes into account the sphericity of the grains and can be taken to be an indication of the textural maturity of the sample.

A simple test can be carried out to determine grain shape. If an aggregate is rubbed between the fingers, there is a roughness or 'crackle' to angular or sharp grains; rounded grains tend to roll between the fingers more smoothly.

Munsell® and simple colour

The Munsell® Soil Color Chart, revised in 1994, is recommended by the United States Department of Agriculture as a way of standardising the colour descriptions of soils. They are also used by organisations such as the British Geological Survey to describe sediments and rocks, and as such are useful for describing the colour of sands and gravels. The Munsell® colour charts provide a standard for colour description which allows comparison of the results found in this project with other work, in particular the sand library held by English Heritage.

Comparison of a uniform colour panel, as in the colour charts, with a material composed of a variety of grains is, at best, subjective. In cases where the material contains more than five per cent grains with a diameter of greater than 2.36mm, the colour is approximate. In the case of grits and gravels, which are extremely difficult to assess and have the additional problem that particles are commonly coated with fine dust, colour values are given as a rough guide. Crushed rock products tend to be more consistent in colour although fine rock dust is commonly lighter than larger rock fragments.

As well as colour matching of the whole sample, the fine (<0.15mm) fraction, which is of most importance in determining the eventual colour of the mortar, is also allocated a Munsell® colour.

Because the Munsell® colour scheme is complex, the aggregates are also allocated a simple colour name.

Mineralogy

Dry aggregates are examined using a binocular microscope (Figure 14) with a magnification of between times ten and times forty. The major and minor mineral components are noted along with any other materials such as plant fibres and wood fragments.

In the majority of cases, grains can be subdivided into three groups; quartz, feldspar and rock fragments.

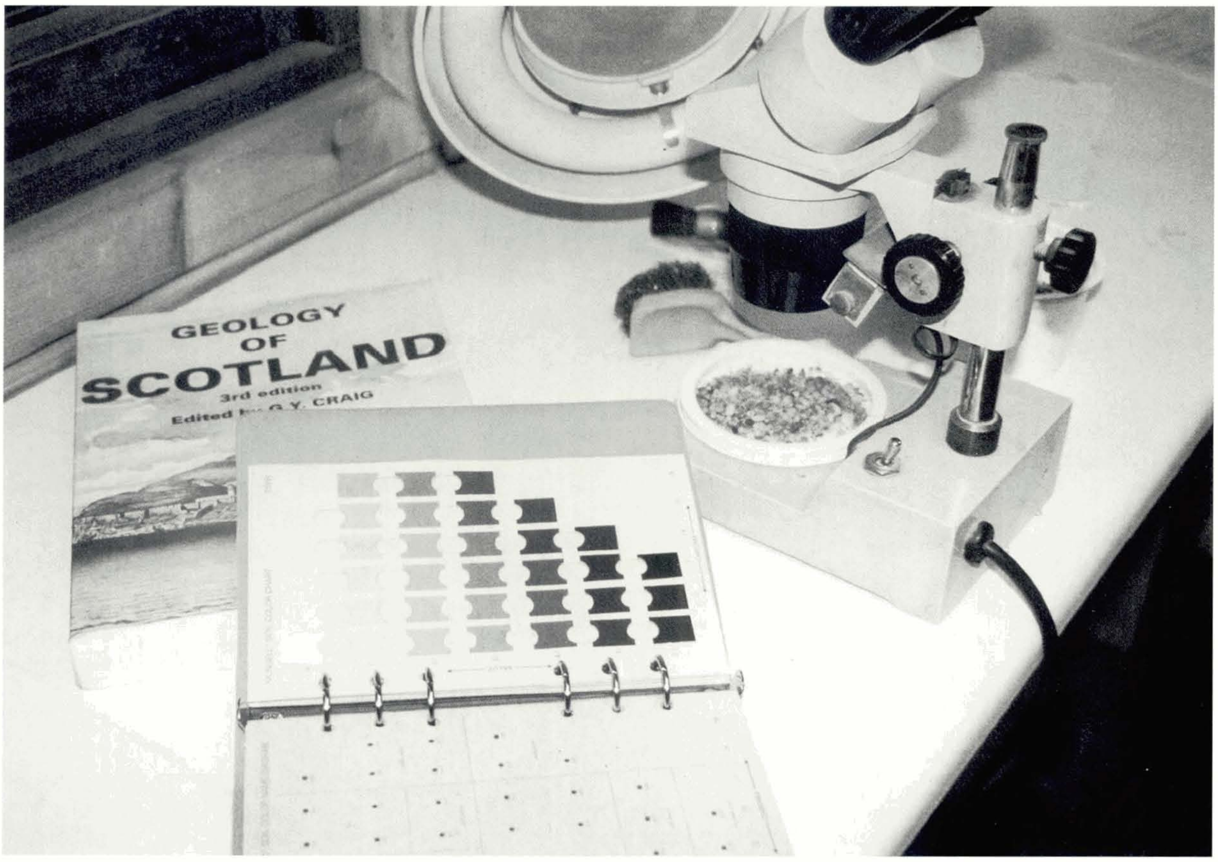


Figure 14 Laboratory showing microscope for detailed examination of mortar and aggregate samples.

Small amounts of mica, ferromagnesian minerals, coal and plant fragments are also common. The percentages of each major component given in the analysis are a semi-quantitative measurement of composition. The apparent abundance of each component is partly dependent upon grain size, and the proportion of rock fragments, which are commonly larger than other clasts, may have been over estimated. The following descriptions are very basic and it is recommended that a suitable guide to the identification of rocks and minerals is also used when identifying the components of an aggregate.

Quartz - clear or glassy crystals, sometimes fractures with a concentric, glass-like pattern, crystal faces uncommon. Quartz derived from sandstones can be coated by red or yellow iron oxides.

Feldspar - cloudy or opaque, white or pink coloured (commonly pink in granites). Some flat planes (crystal faces) seen on grains, can have a blocky shape.

Mica - usually dark coloured or less commonly clear, very flat, thin and platy shape, distinctive shiny surface.

Ferromagnesian minerals - usually dark or dark green in colour, tabular or brick-shaped crystal form. Common in basalts (but normally too fine grained to identify) and metamorphic schist.

Shell fragments (calcite or aragonite, both $CaCO_3$) - white or yellow, soft grains. Shell fragments usually have a distinctive shape. All $CaCO_3$, including limestone rock, reacts (fizzes) with hydrochloric acid.

Coal - dark or black, shiny, various shapes. A bubbled, porous texture means the coal has been burnt, usually in a kiln along with limestone as part of lime production. Burning an impure coal can also result in fragments of red – brown slag. Burnt coal is not, therefore, a component of the aggregate as such but may be present in mortars.

Iron pyrites (and other metallic minerals) - not common, most have a metallic sheen. Pyrite has a pale yellow colour and may have a cubic crystal shape.

Rock fragments - rock types are subdivided into igneous (formed from molten material from within the earth), metamorphic (formed through change of pre-existing rocks by heat and pressure during burial in the earth's crust) and sedimentary (either formed from pre-existing rocks by weathering, deposition and lithification - sands, silts, clays, or formed by precipitation from water - limestone or salt). A mixture of interlocking crystals of quartz, feldspar and some mica is probably an igneous granite. Rocks with mostly mica and quartz crystals orientated in one direction are usually metamorphic, commonly a schist. Fragments made up of small grains stuck together are sedimentary, usually sandstone or siltstone. Dark, fine grained fragments, commonly containing white tabular feldspar crystals, are basic (silica poor) igneous such as basalt; some sedimentary mudstones may appear similar although they are commonly softer and contain small grains as opposed to crystals. (See the Glossary).

In general, natural aggregates become more quartz rich through time as erosion and weathering take place. Most other minerals are physically softer than quartz and are worn down more quickly. Furthermore, feldspars, micas and ferromagnesian minerals are chemically unstable and break down into clays which are washed away, leaving 'mature' quartz sands. The geological terms immature and mature are used to indicate both the textural (trending towards rounded grains of a consistent grain size) and the mineralogical (trending towards a quartz-rich aggregate) evolution of a sample towards maturity as erosion and weathering take place. During weathering, coarse-grained rock fragments are broken down into individual mineral grains and so the fine-grained fraction in sands tends to be more quartz rich.

Calcium carbonate ($CaCO_3$) content

During examination, a number of samples were selected for analysis of calcium carbonate ($CaCO_3$) content. Calcium carbonate can take the form of rock fragments composed of limestone (calcite) or shell fragments (calcite or aragonite, both $CaCO_3$ but with a different crystal structure). The mineral dolomite ($CaMg(CO_3)_2$) is present in some limestones but is not common in Scottish mortars and behaves in essentially the same way as calcite. Most natural Scottish aggregates have no $CaCO_3$ and crushed rock products of known lithology do not commonly require analysis. In cases where there was uncertainty regarding $CaCO_3$ content, a sample of material from each quarry, usually a concrete sand, was selected for analysis.

$CaCO_3$ content is assessed by measuring weight difference before and after reaction with hydrochloric acid, and is expressed as a percentage of the total weight of sample.

Void ratio

Void ratio values are a measurement of the volume of a sample occupied by the space between grains, expressed as a percentage of the whole (Figure 11). Void ratios in good mortar sands generally lie between thirty per cent and thirty seven per cent and this proportion is represented in the commonly used ratio of 1 part binder : 3 parts aggregate by volume in various types of mortar. Void ratio is determined by the grading and grain shape of the constituent grains: larger rounded grains of similar size, like ball bearings, will have a greater volume of space between them than angular grains of varying sizes, and the actual ratio of binder to aggregate in a mortar should therefore be determined by the characteristics of the aggregate.

To establish void ratio of the database samples a small sample of dried material was placed into a 50ml measuring cylinder. The cylinder with sample was placed on a balance with a precision of ±0.05g and the reading was set to zero. Water was then added to the sample which was agitated to remove any entrapped air bubbles. The sample was allowed to settle and the volume taken up by the sample was read from the side of the cylinder to the nearest 0.2ml. The volume of excess water in the cylinder (ie that lying above the sample) was measured by taking the difference in volume between the top of the sample and the top of the water and converting this volume into a weight (1.0ml of water weighs 1.0g). The weight of the water added to the cylinder was then measured. The total weight in grams of water, minus the weight (volume) of excess water above the sample, is equivalent to the volume in millilitres of water within the pore spaces of the sample material. The void ratio, expressed as a percentage, is given by the volume of water multiplied by 100, divided by the volume of aggregate within the sample.

A simpler method for measurement of void ratio on site, can be used. A sample of dried aggregate is placed into a large (1 litre) measuring cylinder and the volume noted. Sufficient water is added to fully saturate the sand, making sure that air bubbles are eliminated. The volume of water used is then noted. The void ratio percentage is calculated by multiplying the volume of water within the aggregate by 100 and dividing by the volume of aggregate.

Pozzolanic content

A pozzolan is a material added to a mortar which, when added to a mortar, reacts with calcium hydroxide to form crystalline materials giving a mortar a chemical or cementitious set. Pozzolans are defined as:-

'a siliceous or siliceous or aluminous material which, in itself, possesses little or no cementitious value but which will, in finely divided form in the presence of moisture, react chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties' (ASTM C 618-94a).

Pozzolans can be naturally derived, such as volcanic ash, or artificial materials like fuel ashes, crushed brick or tile. Pozzolans are commonly added to lime mortars as a separate component.

It is apparent that certain aggregates also have an element of pozzolanic reactivity. The presence of any potentially pozzolanic materials within an aggregate was noted but due to the small quantities commonly found in Scottish aggregates no quantification of the pozzolanicity of the aggregate was undertaken.

