# Building stones of Edinburgh: geological characteristics of building stones



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## Contents



## The geological characteristics of building stones

**'Geology is the fundamental science which determines not only the scenery of any region but also its architecture'**

Frank Dimes (In J Ashurst and F.G. Dimes, 1990).

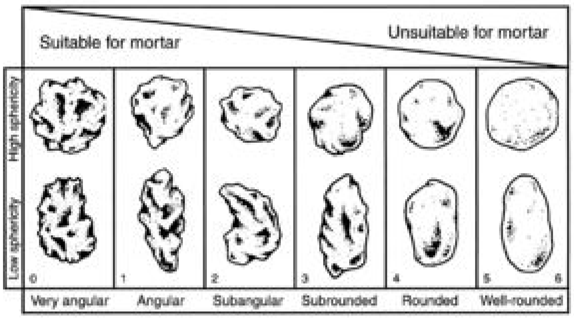
### Introduction

Scotland is endowed with a rich variety of sedimentary, igneous and metamorphic rocks that have been used extensively as building materials over the centuries. The characteristics and properties of building stones are related to the geological origin of the material. Thus many of Edinburgh's buildings constructed before the 20th century owe their character principally to the locally available material of sedimentary origin, namely sandstone. Igneous rocks were also used for some of the early buildings and as a prime source of good quality, hard-wearing setts. In the early days of building, field-stones, river beds and local outcrops of rock from which stone could be easily extracted provided building material. Much of this stone was used with little if any further dressing to form random rubble walls. In areas where suitable rock cropped out, quarries were developed and stone became established as the local building material. As the means of transporting stone, and as roads, canals and railways developed, it became economic to use a variety of stones from further afield for general domestic, industrial and commercial use.

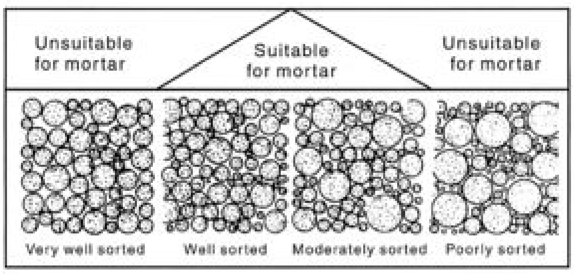
Sedimentary rocks are formed by the accumulation of sediment, undergoing natural compaction, dewatering and cementation over a long time. The process of sedimentation may take place in a variety of depositional environments, for example in deserts, rivers, lakes and seas. Common rock types include conglomerate, sandstone, siltstone, mudstone and coal. Sedimentary rocks also include salt, formed by the process of evaporation of lakes and shallow inland seas, and limestone, formed by the accumulation of calcareous organic remains. Sediments may vary in grain-size from clay particles (< 1/256 mm) to boulders (> 256 mm). Many different grain-size classifications have been proposed. This series of articles generally follows the geological (sedimentological) definitions of the British Geological Survey.

Sediments may be derived from previously existing rocks, organisms and vegetation. Changes in the environment during deposition and variations in the incoming sediment produce layers or beds of rocks of differing characteristics. Minerals taken into solution by surface and ground water are re-deposited as precipitates or crystals, cementing the grains or fragments of sediment together. Progressive burial produces compaction in the sediment that eventually becomes lithified into rock. Shrinkage of the drying sediments and movement of the earth's crust create joints perpendicular to the bedding planes which separate the layers of rock. Thus the constructional properties and characteristics of sedimentary rocks depend upon the particles, the cements and the spacing of the bedding planes and joints. The combinations of these widely varying factors produce a wide range of sedimentary rocks, many of which are unsuitable as constructional stone for building but may have other applications. For example some shales and mudstones provide the raw material for brick-making.