A test for pozzolanic property of a substance can be carried out using measured quantities of the potential pozzolan and lime in water. The test measures the expansion of the mixture over a period of seven days, the amount of expansion being related to the volume of reactive pozzolan in the sample. This method is only appropriate with a strongly pozzolanic substance and cannot be used with sands that are predominantly inert.

Pozzolanic reactivity is in a large part controlled by the grain size of the material, and commercial pozzolans are ground to a very fine powder to give a strongly reactive material. There are no sand and gravel aggregates sampled in this study which are sufficiently pozzolanic to show a significant reaction using the standard test. In all cases the volume of inert aggregate makes measurement of the small volume change associated with the active pozzolan impossible. Crushed rock aggregates are usually too coarse grained to be reactive. Some finely ground basic igneous rocks, however, do show a significant pozzolanic reaction and could potentially be used as mortar additives.

Bulking ratio

A damp aggregate has a greater volume than a dry or water saturated one, since the film of water surrounding grains tends to push them apart causing an increase in the volume of the material. This is known as bulking and is controlled by both the grain size and the water content of the aggregate. Analysis of the bulking ratio of individual samples was not carried out on aggregate samples since the bulking of samples is dependant upon on site conditions which are highly variable and only valid for the sand at the time of measurement.

For the purposes of mortar making, the normal building industry convention of an allowance of twenty per cent for bulking of damp sand is considered acceptable. A diagram giving notional bulking ratios for fine sands, coarse sands and crushed rock sands is given below (Figure 15).

If necessary, a quick test can be carried out on site to confirm the actual value before use. A sample of damp sand, as intended for use, is placed in a measuring cylinder or other container and the volume noted. Sufficient water is added to fully saturate the sample and, once any air bubbles have been removed, the volume now taken up by the sand itself is measured. The ratio of the two volumes, of the damp and the saturated sand, indicates the bulking ratio and should be taken into account if an absolutely accurate volume

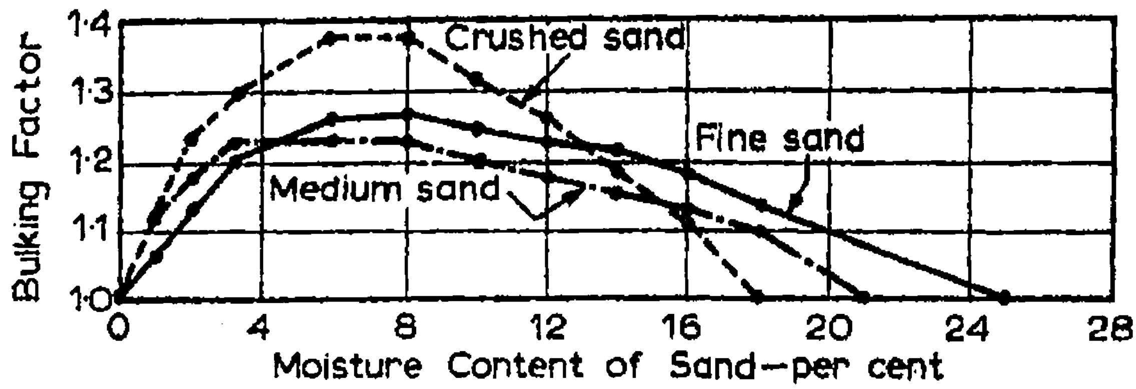


Figure 15 Decrease in true volume of sand due to bulking (for a constant volume of moist sand). Taken from Neville (1995, page 135).

mix is required. If a damp sand occupies 1000ml (1 litre) in a measuring cylinder, and excess water is added, the volume should become approximately 800ml after some agitation to remove trapped air. This gives a bulking ratio of twenty per cent, or a bulking factor of 1.25.

In practice, ignoring the bulking effect of damp sand will result in a slight increase in the lime content of the mortar.

3.02 Mortar analysis and interpretation

Traditional mortars consist of a mixture of carbonated, and / or set hydraulic, lime and aggregate, with possible additional constituents such as clay, gypsum, cementitious materials and reinforcing fibres in the form of animal hair or other fibrous materials. Small quantities of other organic substances may also be present.

Mortars and their constituents can be analysed in a variety of ways ranging from formal laboratory procedures in accordance with British Standards documents BS 890, BS 6463 and EN 459, to visual and qualitative evaluation. The laboratory based tests are designed primarily for modern cementitious mortars but can, in some circumstances, provide useful backup in the evaluation of lime mortars. Other potential analysis methods include x-ray analysis techniques (to identify the presence of various elements and minerals); examination of thin and polished sections, and other visual and microscopic examinations; and simple acid dissolution and aggregate quantification. Methods can also be employed to identify, for example, traces of organic materials.

The main reasons for the analysis of historic, and other, mortars are

- to provide a reasonably accurate estimate of the original constituents and their relative proportions, in order that a matching or compatible mix can be identified,
- to aid the understanding of traditional methods of production and use of historic mortars,
- to enable comparisons to be made between various parts of a historic building as an aid to establishing the sequence of construction or alteration,
- to provide an accurate detailed record, for research or archive purposes, of the constituents of an historic mortar, and
- to investigate mortar constituents and curing in the event of problems being encountered with a new lime based mortar.

The methods of investigation chosen will normally relate to the reasons for analysis. In most instances, and particularly where the purpose of the analysis is to assist in the specification of a matching or compatible mix, it is common practice to start with a detailed visual evaluation and simple analysis through the dissolution of the lime binder using acid. This will provide information on the nature of the mortar and its probable original method of production; on the type of lime, or other binder, used; on the type and characteristics of the aggregate and on the relative proportions of the various constituents. Analysis using acid dissolution is a method that is particularly suited to the examination of Scottish mortars (Leslie & Gibbons 1999), which do not commonly contain limestone or shell aggregate.

For the purposes of identifying a compatible repair mortar, information on the type of lime, on the relative proportions of lime and aggregate and on probable production methods can form the basis of a specification, and information on the aggregate component of the mortar can be matched to information held in the database to identify a suitable, if possible, local, source of aggregate. In cases where a suitable local source is no longer available, a good match can commonly be found from elsewhere within Scotland.

Where unusual conditions are encountered or more detailed information is required the basic acid dissolution analysis can be supplemented by more complex and sophisticated analysis procedures.

The examination of mortars by use of thin section analysis is a relatively recent method. A thin section is a slice of mortar 0.03mm in thickness, commonly held together by a resin during cutting, which is examined using a petrological microscope with a magnification of up to 400. Thin section analysis can reveal details of mortar structure such as distribution of porosity, aggregate mineralogy and binder crystallisation which leads to a much deeper understanding of the processes operating during and after mortar application.

3.03 Specification of matching or compatible aggregate

Matching of aggregates used in historic mortars with modern commercially available materials (Figure 16a & 16b) is primarily a visual process. The comparison of profiles of the sand taken from a mortar during analysis and sands from likely quarries is a simple and efficient way of matching grading and colour. The selection of quarries for comparison can be made much easier by use of the database.

There is also a balance to be reached between finding the closest match from all of the sources in Scotland and further afield and reducing as much as possible the cost and inconvenience of transport. This balance is dependent on both the importance of economy and the need for an exact match. If necessary a number of aggregates can be recommended, including the closest

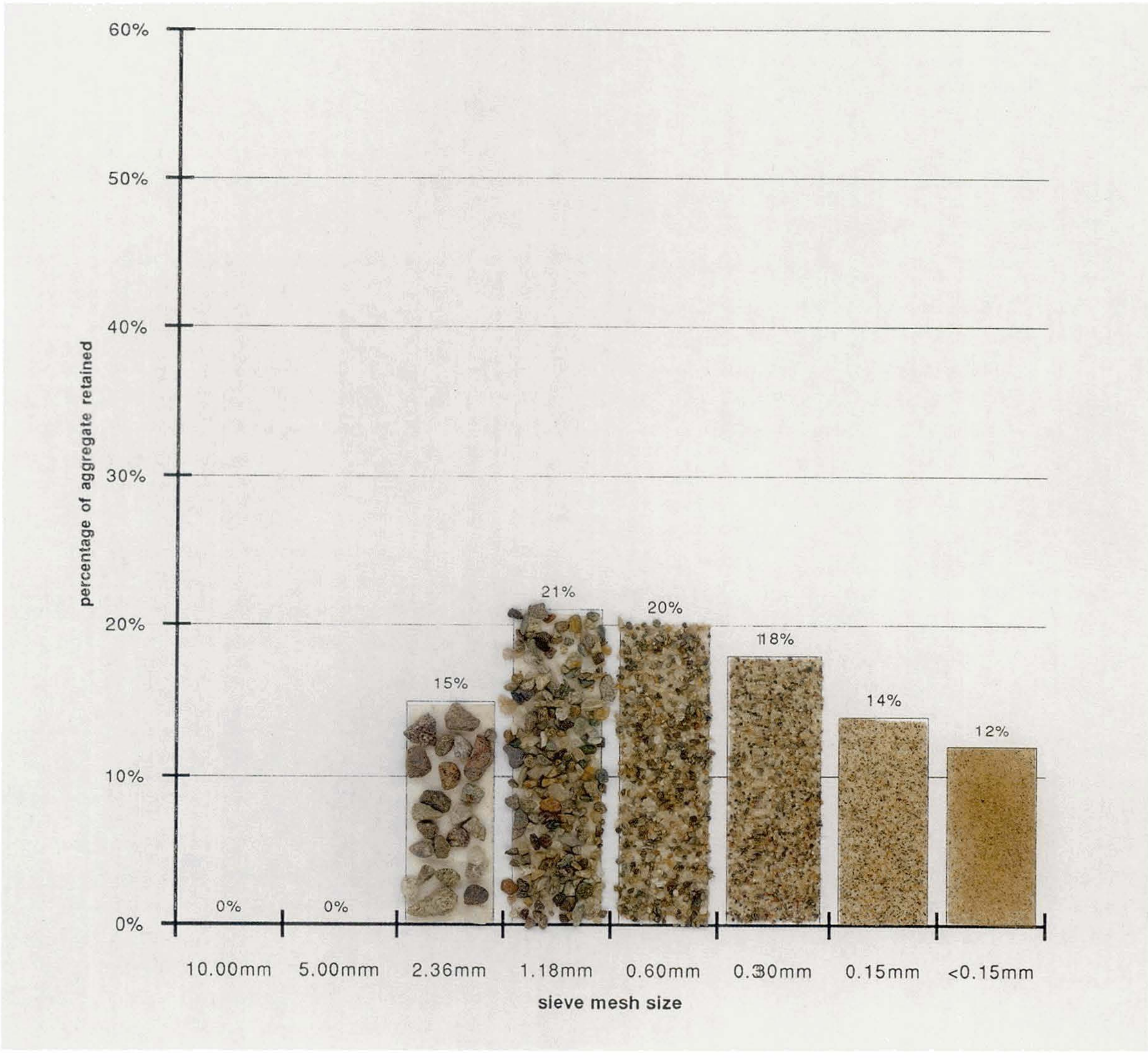


Figure 16a Aggregate matching using the sand profiles. Aggregate taken from mortar sample.

match and also a number of good matches from sources more local to the building needing repair.

In some circumstances the aggregate specified will not be the best match for that in the original mortar, but a good match which is more appropriate for the work to be carried out, bearing in mind modern building practices.

3.04 Specification of matching or compatible mortars

Once a matching aggregate has been identified, a specification for the replacement mortar is given if required. From analysis of the mortar sample, the hydraulicity of the lime can be estimated and a lime with similar properties specified in the replacement mix. If gypsum, hair or other materials are identified, the original amounts should be estimated and added to the mix specification.