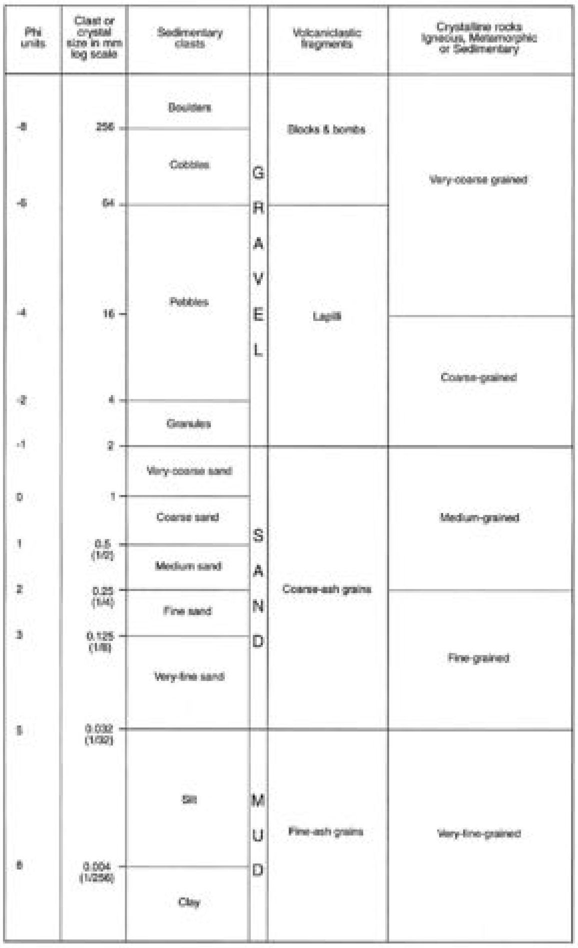
## Sandstones




Categories of roundness for sediment grains and suitability for mortar.




Degree of sorting and suitability for mortar.



A scale of grade and class terms for clastic sediments. Based on Wentworth, C.K. 1922. Geological Journal Vol 30 377-392.

The dominant rock type used in Edinburgh's buildings is sandstone. Sandstones originate as unconsolidated loose grains of sand deposited on the seabed, in coastal and desert dunes, on beaches or by rivers. The grain-size of sandstone ranges in diameter from about 1/32mm to 2mm. The composition of the grains reflects the composition of the source rocks and the physical and chemical resistance to weathering of the constituent minerals. The texture, grain shape and sorting of sandstones is affected by the mode of transportation of the grains, for example by water or wind.

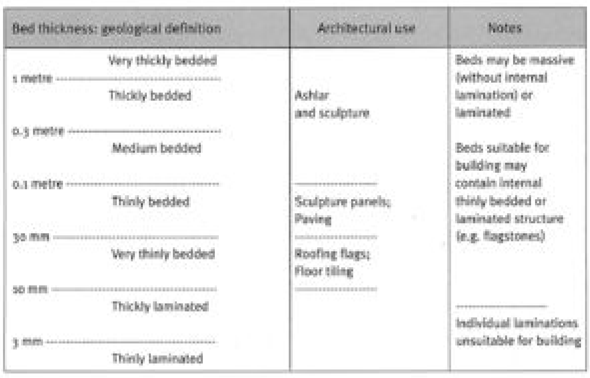
The geological characteristics of shape and sorting apply equally to unconsolidated sediments and to their lithified (rock) equivalents. Wind is often a good agent for sorting the sand, so that the range of particle sizes is small: the best-sorted sands tend to be those which have been transported and deposited by winds in deserts. These sands are also characterised by well-rounded grains. Note, however that a geologically well sorted sand is commonly considered to be poorly graded in quarry operator's terminology. When considering the suitability of sand for mortar it is important to assess both particle shape and degree of sorting. Generally angular, moderately sorted sands are best. A moderately sorted sand is considered to be well graded (i.e. with a normal particle distribution and median grain size of about 0.5 - 0.6mm).