Two calculations are required before a specification can be made. The weight of carbonated material (calcium carbonate) in the set mortar must be converted to the weight of original lime which was used when the mortar was mixed, whether putty, hydrate (both calcium hydroxide) or quicklime (calcium oxide). After this is done, the relative weights of each component of the mix can if necessary be converted to a ratio by volume, to allow for easy mixing on site. Further information is available in Historic Scotland Technical Advice Note 1.

As with recommendations for matching sand, mortar specifications may take account of modern building practices and for changes in the condition or function of a building since construction. They are not necessarily exact matches for the original mortar.

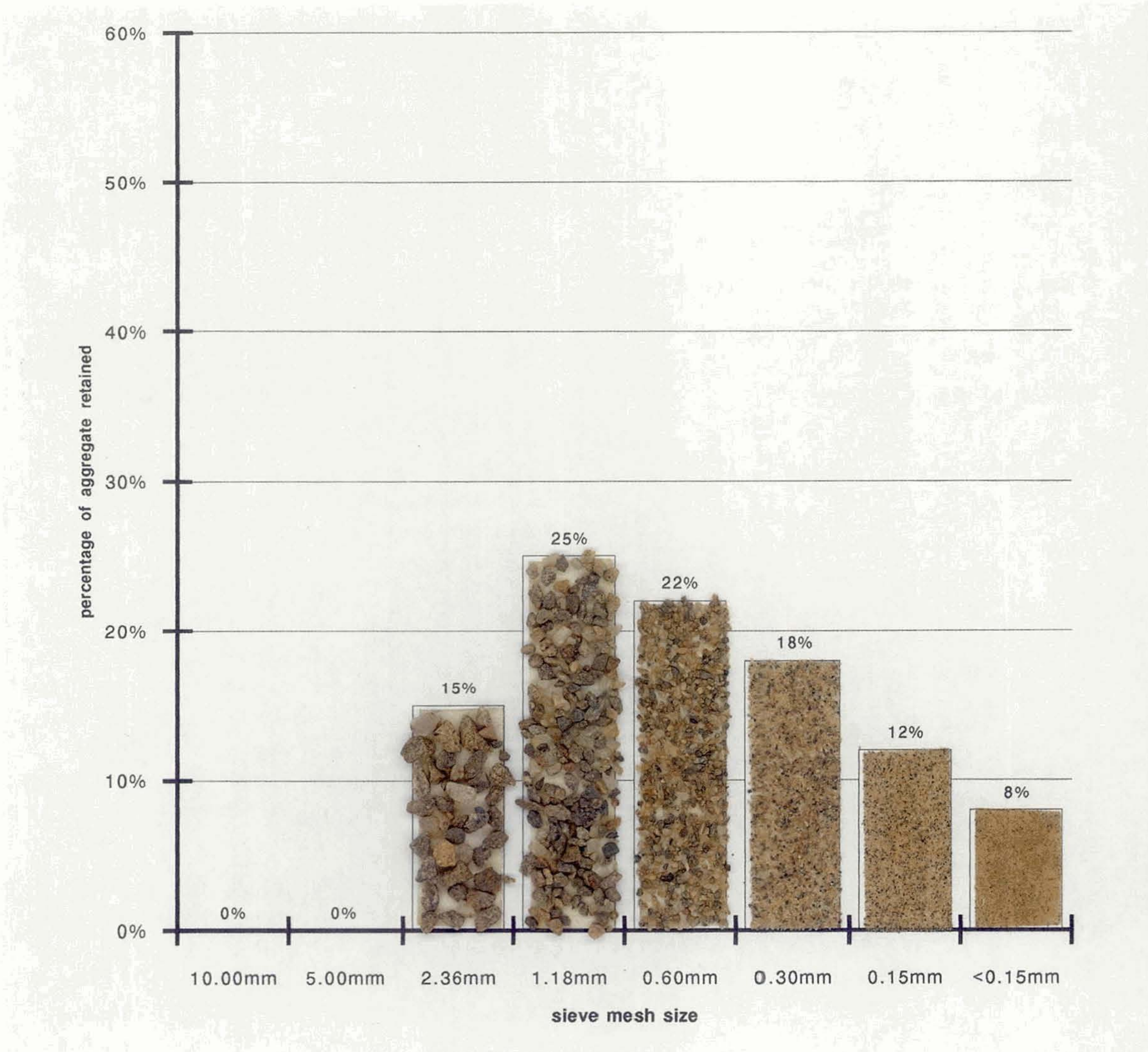


Figure 16b Aggregate matching using the sand profiles. Matching sand taken from database of aggregates.

4 SUMMARY OF INFORMATION ON SCOTTISH AGGREGATES

4.01 Introduction

This chapter contains information on aggregates of particular type which might be of use in specific projects. A list of aggregate types according to various characteristics such as colour and mineralogy and also suitable for specific construction jobs is given along with a discussion of unusual aggregate types and artificial materials which can be used in mortars.

This chapter is not intended to be a substitute for use of the database, which should be consulted where there is a need for matching of aggregates. The database contains more information than can be printed in a document, allows easy manipulation of the data and is by far the best means of matching aggregates.

If an aggregate is specifically mentioned in this chapter, the quarry and if necessary product name are given. Full quarry addresses, telephone numbers and details of products are found in Appendix A. In most cases individual quarries and products are not specified, since this document cannot be seen to show a preference for any one operator.

4.02 General aggregate characteristics

Aggregate grading and grain shape

Many of the sands in use in the construction industry are well graded. The natural processing of an aggregate by ice, water or wind leads towards a size range with a 'normal' distribution, although the range of sizes is variable. Thus the grading profile of a dune sand, formed by wind action, will have a good curve shape but will also be very fine grained and not necessarily suitable for all tasks. River and especially glacial aggregates can contain much more coarse grained material, and will commonly require to be processed to remove the larger grains.

Many coarse or concrete sands and some crushed rock products can be classified as well graded. Building and plaster sands may also have a good grading curve but are more fine grained with the majority of grains smaller than 1.0mm. The suitability of the grading curve is therefore dependent on the size range as defined by the type of work being carried out. A qualitative measure of grading is given in the database.

Grain shape is also assessed qualitatively but most natural aggregates contain a range of shapes and their average grain shape is intermediate (either sub angular or sub rounded). Although there are a small number of aggregates which contain very rounded quartz grains, most Scottish materials have an acceptable range of grain sizes and shapes.

Coloured aggregates

Most of the aggregates throughout Scotland have a brown colouration. The most common colours are brown, yellowish brown, olive brown and brownish grey. Colour names in this document are standardised by using the Munsell® Soil Color Charts (1994). There are regional variations in the strength of colour and shade and in many cases a particular area produces sands which have similar characteristics. Other than red aggregates, strongly coloured materials are not common in Scotland.

Red

Red coloured aggregates are relatively common in Scotland, in most cases associated with the presence of iron stained source rocks.

Red coloured sand and gravel deposits occur in three areas. Sands around the Firth of Tay are commonly red coloured, and the quarries at Wormit and Straiton supply strongly coloured products. The sands from Perth Wharf and Gowrie, both on the River Tay near Perth, have a less pronounced red colour. The Quarries at West Reston Mains, Kinegar and Longyester to the east of Edinburgh produce brown / red coloured sands. Near Dumfries and Carlisle a number of quarries produce red coloured sands, including Grange, Hallguards, Mid-Dargavel and Stepends Farm near Dumfries, and Cardewmires, Hardbanks and Lazonby Fell near Carlisle.

Red coloured crushed rocks are also relatively common, these are mostly crushed igneous rocks of composition similar to that of a granite. Red crushed igneous rocks are produced at Balmullo in Fife, Cloburn near Lanark, Daviot south of Inverness, Kemney near Aberdeen, Swinlees in Ayrshire, Tongland by Kirkudbright and Biddlestone in Northumberland. Crushed red sandstones are produced at Locharbriggs Quarry, Dumfries and Dunduff near Lesmahagow. A strongly red coloured aggregate is produced by Florence Mine in Cumbria from iron ore.

Other aggregates have a slight red colouration, in particular sands which are derived from granitic rocks. These sands derive their colour from pink feldspars and are commonly described as brown or pale brown rather than red, but they may still give a mortar a pink or red tint.

Yellow

There are no strongly yellow coloured aggregates currently produced in Scotland, although many sands in the northeast of Scotland have a pale brown colour.

Two yellow aggregates from the north east of England are available, both are produced from essentially the same geological source. Dunhouse and Sherburn quarries produce a fine-grained, quartz rich sand from a soft sandstone, the quartz grains being coated with a yellow iron stain in the same way as Dumfriesshire sandstones are coated with a red colouration.

Green

There are no green sand and gravel aggregates currently produced in Scotland. Some beach sands on the northwest coast are rich in minerals such as olivene and pyroxene and have a green colour but these are not commercially available. Many crushed rock aggregates derived from basic igneous rocks such as basalt have a green colouration, but the overall colour is very dark.

One sample of sand which has an olive green / yellow green colour is from the Double Arches Quarry in Bedfordshire. It is derived from soft sandstone (Cretaceous Lower Greensand) which is fine grained and composed of quartz and pellets of a green clay called glauconite. This sand is exploited in many quarries across the south east of England.

Black / grey

Igneous rocks which are basic (silica poor) in composition, including basalt, andesite or gabbro, are very dark grey or black in colour. Such rocks are exploited throughout Scotland, but are most common in the Midland Valley (Figure 1). Most of the quarries exploiting Lewisian gneiss which were sampled in this study produce a dark grey crushed rock.

In the Southern Uplands (Figure 1), basic igneous rocks and dark grey sandstones both give dark coloured crushed rock products. The sand and gravel deposits of parts of the Southern Uplands are also dark coloured, having large numbers of grey sandstone grains.

White

White coloured aggregates include shell sands, most silica sand products and some limestones. Most of the silica sands have a brown or yellow colouration (from iron staining) but are considered to be white for most building purposes. The sand from Lochaline Mine in Morvern is a very pure white. Some of the limestone products from Cults, Ledmore, Torlundy and Torrin quarries are white, and the shell sands from Barra (Traish Mhor beach) and Cornwall (calcified seaweed) are predominantly white. The crushed granite from Craignair Quarry near Dalbeattie is also white.

Aggregate mineralogy / lithology

Quartz-rich aggregates and rocks (including silica sands)

There are seven quarries producing silica sand in Scotland, and several more produce quartz rich aggregates which are not marketed specifically as silica sands. The aggregates defined as silica sand are mostly crushed from sandstone. Only one quarry, Lochaline Mine in Morvern, is producing a very pure, white silica sand. Of the other six quarries, five - Burrowine Moor, Devilla Forest, Gartverrie, Hullerhill and Levenseat - are producing from Carboniferous sandstone in the Midland Valley (Figure 1) and the sixth, Ivy Cottage on the Isle of Arran, is producing from a river sand.

Many of the silica sand quarries produce aggregates which are particularly fine grained and colourless and thus good for ashlar and fine joint work.

Cairds Hill Quarry near Keith and Fyvie Quarry north of Aberdeen produce a quartz rich aggregate from metamorphic rocks. The quarry at Douglasmuir north of Glasgow markets its products as quartz rich; although classed as a sand and gravel working, the quarry actually exploits quartz rich Carboniferous sandstone and conglomerate. Yellow and green coloured sands described above are also composed primarily of fine grained quartz. As well as green sands, some of the products from the Double Arches Quarry in Bedfordshire have an off-white colour.

These products have a quartz content of over ninety per cent. Many other aggregates in Scotland, in particular fine grained sands, are relatively quartz rich and have quartz contents of up to seventy per cent.

Sandstones (other than silica sand)

Twelve sandstone quarries were sampled in this project, although there are more than double this number in operation in Scotland. Many do not supply crushed rock products and are not relevant to this study.

A selection of quarries was chosen to reflect the range of sandstone types currently exploited.

Almost all of the quarries produce crushed rock products that could be utilised in mortars, although the fragments are commonly angular, possibly making the mortar difficult to work. The colour and character of the rock in each quarry is dependant on the rock type, thus quarries such as Cowieslinn, Coatsgate and Morrinton in the Southern Uplands supply grey, fine grained Ordovician or Silurian sandstones (greywacke). Dunduff near Lesmahagow and Spittal in Sutherland exploit a dark red coloured Devonian sandstone. The sandstone quarry on Skye is producing from a grey coloured Torridonian rock.

Limestones

There are currently thirteen quarries in Scotland which are marketing aggregates composed primarily of limestone (calcium carbonate). Of these, one (Cults Quarry in Fife) makes products from lime imported from Shap Quarry in Cumbria. The Blue Circle quarry at Dunbar only produces coarse aggregate for its own use in production of cement.

Limestone quarries can be subdivided on the basis of the type and age of limestone being exploited. The quarries at Dunbar, Middleton south of Edinburgh and Trearne near Paisley are exploiting sedimentary Carboniferous limestones of roughly the same age as the limestone historically quarried at Charlestown in Fife (Figure 7). These limestones are commonly light grey in colour and contain up to twenty per cent impurities (such as sand and clay).

The quarries at Boyne Bay near Banff, Parkmore at Dufftown, Sheirglas at Blair Atholl, Torlundy near Fort William, Ballygrant on the Isle of Islay and Calliburn at Campbeltown all exploit metamorphic Dalradian limestones which form a number of seams which can be followed from northeast to southwest across the country. The products range in colour from almost white to brown or grey, and contain a variable proportion of impurities.

Morefields and Ledbeg quarries near Ullapool and Torrin Quarry on Skye all mine the metamorphic Durness Limestone. This limestone is usually white or very pale coloured, and contain no more than five per cent impurities.

Tormitchell Quarry, near Girvan, exploits a calcareous siltstone which contains up to sixty per cent calcium carbonate. The quarry at Tongland near Kirkudbright produces a grey fine grained siltstone which contains twenty per cent calcium carbonate.

In England, the crushed limestone from Hartley Quarry in Cumbria has a pale pink colour.

Most of these quarries can supply a fine grained rock dust which can be used as aggregate in a mortar mix. Many of the products are very fine grained, however, and although they may aid the carbonation of a lime mortar they would not be suitable as the sole component of the aggregate.

Shell sands

Shell material can be used in a number of ways. Crushed shells can be used as an aggregate and whole shells as 'pinnings' to reduce the volume of mortar between stones and improve the stability of the masonry. Oyster shells in particular were popular as pinnings in masonry.

The beach at Traish Mhor on the Isle of Barra produced a crushed shell aggregate, but has recently stopped production.

One 'shell sand' from England is available from Scottish suppliers. It is termed a 'calcified seaweed', is produced in Cornwall and is available through the Middleton Quarry south of Edinburgh. This is a beach sand consisting of fifty per cent calcium carbonate and a quartz rich, granite derived aggregate.

Since there are no commercially available shell sands in Scotland the Scottish Lime Centre is evaluating the resources of waste shell material from the seafood industry. A number of companies produce relatively small amounts of waste shell and it is possible that some materials will be available in the future. Products might include oyster shells for pinnings, and crushed shell for use as an additive to aggregates.

Igneous rocks

As with sandstone quarries, a representative sample of roughly one third of Scottish igneous rock quarries was taken. The igneous rocks most commonly exploited in Scotland are granite - coarse grained, grey or pink in colour containing quartz and feldspar, and basalt or basic rocks - dark coloured and fine grained.

In general, granites are common in the Highlands of Scotland and to the west of Dumfries, a number of small granitic rock outcrops have been exploited in the Midland Valley, such as Broadlaw south of Edinburgh (not operational at present) and the red coloured, fine grained felsites of Cloburn near Lanark and Balmullo in Fife.

Most of the igneous rocks mined in the Midland Valley are basic in composition, either basalts or the slightly coarser grained dolerites. Powdered basic igneous rocks may be pozzolanic (see § 4.04).

Granite sands

Granite sands, sediments that are derived predominantly from granitic rock, are common in Aberdeenshire where there are a large number of granites exposed at the surface and providing material for weathering. Many of the sand and gravel deposits in Aberdeenshire and also to the west in Moray and north of Inverness are mostly granite derived.

Granite sands are commonly pale brown, and also have a pink colouration from the presence of feldspar. Coarse grains of feldspar can have a distinct effect on the appearance of a mortar.

Metamorphic rocks

The classification of metamorphic rocks is problematic in that the original rock type (before metamorphism took place) is often still identifiable. The metamorphic rocks which make up much of the Highlands of Scotland and the Outer Hebrides were originally sandstones, siltstones and igneous rocks (and also from limestones, which are described above). When examining sand sized grains, especially fine grained sands, the metamorphic character of the rock can sometimes be difficult to detect.

Crushed rock products of metamorphic origin range in composition from almost pure quartz at Cairds Hill near Keith to fine grained grey schists at Daviot south of Inverness. All of these are classified as metamorphic rocks of Dalradian age, and are commonly called schist. Metamorphic rocks in the Outer Hebrides are composed of Lewisian Gneiss which is variable in composition but commonly coarse grained. In metamorphic rocks of granitic composition the resulting crushed products can be very similar to granitic aggregates.

Sands which are predominantly derived from metamorphic rocks tend to occur in the west of the Highlands, where granites and granite sands are less common. Sands to the south of the Highlands in Callander, Perth, Forfar and Stonehaven also have a large proportion of metamorphic rock fragments since glacial action moved sediment from north to south. Sands which are particularly rich in metamorphic schist may be detrimental to mortar stability in some cases, see § 4.04.

4.03 Aggregates suitable for use in mortar for specific purposes

Introduction

As well as modern cementitious binders, various limes are available to the construction trade in Scotland. In most cases the form of lime (whether quicklime for a hot mix, dry hydrate or putty) and the hydraulicity of the lime to be used will be specified along with instructions for site practice.

As well as identifying the most appropriate type of lime to be used for the construction or repair, a good mix specification will also give details of the aggregate and any other component of the new mortar. Since mortars commonly consist of seventy five per cent aggregate the characteristics of the sand chosen can be critical to the performance of the mortar. Within the overall requirements set out in Chapter 2 more specific requirements can be identified in relation to mortars for specific uses.

More details of the requirements of lime mortars for specific purposes are given in Historic Scotland Technical Advice Note 1.

Mortar types

Unless otherwise stated, all of the binder (usually lime) : aggregate mix ratios are given by volume, with binder quantity given first.

Masonry construction (wall core)

Mortars for use in mass construction within the core of a rubble wall generally contain a high proportion of much larger aggregate than that found in jointing mortars. In some instances the nature of the wall core mortar in older construction may be closer to lime concrete (a wetter mix with coarse grained (>10mm) aggregate intended for filling larger volumes) than lime mortar. Provided the aggregate contains a good range of sizes the maximum size is only constrained by what is workable in any given situation. For repairs to ancient wall cores the full original range of aggregate sizes should be included. The use of larger aggregates has a similar effect to the use of 'pinnings', reducing the amount of lime binder required and minimising drying shrinkage.

Rubble pointing

For repointing of rubble masonry a well graded, coarse, sharp aggregate will normally be selected. The maximum size of the aggregate grains is normally not more than one third of the joint width. (For example joints of around 4.5mm wide would require a maximum aggregate size of approximately 1.5mm.) Aggregate of this nature will normally require a binder : aggregate ratio of around 1 : 3 to fill all voids and coat all aggregate particles, but exact ratios will vary with different aggregates. In wider joints, pinning stones should also be used to reduce the volume of mortar required. (Fig.17)

Figure 17 Repointing of a rubble wall. Note the use of pinning stones (to left of trowel).

Ashlar pointing

For the repointing of ashlar work the same principles apply but, clearly, the maximum aggregate size will be smaller. Fine grained, sharp or angular sands should be used in preference to soft (rounded) sands. The binder to aggregate ratio will normal require to be slightly higher (1 : 2.5) to retain workability in fine mortars. Where there may be a proportion of wider joints in an ashlar facade the basic mortar can sometimes be modified as required by the addition of a small proportion of slightly coarser sand, bringing the overall proportion back to 1 : 3. It is therefore sometimes recommended that a supply of matching, but slightly coarser, sand is kept on site for this purpose. If necessary a small quantity of lime putty can also be added to the basic mix to retain the overall proportions of the mortar.

The repointing of very fine ashlar joints can be difficult. Since these joints should never be widened a very fine mortar mix is required. Traditionally, mortar for finishing ashlar joints is based on a mixture of mature lime putty and a 'filler' of either whiting (crushed chalk) or very fine silica sand and a few drops of raw linseed oil. These mixes are normally made up by hand to suit the individual joints and finely crushed stone dust can be used as a filler if a slight colour is required. The ashlar putty should be of a stiff plastic consistency and the proportions of filler to lime are adjusted to achieve the appropriate workability. If desired a small quantity of hair can be incorporated to ease insertion into very fine joints.

Cast or thrown coatings (harling) (Fig.18)

The Historic Scotland Technical Advice Note 'Lime Harling and Rendering' should be consulted for further information on harling methods.

The mortar mix for traditional cast coatings in Scotland is almost always the similar to that for other construction operations, comprising a blend of lime binder and well graded, coarse, sharp aggregate in the proportion of around 1 part binder to 2.5 parts aggregate. Any variation from this would normally be towards a richer mix, possibly 1 : 2 or 1 : 1.5. The nature of the aggregate selected can have a marked influence on the appearance of the cast coating, and in matching harling for historic or traditional buildings the use of a local aggregate will frequently be found to give the best match. The distinctive texture of shell sands, as opposed to river sands, will be clearly visible in the finished work and the use of crude crushed rock aggregate, as found in modern wet dash cementitious coatings, can be particularly unfortunate. Traditional harling is applied in very thin coats, often no more than twice the thickness of the sand grains. Where the wall surface requires to be levelled up this must be done as a separate operation before application of the harling, using a coarse lime mortar with plenty of pinnings. Hair reinforcement may also be incorporated in this preparatory work.

The nature of the aggregate used in the harling mortar will affect the process of limewashing the harling; dense impervious rock, such as whin, will not readily accept limewash, which may weather off rapidly leaving a dark speckling to the surface. If, for any reason, the harling is not to be limewashed the colour of the aggregate will be particularly important in establishing the final colour of the harling.

Figure 18 Application of the final (thrown) coat of harl.

Trowel applied renders

Renders which are to be applied by trowel should normally be based on sharp, well graded sands to achieve a sound coating. There is sometimes a preference stated by the contractor for the use of rounder, less angular aggregates to improve spreading properties, but these aggregates do not provide such a sound mortar and are more likely to be prone to shrinkage cracking. Trowel-applied renders may incorporate hair reinforcement in all but the fine finishing coats. Like harling, renders should be applied over a previously levelled background, in thin coats. These coarse mortars can normally be worked to a flat, but slightly open textured, surface using a wood float. If a fine surface finish is required a fine grained, but still sharp, sand should be selected for the finishing coat, usually with a slightly higher proportion of lime.