Compositional maturity of a sandstone is defined by the constituent minerals which are determined by the source and agent of transport of the sand. Sands that are rich in chemically stable minerals, such as quartz (silica), are said to be mature. Sands with a wide range of mineral constituents, including a high proportion of clay minerals (complex silicates), are both texturally and compositionally immature. Sandstones suitable for use as building stone commonly consist of strong, chemically stable, particles of colourless quartz or light buff and pink feldspar. However the presence of particles of weaker minerals is not uncommon. An example is the flaky silicate mineral, mica, each flake reflecting light and giving a lustre to the fresh stone.

**Bedding characteristics**

Cross-bedded Carboniferous Polmaise sandstone (Stirlingshire), Teviot Medical School, Edinburgh.

The natural sequence in which sediments are deposited results in the youngest layer lying at the top and the oldest at the bottom (the 'principle of superposition'), providing the sedimentary pile is not disturbed or overturned by some external force. In building works it is often desirable to simulate this natural arrangement of sediment layers by laying stone 'in bed' and the 'right way up'. This is because the stone is not only better equipped to take imposed loads at right angles to its natural bed but also has the potential to weather better. When used in buildings, stratified stone is most resistant to compressive forces if laid with the bedding horizontal. 'The stone thus placed is best able to resist atmospheric disintegration and occupies in the artificial structure a similar position to that which it originally occupied in nature'.' There are circumstances, in the building of arches and corbels, where this arrangement is undesirable for structural reasons. Examples include edge bedded arch blocks in which the planar edge forming the length of each block is aligned parallel to the natural bedding. Each block is rotated a few degrees to form a curved arch. The visible surface of each arch block, thus exposes the natural bedding at an angle between horizontal and vertical. The extreme case where the block is laid 'on cant' with vertical bedding on the exposed face (also known as end bedding) is often seen in columns. Face bedded blocks, where the exposed face is parallel to the bedding, may suffer from de-lamination.



| Bed thickness: geological definition | Architectural use | Notes |
| --- | --- | --- |
| Very thickly bedded | | Beds may be massive (without internal lamination) or laminated |
| 1 metre | | |
| Thickly bedded | Ashlar and sculpture | |
| 0.3 metre | | |
| Medium bedded | | Beds suitable for building may contain internal thinly bedded or laminated structure (e.g. flagstones) |
| 0.1 metre | | |
| Thinly bedded | Sculpture panels; Paving | |
| 30 mm | | |
| Very thinly bedded | Roofing flags; Floor tiling | |
| 10 mm | | |
| Thickly laminated | | Individual laminations unsuitable for building |
| 3 mm | | |
| Thinly laminated | | |

Terminology of bed thickness and typical architecture use.

Water-lain sandstone in Hailes Quarry, Slateford, Edinburgh. The fresh surfaces of rock clearly demonstrate characteristic wispy, black, carbonaceous, ripple laminae, a feature frequently seen in buildings constructed of this stone. The tools used included picks and wedges. The latter have been driven vertically into 'back' joints at the back of a bed. BGS Photograph P216874. C3114 (c.1926).

During the formation of the sandstone, the lapse of time between one layer of sediment being laid down and another is represented by a lateral discontinuity in the structure, known as a bedding plane, separating one bed of rock from another. Each bed can be sub-divided into smaller units and the thickness of the unit to be described as a bed may depend upon the context in which the term is used. Beds may be many metres in thickness but below an arbitrary lower limit of 10 mm thickness the units are known as laminations. Some medium- to thick-bedded sandstones have internal lamination which may render them unsuitable for polished ashlar but suitable for squared rubble work e.g. Hailes Quarry.

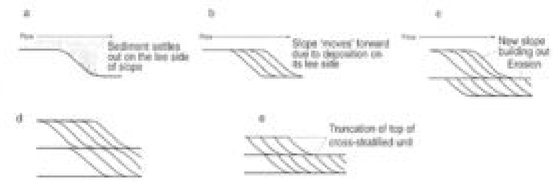
Flagstones are laminated sandstones which split along bedding planes to produce slabs of uniform thickness up to 70mm. They have been quarried, mainly in the Northern Isles, Caithness and Angus for use as paving stones or roofing slabs. Many quarries in central Scotland supplied both thinly bedded sandstone for pavement and thicker beds for ashlar or rubble work. Hailes Quarry, for example, was noted for the production of laminated sandstone which was used extensively in Edinburgh for stairs, landings and paving stones. Other parts of the quarry yielded stone suitable for rubble work in walls. A freestone is a massive, medium- to thick-bedded sandstone in which no internal lamination is apparent and which can be worked with equal ease in all directions. Historically this was frequently referred to as 'Liver Rock'. Often, but not necessarily, the stone has a uniform appearance. The best unstratified stone from Craigleith, Edinburgh was described as 'Liver Rock'. However, it was a hard sandstone, difficult to excavate and dress. In the 19th century architects took much trouble, not only carefully to specify sandstones of varying bed thickness and durability, but also to note how they were to be used. This is exemplified by the detailed specifications recorded in the Director's Minute Book (1823) for the construction of **The Edinburgh Academy** [85], Henderson Row:

'The whole Ruble stone will be got from Craigleith or Hailes Quarry. The Portico steps and whole landing within the Portico... and all the other stair steps and landings will be executed with the best Craigleith stone... The hearth of fireplaces and the Floors of the small entrance lobbies will be done with Dundee or Arbroath pavement, the whole ashlar work (Portico, Pilasters, mouldings, base etc.) on the principal front and East and West returns will be executed with the best liver rock from Collalo quarry; the remaining fronts being done with the best liver rock from Denny or Redhall Quarries.

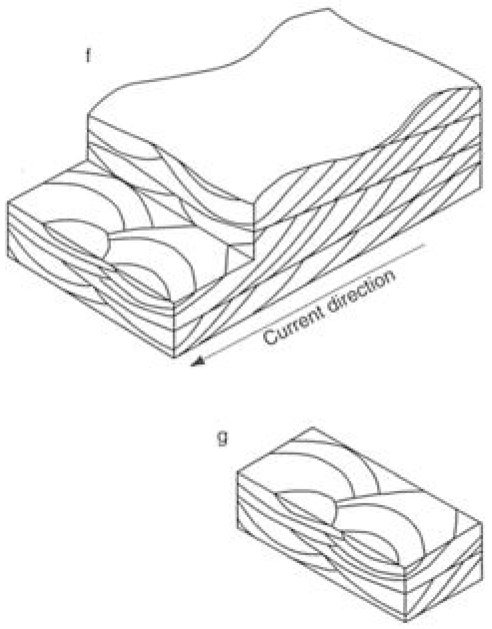
The whole stone of whatever description used in the building must be laid upon their natural beds, and lime will be mixed up with clean sharp pit sand and pure fresh water. The whole walls and ceilings in the building will be finished with three coat plaster... The plaster lime must all be mixed with hair of the best quality, and be prepared at least six weeks before it is laid on the walls...

"The lead used in every part of the work must be cast and all of the best quality. The whole roofs of all the buildings will be covered with the best Welsh Queen slates, hung with malleable iron nails, steeped in linseed oil when hot and laid on a shouldering of haired lime..."

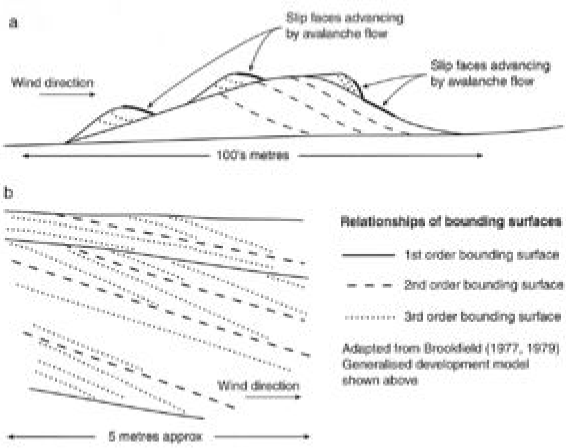
**Sedimentary structures in sandstones**



a. Flowing water carries sediment particles in suspension and these are deposited out on the lee side of the slope, where the velocities are lower. b. Due to deposition on its lee side, the slope 'moves' forward producing layers' of the form indicated so producing a cross-stratified unit. c. After the formation of one cross-stratified unit, its top is eroded and another formed above it. d. Two units of cross-stratification formed without any erosion occurring. e. Two units of cross-stratification produced by deposition and erosion, so that their tops are truncated. Sedimentary structures: the development of cross bedding in a water flow.