Internal plaster

Preparation of the surface will normally be done in advance of plastering, by dubbing out in as coarse a lime mortar as possible with plenty of pinnings. Traditional lime plasters are based on well graded, coarse, sharp aggregates, normally incorporating hair in all but the final finishing coat. Where a fine close surface is required to the plaster it may be finished by the application of a very thin (up to 3mm in two passes or applications) coat of 'setting stuff'; i.e. a mix of mature lime putty and very fine sand, such as a silica sand of less than 0.3mm, in the proportions of 2 or 3 parts lime : 1 part sand.

Lime concrete

Like modern portland cement concrete, lime concrete (for work such as foundations and floor screeds) contains a wide range of aggregate sizes from fines to very coarse material. Most lime concretes rely for their set on a hydraulic or pozzolanic reaction and this was sometimes obtained through the use of pozzolanic aggregates, as well as through the use of hydraulic lime or of pozzolanic additives. The use of broken brick as an aggregate is common, both in Roman construction and in more recent local work such as C19 concrete. A mix of lime and gypsum is also found in concrete floors.

New construction work

Mortar mixes for new construction, or for reconstruction, are basically the same as for repair works. In new work, especially when laying masonry blocks or bricks, the mortar will be used somewhat wetter than for repointing. It will also often be possible to use a slightly larger aggregate in relation to the joint width.

4.04 Special aggregate types

Naturally occurring pozzolanic aggregates

Pozzolanic aggregates contain a substance or substances which can react with lime to form calcium aluminosilicates, thus giving the mortar a chemical set, similar to that of hydraulic limes or cements, which can be beneficial where conditions are damp and a rapid set is required. A number of substances present in natural aggregates are considered to be pozzolanic.

Sands with particles of coal or high clay content are commonly thought to have pozzolanic properties, as are some rock types which contain ferromagnesian minerals (mineral types which contain iron, magnesium and aluminium and therefore proportionately less silica). Thus sands containing grains of muddy sedimentary rocks like greywackes, basic igneous rock such as basalt and dolerite, and metamorphic rocks with large amounts of mica (mica schists) may have some pozzolanic set to them. This pozzolanic effect, if it does exist, is not easily measurable since the proportion of reactive material will be very small. Furthermore, mica or coal in an aggregate may in some circumstances be detrimental to mortar strength.

Whether any Scottish natural aggregate has sufficient pozzolanic material to effect the set of a mortar is questionable. Several sands with high clay or mud content have been observed, or reported, to promote a rapid set in mortar, but the process has not been studied and the scientific measurement of a small amount of pozzolanic reactivity is difficult. Pozzolanic reactivity can also be enhanced by using 'hot lime' mixes, ie mixing quicklime and aggregate with water to create a mortar. Crushed basic igneous rock, if very fine grained, has a measurable pozzolanicity and may have potential as a mortar additive.

Coal is common in sand and gravel quarries lying in the area between Glasgow, Stirling and Edinburgh and several sands contain up to fifteen per cent coal. The silica sand works at Burrowine Moor, Devilla Forest and Levenseat produce aggregate containing no more than five per cent coal.

While pozzolanic constituents in a mortar are commonly thought to be beneficial, there are also problems associated with the materials. Coal can sometimes cause expansion in a mortar, and in some cases fragments of coal can move to the surface of a mortar and give rise to 'pitting'. In a similar way clays are not normally regarded as beneficial to a mortar since they can lead to poor adhesion to a surface and to excessive shrinkage, although it is possible that, in a 'hot lime mortar', a low level of pozzolanic activity might be produced by the incorporation of a small quantity of clay. The presence of large numbers of fragments of muddy sandstone (greywacke) may be associated with shrinkage problems in some mortars. In general a knowledge of potentially pozzolanic aggregates can assist with the interpretation of old mortars, but their use in new work requires further investigation.

Natural aggregates which have been exploited in the past for their pozzolanic content exist in Scotland in various parts of the Midland Valley. Volcanic ashes and earths derived from volcanic rocks (commonly known as trass in Germany) are known to exist in small deposits but are not worked at present. Similar deposits in Italy were exploited in ancient times near the village of Pozzuoli, which is the origin for the term pozzolan.

Mica rich aggregates

Aggregates which are rich in fragments of the metamorphic rock schist or the igneous rock granite are common in the north and west of Scotland. Schist and granite outcrop throughout the Highlands and commonly contains large amounts of the mineral group mica. These minerals have a sheet-like structure and are susceptible to alteration when in contact with water. This can cause expansion of the rock fragments and in some cases this may lead to fracturing of the mortar. This effect is known to have occurred in a few cases, but many mortars made with schistose aggregate have been successful. There is a need for some research into the stability of mortars made with aggregates of various types.

Mica in aggregates is known to have caused problems in concretes by reducing the overall strength of the mix and a maximum mica content of one per cent has been suggested (Smith & Collis, 1993). Whether this reduction in strength also occurs in lime based mortars is not known. In some cases the mica content of sands derived from granites and schists is close to ten per cent and there is no recorded evidence that such sands have caused a deterioration of lime mortars.

Man-made aggregates, admixtures & other additives

Additives to mortars either take the form of pozzolans, which encourage a chemical set, or particulate porous materials (air entrainers), which increase the frost resistance.

Pozzolanic additives are generally very fine grained, since the grain size is an important control on reactivity. The more fine grained a potential pozzolan is, the more reactive surface area and the greater the pozzolanic set.

Air entrainers, by contrast, require grains sufficiently large to have a porous structure which will retain air during mixing and setting of the mortar.

In general, an additive (either pozzolan or air entrainer), where used, should make up around one third of the aggregate volume.

As with powdered lime, care must be taken not to inhale fine grained materials such as high temperature insulation powder and masks should be worn if appropriate.

Brick dust & crushed brick

Crushed brick acts as both a pozzolan and, if not crushed too finely, an air entrainer when added to a mortar. A large number of old mortar samples contain fragments of crushed brick which were presumably recycled from construction spoils. A lightly fired (up to 800°C) brick is considered the best additive since materials fired at higher temperatures tend to lose their pozzlanic properties.

Crushed tile

Crushed clay tiles can have the same properties as crushed brick products and can be added to mortars in the same way. Although tiles were probably used as often as brick in Scotland, the differentiation between tile and brick fragments in a historic mortar sample is very difficult.

Clay powders

A number of fine grained powders composed of processed clay are available which can be used as pozzolanic admixtures. These powders are extremely fine grained and consequently have a high reactivity.

Pelleted clay

Clay which has been formed into pellets and baked at low temperatures has been used recently as a low density, air entraining artificial aggregate in concrete. These clay pellets have a very high porosity (eighty per cent), and could potentially be used in lime based mortars, with the additional benefit of being pozzolanic if a proportion of the material is crushed to form fine powder.

Burnt coal / pulverised fuel ash / furnace slag

Burnt coal or wood is very common in historic mortars, having been incorporated into the lime during the burning process. Ashes from these fuels, if they become incorporated in the mortar, can have a pozzolanic effect. Lime ash, the mixture of fuel ash and fine grained quicklime from the kiln floor, was valued as a flooring material. Modern limes are much 'cleaner' and do not commonly contain ash or fragments of the original fuel.

Other fuel ashes have been added to mortars to give a pozzolanic set, usually in industrial settings where the material is readily available.

Modern pulverised fuel ash (PFA) from coal-powered power stations is available for use as a pozzolan. PFA should be used with caution in lime mortars as it can induce a very hard set.

HTI (high temperature insulation) powder

HTI powder is a burnt fireclay that has been recommended as an artificial admixture giving a pozzolanic set to a mortar. It is now largely superseded by purpose made pozzolans.

Air entraining additives

As well as brick and tile, air entrainers can include soap based substances and detergents. Other resinous materials may result in impervious mortars and should therefore be used with caution. Substances such as beer and urine have been used in the past, but there is no record of their effectiveness.

Crushed recycled mortar

One of the best additives to incorporate into conservation work is the crushed original mortar (assuming it is basically sound) from the building under repair. This material will contribute to the continuity of the nature and appearance of the building, in particular when patching repairs are taking place. Provided sufficient binder is used to contain the lightly crushed mortar, this aggregate is likely to produce an excellent new mortar.

Recycling of old mortar is also environmentally beneficial and illustrates the reusable nature of lime based materials.

Hair and fibres

Animal hair can be used both to improve the tensile strength of a mortar and to reduce shrinkage in renders, harling and plasters. Goat hair is widely available, and other hair types (bovine, horse body) are also suitable. Very 'springy' hair, such as that from horse tails and pigs, is not considered suitable for use in plasters.

Pigments

Pigments are not commonly used in traditional mortars, whose colour is derived from the aggregate and the type of lime used. Pigments can make a mortar difficult to work and need to be thoroughly mixed to avoid unsightly colour differences. Pigments are more commonly added to limewash coatings.

APPENDIX A: LIST OF QUARRIES

The following is an alphabetical list of all of the quarries which have been visited or from which samples have been provided during the survey. Information is given on quarry name, address, status, operator, commodity type or types, product type or types and Council Authority area. If there is no telephone number listed for a quarry, one is given for the operator. Additional information, for instance if a quarry is franchised and the products sold at another site, is given in brackets. Where known, the National Grid Reference is given to the nearest square 100m. An approximate indication of quarry locations is given in Fig.19.

If a quarry name is given in italics, then the status of the site is uncertain. It may either have closed down, have been mothballed, be open only intermittently or be in the process of closing down. If products are not commercially available then they are described as such.

If a quarry name is underlined, then it is known to have closed since sampling took place. The sample information is retained since it is possible that quarries will be reopened in the future, or that small samples of aggregate may be available for important conservation work.

If a quarry operator is given in italics, then the ownership of the site is uncertain. A question mark indicates that the ownership is not known.

Five sites where material was sampled for Scottish Lime Centre purposes were included in the original list of quarries. The sands sampled are not commercially available and the numbers Q186, Q192, Q200, Q201 and Q211 are not, therefore, included in this list.

This listing is, as far as possible, correct as of the time of writing. Much of the information has been taken from the British Geological Survey Directory of Mines and Quarries, published in 1994. The British Geological Survey is at present collating data for a new Directory, to be published in 1999. As far as possible these revised data have been incorporated into this publication. In some cases unopened quarry sites with permission for future aggregate extraction have been included in the list, since opening is likely within the next twelve months. It has not been possible, however, to check all of the details of operators, phone numbers, etc.

Rock types can be subdivided into sedimentary, igneous and metamorphic categories. In this report, the sedimentary rocks are further subdivided according to composition, following the British Geological Survey classification. Silica sands are commonly produced from quartz rich sandstones. Similar materials can also be produced from metamorphosed sandstones (quartzites)

Key

Quarry commodity types are identified by the following letters:

I	Igneous rock types such as granite or basalt.
M	Metamorphic rocks, such as schist or gneiss.
L	Limestones including dolomitic limestone.
S	Sandstones.
S & G	Sand and gravel deposits, whether a deposit of glacial, river, beach or wind action.
SS	Silica sands, either produced from sandstones or from sand and gravel.

Quarry product types are identified by the following letters:

as	asphalt sand.
ps	plaster sand (including products known as fine sand).
bs	building sand.
cs	concrete sand (including sharp sand, rough sand).
as-dug	material dug on site and unprocessed, includes 'unwashed' products.
dune sand	wind blown sand, usually as dug but fine grained (plaster or building sand) in size, commonly with some shell material.
grit	grit.
gravel	gravel.

shell sand aggregate marketed specifically as shell sand, not simply sand containing shell material.

d dust (rock dust, rock fines).

cr crushed rock.

(6)mm aggregates specified by the size (e.g. 4 - 2mm), these also commonly have a description such as gravel, crushed rock, etc.

(The two classifications grit and gravel are, for the purposes of defining quarry products, more or less interchangeable.)