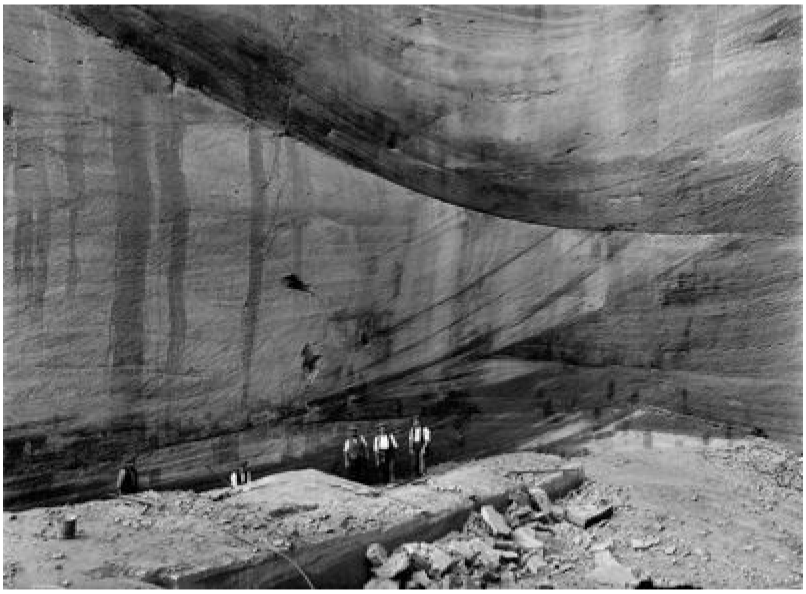



f. Three dimensional block illustrating the form of trough cross-bedding shown in (e). g. The surface characteristics of a finished ashlar block cut from the sandstone beds shown in (f). Sedimentary structures: the development of cross bedding in a water flow.

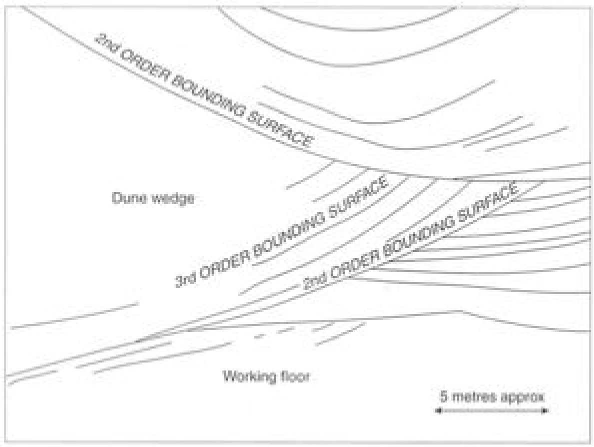



Sedimentary structures: section through an idealised large wind-blown sand dune Adapted from Brookfield, M E. 1977. The origin of bounding surfaces in ancient aeolian sandstones.

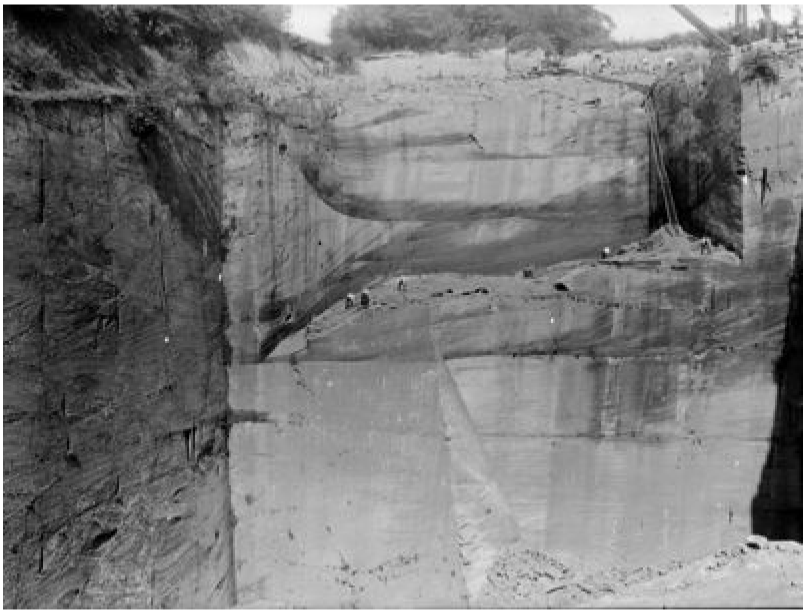
Water- or air-borne particles are subject to physical laws which determine how they are transported and deposited. In a river, for example, cobbles and pebbles (the bedload) may be rolled or bounced along the floor of a channel. Finer sediments including sands may be transported partly as the bedload and partly in suspension. The finest sediments such as silts and clays will be carried in suspension. It follows that if the velocity of the current carrying the particles in suspension is high, only the larger and denser particles will settle; as the velocity drops successively smaller and less dense particles settle. Assuming that the current wanes uniformly, the resultant sediments will exhibit graded bedding, the particles in the bed grading from coarse at the bottom to fine at the top. Features such as graded bedding observed in sandstones indicate that depositional processes millions of years ago were the same as those today. Comparisons can be made with many easily observed modern sedimentary structures. For example, ripples, similar to those seen on beaches today, are seen preserved in ancient sandstones and their wavelike structures can be seen in vertical section as well as on exposed bedding planes.



Ballochmyle Quarry, Mauchline. Ayrshire. Permian red desert sandstones showing large-scale aeolian (wind-blown) dune-bedding. A close-up of C02912. The view shows five quarrymen standing in front of the working face. The dune-bedding is composed of three large wedges, the bounding surfaces represent a time when the underlying dune was eroded prior to the deposition of the next dune. New Red Sandstone of Permian age. The size of sandstone block that can be hewn depends on the position from which the block is taken. For example thick beds may be worked from near the top of each major wedge defined by the 2nd order bounding surfaces.




Part of a former very large dune composed of smaller migrating dunes. The three large wedges are bounded by 2nd order bounding surfaces. The surfaces represent a period of time when the underlying dune was eroded, prior to deposition of the next dune. Within each wedge fainter laminations, 3rd order bounding surfaces (best seen in the middle wedge), converge downwards. These 3rd order bounding surfaces dip at angles in excess of 35° and flatten out as they curve towards the base of the unit.



Ballochmyle Quarry, Mauchline. Ayrshire. New Red Sandstone (Permian) red desert sandstones showing large-scale aeolian (wind-blown) dune-bedding. The huge size of the quarry is indicated by using the figures for scale - often over 64 m. deep. Access to the working face by ladder is clearly seen. Large blocks are lifted by crane powered by a vertical steam boiler. The sandstone consists of well-sorted, mostly rounded and frosted sand grains. They are red in colour due to a coating of haematite, an iron oxide.