For each quarry products are, in most cases, listed with the finer grained materials first. Unusual product names, such as tile sand or filler dust, are given in full.

The quarries at Burrowine Moor in Fife, Double Arches in Bedfordshire, Hullerhill in North Ayrshire and Levenseat in West Lothian produce aggregates which are identified with a number or code. The names given for products from these quarries in this list are the equivalent terms used above.

These classifications are not exclusive, and it is obvious that some terms (grit, gravel, 5mm, crushed rock, etc.) can refer to the same material. It is also apparent that rock dust (d) and crushed rock (cr) will in many cases describe the same product. The name given for a product is, therefore, that used by the quarry when sampling took place. In some instances, the terms fine, coarse, sharp and rough sand have been replaced by building or concrete sand as appropriate to give some internal consistency to the classifications. The terms washed or screened, common prefixes to sand names, are not included in the list.

List of quarries: (details correct at October 1999)

Quarry name, address, telephone number and grid reference	Commodity	Products	Local Authority	Operator
Alturlie Quarry, Declares, Inverness. (Q189) NH 714 491 (open irregularly; supplied from other CQP sites)	S & G	bs.	Highland	Caledonian Quarry Products
Annfield Quarry, Leuchlands, Murcar, Aberdeen. (01358 742793) (Q134) NJ 930 144	S & G	cs, coarse s.	Aberdeen City	Bardon Aggregates
Annieston Quarry, Thankerton, Biggar, ML12 6NJ. (01899 308372) (Q035) NS 979 372	S & G	ps, bs, 5 mm.	South Lanarkshire	Tinto Sand & Gravel
Arbrack Quarry, Whithorn. (01988 500417) (Q193) NX 451 373	S & G	cs, rough cs, gravel.	Dumfries & Galloway	McMiken, J
Arndean Quarry, Brackletter, Spean Bridge, PH34 4DX. (0139781 751) (Q086) NN 191 828	S & G	grit.	Highland	Caledonian Quarry Products
Arnhall Quarry, Edzell. (Q007) NO 608 696 (01561 361265)	S & G	bs, cs.	Aberdeenshire	Bruce
Askernish Quarry, Lochboisdale, South Uist. (01878 44571) (Q146) NF 747 237	M	dust.	Western Isles	Askernish Quarry Co Ltd
Auchterforfar Quarry, Forfar. (Q222) NO 476 501 (Not opening until end 1998)	S & G	as dug.	Angus	Laird Brothers (Forfar) Ltd (01307 466577)
Auchtertyre Quarry, Elgin. (01343 544702) (Q016) NJ 178 585	S & G	(bs), cs.	Moray	Caledonian Quarry Products
Avondale Quarry, Polmont, Falkirk. (Q103) (01324 714477) NG 958 788	S & G	bs, cs, 6 - 3 mm.	Falkirk	Golday Ltd. (Manchester)
Balblair Quarry, Beauly, Inverness, IV4 7BG. (Q069) NH 512 446	S & G	bs, cs.	Highland	Bardon Aggregates (01463 782345)
Balelone Quarry, Balmartin, North Uist. (Q148) NF 723 739 (as dug, dune sand)	S & G	dune sand.	Western Isles	Macauley, Norman
Ballaharra Quarry, Peel, Isle of Man. (Q229) SC 264 824	S & G	bank s.	Isle of Man	Corlett, NR (01624 842200)
Balloch Bridge Quarry, Creetown. (Q219) NX 488 587	S & G	as dug.	Dumfries & Galloway	Scott Plant Hire (01671 402038)
Ballygrant Quarry, Ballygrant, Islay. (Q183) NR 395 661	L	d, cr.	Argyll & Bute	Dunlossit Trustees Ltd (01496 840664)
Balmullo Quarry, Quarry Road, Balmullo, Leuchars, KY16 0BH. (01334 870208) (Q095) NO 419 214	I	grit, 5 mm - dust.	Fife	Hewden Quarries Ltd
Balnapolaig Quarry, Dornoch. (Q157) NH 785 905	S & G	cs.	Highland	Mackay, Alistair (01862 810459)

Quarry name, address, telephone number and grid reference	Commodity	Products	Local Authority	Operator
Bu Links Quarry, Valhalla, Burray. (01856 731238) (Q197) KY 485 970	S & G	bs.	Orkney	Dass, JR
Burnside of Marlee Quarry, Blairgowrie. (Q223) NO 155 435 (not opening until late 1998)	S & G	as dug.	Perth & Kinross	Laird Brothers (Forfar) Ltd (01307 466577)
Burrowine Moor Quarry, Bogside, near Alloa, FK10 3QP. (01259 731379) (Q003) NS 966 901	SS	ps, bs, cs, coarse sand.	Fife	Fife Silica Sands
Cairds Hill Quarry, Blackhillock, Keith. (01542 882273) (Q015) NJ 443 479	M	d, 2 - 4 mm.	Moray	Caledonian Quarry Products
Cairnmuir Quarry, Memsie, Fraserburgh, AB4 4AR. (01346 541341) (Q169) NJ 980 620	S & G	bs, cs, crusher dust.	Aberdeenshire	RMC
Caistron Quarry, Hepple, Rothbury, NE65 7LG. (Q206) NU 002 014	S & G	cs.	Northumberland	Ryton Gravel Co (0191 232 9678)
Calcified Seaweed. Cornish Calcified Seaweed Co., Newham, Truro. (Q209) Grid ref unknown. (supplied by Company	S & G	shell sand.	Cornwall	Cornish Calcified Seaweed
Middleton Quarry, near Edinburgh, 01875 820339)				
Calliburn Quarry, Campbeltown. (Q181) NR 714 252	L	cr.	Argyll & Bute	MacFayden (01586 552962)
Cambusbeg Quarry, Doune Road, Callander, Perth, FK17 8LJ. (01877 331104) (Q029) NN 667 047	S & G	cs, 6 mm.	Stirling	Bardon Aggregates
Cambusmore Quarry, Callander, Perth, FK17 8LJ. (01877 330304) (Q073) NN 645 055	S & G	cs, tile sand, grit.	Stirling	Russell Quarry Products
Cammie Wood Quarry, Strachur, Banchory AB31 5JU. (01330 824099) (Q063) NO 692 919	S & G	bs, cs.	Aberdeenshire	Taylor, IR
Caplich Quarry, Alness, IV17 0SS. (01349 882377) (Q060) NH 667 706	S & G	ps, bs, cs.	Highland	Munro, P
Capo Quarry, Northwaterbridge, Laurencekirk, AB3 1RQ. (01674 840278) (Q121) NO 631 670	S & G	bs, cs, 6 mm, grit.	Aberdeenshire	Tilcon
Cardewmires Quarry, Cardewlees, Dalston, Carlisle, CA5 6AF. (01228 710412) (Q204) NY 347 509	S & G	cs, 6 mm.	Cumbria	Tilcon
Carnish Quarry, Carnish, Uig, Isle of Lewis. (01851 672326). (as dug). (Q072) NB 033 312	S & G	cs.	Western Isles	Maciver, A
Carstairs Quarry, Conford Bridge, Cleghorn, Carstairs, ML11 8SA. (01555 870207) (Q037) NS 961 469	S & G	bs, cs.	South Lanarkshire	Tarmac Quarry Products
Castle Farm Quarry, Kintore. (Q129) NH 782 153 (closed? very small, 2 colours as dug samples taken)	S & G	as dug.	Aberdeenshire	Allan, M
Caysbriggs Quarry, Lossiemouth. (01343 813449) (Q014) NJ 248 671	S & G	ps, bs.	Moray	Caledonian Quarry Products

Quarry name, address, telephone number and grid reference	Commodity	Products	Local Authority	Operator
Cruiks Quarry, Cruiksness Road, Inverkeithing, KY11 1HH. (01383 413241) (Q100) NT 133 817	I	d, 6 mm.	Fife	Tilcon
Dalmore Quarry, Westerdale, near Wick. (01847 841221) (Q156) ND 156 475 (also known as Dirlot Quarry)	S & G	bs.	Highland	Gunns (Lybster)
Daviot Quarry, Daviot, Inverness, IV1 2XR. (01463 772210) (Q017) NH 719 392 (building sand comes from Morayhill Quarry)	I + S & G	(bs), cs, cr (red), cr (grey).	Highland	Tarmac Quarry Products
Devilla Forest Quarry, Bogside Station, Alloa, FK10 2QE. (01259 30621) (Q078) NS 975 913	SS	bs.	Fife	UG Sand Developments Ltd
Dhurrie Quarry, Campeltown. (Q180) NR 684 224	S & G	cs, as dug.	Argyll & Bute	MacFayden (01586 552962)
Double Arches Quarry, Eastern Way, Heath and Reach, Leighton Buzzard, LU7 9LF. (01525 237056) (Q202) Grid ref unknown.	S & G	5 fine sands.	Bedfordshire	Hepworths Minerals & Chemicals
Douglasmuir Quarry, Milngavie, Glasgow, G62 7HT (0141 554 1818 or 956 4511) (Q066) NS 525 747	S & G (SS)	bs, cs, 4 - 7 mm.	East Dunbartonshire	Tilcon
Drimore Quarry, Creogarry, South Uist. (Q147) NF 762 401 (as dug, dune sand)	S & G	as dug.	Western Isles	Macaskill, ND
Drumbeg Quarry, Gartness Road, Drymen. (01360 660423) (Q137) NS 479 878	S & G	as, bs, cs, pit sand.	Stirling	Caulfield, P & Co Ltd
Drumsleed Quarry, near Stonehaven. (Q122) NO 732 776 (as dug ?concrete sand? sampled)	S & G	cs.	Aberdeenshire	*Smith, C and S*
Dunbar Northwest Quarry, Dunbar, East Lothian, EH42 1SL. (01368 863371) (Q108) NT 705 770 (only coarse-grained crushed rock, no fines)	L	coarse cr.	East Lothian	Blue Circle
Dunduff Quarry, Blackwood, Kirkmuirhill. (01555 893000) (Q119) NS 779 410	S	4 mm - dust, 6 mm.	South Lanarkshire	Patersons
Dunhouse "Quarry", Tyne and Wear? (Q083) Grid ref unknown. (crushed yellow sandstone, from several quarries)	S	bs.	Tyne & Wear	Dunhouse Quarry Co Ltd (01833 660208)
Dunragit Quarry, Droughduit, Dunragit, Stranraer, DG9 8QA. (01581 400248) (Q220) NX 153 567 (sand from Balgracie Farm and Little Pinminnock quarries)	S & G	bs, cs.	Dumfries & Galloway	Luce Bay Plant Hire (01581 400248)
Duntilland Quarry, Kirk of Shotts. (0169 870811) (Q028) NS 845 634	I	cr, 6 mm.	North Lanarkshire	Bardon Aggregates
Dyke Farm Quarry, Beattock. (Q216) NT 088 039	S & G	cs, grit.	Dumfries & Galloway	Miller Civil Engineering Ltd (0131 315 6000)
Easter Middleton Quarry, Gorebridge. (0131 315 3505) (Q048) NT 364 584	S & G	bs, 5 mm.	Mid Lothian	Russell Quarry Products
Eckford Quarry, Morebattle Road, Eckford, Jedburgh. (01835 850342) (Q046) NT 731 265	S & G	bs, cs, concrete mix.	Scottish Borders	Tilcon

Quarry name, address, telephone number and grid reference	Commodity	Products	Local Authority	Operator
Hardbanks Quarry, Howmill, Carlisle, CA4 9LL. (01228 70346) (Q205) NY 515 567 (closing soon, nearby Faugh Quarry to supply similar products)	S & G	bs, cs.	Cumbria	ARC - Northern
Hartley Quarry, Kirkby Steven, CA 17 4JT. (017683 714479) (Q210) Grid ref unknown.	L	3 mm - dust.	Cumbria	RMC
Heathfield Quarry, Invergordon. (01349 853071) (Q061) NH 707 728	S & G	bs, cs, as dug (unsorted).	Highland	Invergordon Sand & Gravel
Hill of Dens Quarry, Longside, Peterhead. (Q164) NK 077 422	S & G	weathered granite.	Aberdeenshire	Bruce Plant (01561 361265)
Hillhead Quarry, Murcar, Aberdeen. (Q133) NJ 937 135	S & G	bs, cs.	Aberdeen City	Leith Transport (01224 484198)
Hillwood Quarry, Ratho, Edinburgh, EH28 8LU. (0131 333 4735) (Q039) NT 129 719	I	d, screened fines, reclaimed filler.	City of Edinburgh	Tarmac Quarry Products
Horgabost Quarry, South Harris. (Q149) NG 047 971 (as dug, dune sand)	S & G	dune sand.	Western Isles	Mackay, John (01859 550214)
Hullerhill Quarry, Kilwinning, KA13 7QN. (01294 557515) (Q116) NS 330 452	SS	ps, bs, fine sand.	North Ayrshire	King, Hugh
Hullerhill (dune sand) Quarry, Kilwinning. (Q117) Grid ref unknown. (dune sands taken locally, supplied from Hullerhill)	S & G	washed dune sand, coarse dune sand.	North Ayrshire	King, Hugh (01294 557515)
Hyndford Quarry, Hyndford Bridge, Lanark. (01555 663597) (Q024) NS 903 418	S & G	bs.	South Lanarkshire	Russell Quarry Products
Inchbelly Quarry, Kilsyth Road, Kirkintilloch, G31 3AX. (Q068) NS 639 375 (sample collected at depot in Glasgow)	S & G	cs.	East Dunbartonshire	Tilcon (0141 554 1818)
Invershin (or Inveran) Quarry, Invershin by Lairg, IV27 4EY. (01549 421244) (Q020) NH 583 944	S & G	bs, cs, d, 6 mm.	Highland	Caledonian Quarry Products
Islay Beach Quarry. The Strand, Airport, Islay. (Q184) Grid ref unknown. (sample collected at Ballygrant)	S & G	dune sand, as dug.	Argyll & Bute	?
Islay Machair Quarry, Bridgend, Islay. (Q212) Grid ref unknown.	S & G	as dug.	Argyll & Bute	?
Ivy Cottage Quarry, Brodick, Isle of Arran, KA27 8AX. (Q187) NS 008 373 (Sand also stockpiled on Brodick Beach)	SS	bs, cs.	North Ayrshire	Filtration Supplies & Services Ltd (01770 302121)
Kemney Quarry, Kemney, Inverurie. (01467 43861) (Q131) NJ 737 170 (granite from Corrennie Quarry, crushed at Kemney)	I	cr (red), cr (grey).	Aberdeenshire	Bardon Aggregates
Kettlestoun Mains Quarry, Linlithgow. (Q226) NS 982 766 (not opening until 1998)	S & G		West Lothian	RMC (01786 834055)

Quarry name, address, telephone number and grid reference	Commodity	Products	Local Authority	Operator
Lochhills Quarry, Parkhill, Dyce. (01224 722864) (Q009) NJ 912 145	S & G	bs, cs.	Aberdeenshire	Joss (Aberdeen) Ltd
Lochinvar Quarry, Lochinvar, Elgin. (01343 550946) (Q013) NJ 183 610	S & G	fine s, bs, cs, grit.	Moray	Caledonian Quarry Products
Logie Quarry, Kildary, near Invergordon. (01862 842228) (Q018) NH 774 757	S & G	bs, cs.	Highland	Caledonian Quarry Products
Lomond Quarry, Lomond Hill Road, Leslie, Fife. (01592 741590) (Q098) NO 251 023	S & G	bs, cs, grit.	Fife	Skene Group Construction
Longyester Quarry, Gifford. (01620 81446) (Q031) NT 534 641	S & G	bs, cs, 10 mm.	East Lothian	Bardon Aggregates
Loudonhill Quarry, Strathaven Road, Darvel, KA17 0LY. (01560 320326) (Q050) NS 607 372	S & G	bs, cs, 5 mm.	East Ayrshire	Tilcon
Low Hedgeley Quarry, Powburn. (Q207) NU 061 173	S & G	bs, cs.	Northumberland	Ryton Gravel Co (0191 232 9678)
Lynemore Quarry, Dufftown. (Q178) NJ 294 368	S & G	bs, cs.	Moray	Leith Transport (01224 876333)
Market Hill Quarry, Kimmeridge, Fort Augustus, PH32 4AH. (01320 6360) (Q085) NO 528 341	S & G	bs, cs, grit.	Highland	Clerk, Brian
Marybank Quarry, Stornoway, Isle of Lewis. (01851 703227) (Q151) NB 407 330	M	d.	Western Isles	John Fyfe
Melsetter Beach, Melsetter, Hoy, Orkney. (Q080) Grid ref unknown.	S & G	bs.	Orkney	(MJ Collop) (01856 791396)
Melville Gates Quarry, Ladybank, Cupar, KY7 7RF. (01337 830303) (Q004) NO 308 125	S & G	bs, cs.	Fife	Angle Park Sand & Gravel
Mid-Dargavel (or Nether Dargavel) Quarry, Lockerbie Road, Dumfries, DG1 3PG. (01387 255469) (Q032) NY 020 765	S & G	bs.	Dumfries & Galloway	Currie
Mid-Lairgs Quarry, Daviot, Inverness. (01463 772211) (Q120) NH 713 365	S & G	bs, cs.	Highland	Ross, Alex
Mid Sannox Quarry, Sannox, Isle of Arran. (Q228) NR 008 455	S & G	bs, cs.	North Ayrshire	J..Thomson Construction Ltd (01770 660205)
Middleton Quarry, Middleton Lime Works, Middleton. (01875 820339) (Q109) NT 355 580	L	d, 3 mm - dust, 5 mm - dust.	Mid Lothian	Reid, James & Co.
Mill of Dyce Quarry, Dyce, Aberdeen, AB2 0HA. (01224 722855) (Q136) NJ 873 150	S & G	bs, cs, grit.	Aberdeen City	Bardon Aggregates
Millnain Quarry, Strathpeffer. (Q159) NH 505 590 (small quarry, closed?)	S & G	bs, as dug.	Highland	*Stewart, Kenneth* (01997 421333)

Quarry name, address, telephone number and grid reference	Commodity	Products	Local Authority	Operator
Ravelrig Quarry, Kirknewton, EH27 8EF. (0131 440 4477 or 449 5523) (Q040) NT 142 670	I	d, 6 mm.	West Lothian	Tarmac Quarry Products
Rossie Quarry, Bridge of Earn, PH2 9HR. (01738 812905) (Q074) NO 088 188	S & G	bs, cs.	Perth & Kinross	Skene Group Construction
Rothes Glen Quarry, Rothes. (01340 831700) (Q176) NJ 254 528	S & G	cs, harl chips.	Moray	Speyside Sand & Gravel
Savoch Quarry, Longside, Peterhead. (Q166) NK 065 425	I + (S & G?)	cs.	Aberdeenshire	Connon, JH
Sconser Quarry, Sconser, Isle of Skye. (Q143) NG 549 318	S	d.	Highland	*Highland Council* (01478 612341)
Sherburn Quarry, Tyne and Wear? (Q084) Grid ref unknown.	S	bs.	Tyne & Wear	*Sherburn Stone Co Ltd* (0191 372 0636)
Shewalton Quarry, Shewalton Road, Irvine. (Q115) NS 332 367 (closed, 3 colours of as dug sand taken from face)	S & G grey & brown).	as dug (bs, orange, (01294 551321)	North Ayrshire	*Malcolm, WM Ltd*
Shierglas Quarry, Killiekrankie, Pitlochry, PH16 5LL. (01796 481325) (Q021) NN 881 639	L	d, 5 mm.	Perth & Kinross	Thistle Aggregates
Shiphorns Quarry, Eddleston, Tweedale, EH45 8RD. (01721 730321) (Q195) NT 242 502 (closed at present)	S & G	cs,	Scottish Borders	Russell Quarry Products
Skaill Beach Quarry, Quoyloo, Sandwick, Orkney. (Q198) HY 233 189	S & G	bs.	Orkney	Ibister Brothers (01856 841525)
Skelpie Quarry. (Q097) NO 353 079 (from Shap Quarry, Cumbria, crushed at Skelpie)	L	d, grit, filler.	Fife	Cults Lime Co Ltd (01334 52545)
Smiddyseat Quarry, Tyrie, Fraserburgh. (Q171) NJ 942 613	S & G	as dug.	Aberdeenshire	Davidson, Keith (01346 4360)
Snabe Quarry, Drumclog, Strathaven, ML10 6QF. (01357 440597) (Q065) NS 644 391	S & G	bs, cs.	South Lanarkshire	Filshie, JM & Son
Sorn Quarry, east of Cumnock. (Q053) Grid ref unknown.	S	d.	East Ayrshire	Barr (01292 281311)
Spey Bay Quarry, Nether Dullachy. (Q188) NJ 362 643	S & G	cs.	Moray	Caledonian Quarry Products (01343 820922)
Spittal No 3 Quarry, Spittal, Sutherland. (01847 784239) (Q155) ND 168 538	S	grit.	Highland	Sutherland, A & D
Stannochy Quarry, Stannochy Farm, by Brechin. (Q104) NO 580 590	S & G	bs, cs, 2 mm, 5 mm.	Angus	Geddes (01241 890266)
Stepends Farm, Auldgirth. (Q112) NX 905 885	S & G	bs.	Dumfries & Galloway	Tarmac Quarry Products (0131 440 4477)

Quarry name, address, telephone number and grid reference	Commodity	Products	Local Authority	Operator
Ury Quarry, Stonehaven. (01596 763891) (Q123) NO 864 871 (as dug, other sands sampled at Arnhall, Q007)	S & G	as dug.	Aberdeenshire	Bruce
West Reston Mains Quarry, West Reston. (01890 818426) (Q090) NT 887 617	S & G	bs, cs.	Scottish Borders	Causewaybank Quarries Ltd
Wester Keiss Quarry, Lyth, nr. Wick. (Q154) NO 740 265 (as dug, dune sand)	S & G	dune sand.	Highland	Gunns (Lybster) (01543 721236)
Westhills Quarry, Airlie. (015753 271) (Q106) NO 580 590	S & G	bs, cs.	Angus	Geddes
Whitecrook Quarry, Dunragit, Glenluce. (Q054) NX 165 565	S & G	as.	Dumfries & Galloway	Barr (01292 281311)
Woodside of Auchlea Quarry, Longside, nr. Aberdeen. (01779 82314) (Q167) NK 026 490	S & G	bs, cs.	Aberdeenshire	Patterson, John
Wormit Quarry, Wormit. (01382 541659) (Q005) NO 409 248	S & G	bs, cs, grit.	Fife	RMC

during sampling and analysis between 1996 and 1998; the information on quarry addresses was up to date in early 1998. The 'correct as of date' field gives the date when the quarry aggregate samples were taken, although all of the information was not necessarily checked at this time.

The database has been formatted to include not only information on aggregates, but also on buildings inspected and mortar samples taken during conservation work by the Scottish Lime Centre and on suppliers of lime based materials. The database consists of an interlinked series of seven forms. Two of these forms give information on aggregate suppliers (quarries) and aggregate types (products). Four of the other linked forms give information on buildings on which repairs have been carried out, mortar samples taken from these buildings and the analysis results, suppliers of lime based materials and the properties of these materials. The database contains, therefore, all of the information needed to specify materials to be used in building conservation when a mortar analysis has been carried out. The specifications are listed in a seventh form which can also be used as part of a report.

The database can be consulted either at the offices of Historic Scotland in Edinburgh or at the offices of the Scottish Lime Centre Trust in Fife.

from the north during glacial activity. The quarry at Auchterforfar, from which a sample of as dug material was taken, is not yet operational.

Argyll and Bute Council

Of the twelve quarries sampled in Argyll and Bute, one is producing crushed igneous rock and two are limestone quarries. The other nine are sand and gravel quarries producing grey and brown sands derived from the local rocks which are predominantly metamorphic and igneous types. The two Islay sources produce coarse grained, as dug sands but one also supplies a fine grained dune sand that contains a large amount of shell material.

Of the two limestones, the Calliburn Quarry near Campbeltown produces a dark brown dust, while the Ballygrant Quarry on Islay produces a grey material.

The Clackmannanshire Council

No quarries were sampled in this area. Nearby sand and gravel quarries are located at Linlithgow, Cowie near Stirling, Dunblane and Braco. Silica sand quarries are located to the east of Clackmannan.

Dumfries and Galloway Council

Twenty one quarries were sampled, five of which are producing crushed rock products. The sand and gravel quarry at Locharbriggs also produces a crushed sandstone which has a strong red colour. The natural sand and gravel deposits have a brown or reddish brown coloration. The quarries at Linloskin, Newton Stewart and Balloch Bridge, Creetown do not appear to be operational at present. The site at Dunragit is essentially a depot processing aggregates from sources west of Stranraer on the Rhinns of Galloway.

Of the crushed rock quarries, two supply a light grey granite, two are producing crushed dark grey sandstone (greywacke) and one, at Tongland near Kirkcudbright, produces both red igneous rock and grey calcareous siltstone.

City of Dundee Council

No quarries were sampled in this area. The closest sand and gravel quarries are located in the surrounding Angus Council area, and also at Wormit and Straiton quarries in the north of Fife.

East Ayrshire Council

One sand and gravel quarry and one crushed rock quarry were sampled in East Ayrshire. The sand and gravel quarry at Loudonhill produces brown coloured aggregates rich in rock fragments. The rock quarry at Sorn produces a grey coloured, basic igneous rock dust.

East Dunbartonshire Council

Two quarries were sampled, one of which, Douglasmuir Quarry in Milngavie, produces aggregates which are sufficiently quartz rich to be classified as silica sands. These aggregates are very pale brown or yellow coloured. The other quarry, Inchbelly, produces an aggregate which contains more rock fragments and is brown coloured.

East Lothian Council

One sand and gravel quarry and two rock quarries in East Lothian were sampled. The sand from Longyester Quarry, Gifford is a brown/grey colour, with some red in the fine fraction. The limestone quarry at Dunbar does not produce a fine grained aggregate, but the coarse limestone fragments may be of use for lime burning in the future. Bangly Quarry, near Haddington, produces a brown coloured, igneous rock dust.

East Renfrewshire Council

There were no quarries sampled in this area. The nearest sand and gravel quarries are Greenoakhill in Hamilton (which may be closing), Loudonhill near Darvel and Snabe by Drumclog.

City of Edinburgh Council

The one quarry sampled in the City of Edinburgh area, Hillwood near Ratho, manufactures grey / green igneous rock products including some very fine grained fillers which may be of use as colouring and / or pozzolana in mortars. The nearest sand and gravel quarries are Longyester near Gifford to the east, Easter Middleton near Gorebridge, Shiphorns (currently closed) and Garvald to the south and several quarries near Bathgate and Linlithgow to the west.

Falkirk Council

One sand and gravel quarry was sampled in the Falkirk Council area. Avondale Quarry near Grangemouth produces brown coloured aggregates which contain sedimentary rock fragments.

Fife Council

Fourteen quarries and two other sand sources were sampled in the Fife Council area, eight of which are producing sand and gravel. Of the rock quarries, two in the west of Fife are producing silica sands, four are variable amounts of shell material. Availability of sands from these sources may be unreliable.

Perth and Kinross Council

Six sand and gravel quarries and one limestone quarry were sampled. The sands can be subdivided into those taken from River Tay deposits, which have a red colour, and those to the southwest of Perth which are brown and dark brown. Rossie Quarry at Forgandenny may be closed at present. The Quarry at Burnside of Marlee, Blairgowrie, from which a sample of as dug material was taken, is not yet operational.

Shierglas Quarry near Blair Atholl produces a dark grey limestone dust with a blue tint.

Renfrewshire Council

There were no quarries sampled in this area. The closest sand and gravel quarries are Douglasmuir, north of Clydebank and Greenoakhill in Hamilton (which may be closed).

Scottish Borders Council

Six quarries were sampled in the Scottish Borders area, two of which are rock quarries. The sand quarries produce material from different rock types and thus have different colours; Shiphorns produces a grey coloured aggregate (but may be temporarily closed), Eckford reddish grey, West Reston Mains brown and Kinegar reddish brown.

Craighouse Quarry near Melrose produces a greenish grey igneous rock and Cowieslinn Quarry near Eddleston supplies a grey coloured sandstone.

Shetland Islands Council

Three sand sources and three rock quarries were sampled from the Shetland Islands. The sands are all beach sands; Quendale in the south is a dark grey colour, Tolsta Beach sand is brown. Availability of sands from these sources may be unreliable.

Of the rock quarries, Brindister is a red green sandstone with some schist, and Gutcher and Sullom Mine produces crushed metamorphic rocks grey or brown in colour.

South Ayrshire Council

Two rock quarries were sampled along with a sand from a beach deposit. Tormitchell Quarry near Girvan produces a grey limestone and Hallyards Quarry a grey igneous rock.

South Lanarkshire Council

Of the ten quarries sampled, two are producing crushed rock products. The sand and gravel quarries produce mostly brown or dark brown aggregates. Cloburn Quarry produces a strongly red coloured igneous rock, and Dunduff Quarry produces a red / grey sandstone.

Stirling Council

There are five sand and gravel quarries in the Stirling Council area, one of which (Drumbeg) has recently closed. All have a brown or brown/grey colouration, the Cowiehall Quarry produces a lighter sand containing some coal, while the other quarries contain fragments of metamorphic rocks transported from the north during glacial activity.

West Dunbartonshire Council

There were no quarries sampled in this area. The nearest sand and gravel quarries are Douglasmuir Quarry north of Clydebank and Drumbeg Quarry near Drymen (which may be closed).

West Lothian Council

Five quarries were visited in the West Lothian area, two of which are rock quarries. The sand quarries, Couston at Bathgate (closing for a period) and Linlithgow, produce brown coloured aggregates with a small amount of coal. Kettlestoun Mains Quarry near Linlithgow is not yet operational.

Ravelrig Quarry produces a greenish grey igneous rock and Levenseat Quarry produces silica sands which are greenish or yellowish white in colour.

Western Isles Council

Twelve quarries in the Western Isles have been sampled, six rock and six sand. Five of the six sand and gravel quarries are light brown or white dune sands containing broken shell material. The other is a brown coloured sand derived from metamorphic Lewisian gneiss. A large number of potential sites for sand removal, which can be opened and closed rapidly, are present in the Western Isles where accumulations of wind blown shell sand are common on the west coast of the islands.

Five of the rock quarries are all exploiting Lewisian Gneiss which can have grey, white or pink colouration. The other 'rock' quarry produces crushed shell sand from the Traish Mhor beach on Barra. This source of crushed shell material has recently closed.

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Glaciation Period when ice covered most of the UK, eroding rocks and moving vast volumes of sediment. Most Scottish sand and gravel resources are glacial in origin. Several glaciations have occurred in the last million years, the youngest ending roughly 10000 years ago.

Gneiss Metamorphic rock, very highly deformed, common in the Western Isles and northwest Scotland as Lewisian gneiss.

Granite Intrusive igneous rock, 'acidic' in composition and composed of coarse grained crystals of quartz, feldspar and mica. Fine grained granitic rocks are known as microgranites or felsites.

Grading The particle size distribution of an aggregate, which in well graded sands has a 'normal' distribution with most grains between 2.0mm and 0.3mm in diameter. (See § A2.3.) See also sorting.

Greywacke Sedimentary rock, a grey, muddy sandstone containing a large number of rock clasts which is common in the south of Scotland.

Gypsum A sedimentary mineral (hydrated calcium sulphate), formed through the evaporation of sea water in the same way as rock salt, used as a binder in internal (plaster) mortars.

Hydrated lime[1] Lime (calcium hydroxide) formed by slaking quicklime with water. Hydrated lime is stored either as a powder (dry hydrate) or, if excess water is added, lime putty.

Hydraulic lime Impure lime containing minerals that give a mortar a chemical set which is quicker and harder than the carbonation of pure limes. Lime can be feebly, moderately or eminently hydraulic depending on the proportion of the reactive minerals. Eminently hydraulic limes are not strong when compared with cements. Hydraulic limes cannot be stored as putty for any length of time (because the chemical set will cause them to harden) and they are therefore stored as dry hydrate, and mixed with water on site. A limestone containing clay minerals will form a naturally hydraulic lime. (See also pozzolan)

Igneous Rocks formed through the crystallisation of molten material from within the earth. Igneous rocks range from basic (poor in silica, eg basalt) to 'acidic' (rich in silica, eg granite). If igneous rocks cool quickly at the earth's surface (extrusive), as in volcanic lavas, their crystals are fine grained, if they cool more slowly within the earth (intrusive), such as granites or gabbros, they can be very coarse grained.

[1] The terms hydrated and hydraulic refer to different properties of lime and should not be confused.

Lewisian A series of very highly deformed, very old metamorphic rocks common in the northwest of Scotland and the Western Isles.

Lime (non-hydraulic) Pure lime containing only calcium hydroxide. Also known as fat lime.

Lime inclusions Small fragments of unmixed lime in a mortar, usually formed from imperfect or crude slaking of quicklime. These form white patches in a mortar, which normally convert to calcium carbonate with time.

Lime putty Hydrated lime which has been slaked from quicklime using sufficient water to form a thick liquid and subsequently settled out to a putty during storage.

Limestone Sedimentary calcium carbonate formed either through evaporation of sea water, or precipitated biologically (shells, coral reefs, etc) and then cemented to form a rock during burial.

Lithification The process by which an unconsolidated sediment at the earth's surface (such as sand) is buried, compacted and bound together by natural cements to form a rock (sandstone).

Marble Metamorphic rock formed from limestone; pure marbles are composed of the same mineral (calcite) as the original limestone.

Mica A mineral with a sheet-like crystal form, common in metamorphic rocks and granites.

Metamorphic Rocks altered (recrystallised) by pressure and heat during burial in the earth's crust. If the alteration is not intense, the origins of the rock (igneous or sedimentary) can be identified.

Mineral A crystalline material with a defined chemical composition. Minerals form the main components in both rocks and sands.

Moine A series of metamorphic rocks common in the Northern and Grampian Highlands.

Mudstone Sedimentary rock, formed of fine grained fragments of minerals, including silts (grain size between 63μm and 2μm) and clays (<2μm, 0.002mm). Usually dark grey in colour, mudstones can be confused with basalts, but are softer and do not contain large, rectangular feldspar crystals. Mudstones which are composed predominantly of clays are smooth to the touch. Mudstone is a general term for rock types which include siltstones and claystones.

Pinnings Small stones or shells placed in joints to stabilise masonry and reduce the volume of mortar required.

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