Wave-forms on a larger scale occur in river channels and wind-blown sands, giving current-bedding (cross-bedding) and dune-bedding. Often such features may be seen in ashlar blocks and provide an interesting and aesthetically pleasing structural component to the character of the stone. The development of cross-bedding in water-laid sandstone is shown in the illustration. The tops of the waves are often eroded by the current which eventually deposits the succeeding layer, giving the wave-form a truncated appearance. This enables the orientation of the stone to be determined because the individual sand layers will tend to become parallel to the base of the bed and truncated at the top. The three dimensional appearance of commonly occurring trough cross-bedding is shown diagrammatically and in a finished ashlar block. Sometimes worm burrows are apparent, the 'tunnel' being filled with material which contrasts in texture and colour with the surrounding stone. Dewatering and slumped structures, which are commonly manifested as disturbed or convoluted bedding, may occur where quicksand conditions existed.

In dune bedding of desert sandstones the development of different orders of bounding surfaces together with the joint spacing determine how the stone may be worked. The largest dimension of block which can be removed from the quarry platform is determined by the thickness of strata lying between bounding surfaces. In turn this thickness is determined by the size of the successive sand avalanches involved in the formation of the dune.

**Joints**

The tendency for well-bedded sandstone to split along natural bedding planes is exploited during quarrying operations. In addition to bedding planes the rock often has two systems of joints or cracks almost at right angles to each other. One set of joints usually runs roughly parallel to the dip direction of the strata. In quarries which usually work to the dip of strata, these joints typically cut into the face of the quarry and are known as cutters. The other joint system roughly follows the strike (i.e. at right angles to the dip of the strata) and its planes lie parallel to the quarry face. These joints are known as backs. Dip joints (cutters), strike joints (backs) and bedding planes give three natural planes of division approximately at right angles to each other by which blocks of stone can often be wedged out using a crow bar only. When the rock is very tough or the joints are very far apart, more powerful tools have to be used but even then backs and cutters usually define the shape of excavated blocks and the mode of development of a quarry'

The geological jointing together with the bedding characteristics determine the size of block which can be quarried and dressed. In turn this dictates what size of stone block can be successfully used in a building. Thus the geology of the stone must be fully appreciated and employed in the ultimate build design.

**Classification of sandstones: mineralogy, grain and cement composition and colour**

The appearance (colour and texture) of a sandstone in a building is dependent upon the mineralogical composition of the stone. The mineralogy and composition of both the constituent grains and pore cement should be a prime consideration not only in specification of stone for new buildings but also in planning cleaning operations. For example the use of acidic treatments may etch grains, destroy pore cements and have a serious irreversible detrimental effect on the colour of the 'cleaned' stone.

Characteristics of sandstone which are observable with a hand lens both in the field and in blocks of a building enable a classification based on the mineralogy of the detrital grains to be used. The classification is defined by the relative proportions of quartz, feldspar and rock fragments. Principal categories include quartz arenite, feldsarenite, litharenite and greywacke. Qualifiers based on the cement composition may also be used and commonly sandstones are described as siliceous (silica cement), calcareous (calcite — i.e. calcium carbonate cement) or ferruginous (iron-rich cement). A sandstone with high clay content may be referred to as argillaceous. Sandstones with a coal content are often described as carbonaceous.

The sandstones of Edinburgh's buildings are generally of fluvial or aeolian origin. Many of the local quarries yielded fluviatile quartz arenites, mineralogically mature sandstones composed predominantly of quartz grains cemented either with quartz or calcite. Typically, these sandstones appear almost white or pale grey at a distance. Some of the local sandstones are classed as litharenites which contain a proportion of a variety of lithic (rock) fragments. Stone within one quarry may show considerable variation in colour, texture, bed thickness, hardness and ability to resist weathering. The colour of the stone depends on the lithic fragments and carbonaceous material present. Sandstones with a high carbonaceous or argillaceous (clay mineral) content may be dark grey or brown. Varieties of litharenites (argillaceous sandstones) are prone to failure through the loss of surface skins or veneers.

Stone colour variation can be well illustrated with reference to former quarries such as those at Hailes and Craigleith. At Hailes the lower beds, used for rubble work, were dark grey while the upper beds were of a pinkish hue and ferruginous. There was also a bed of 'blue-grey' rock and a small amount of stone suitable for ashlar. Other quarries could be relied on to produce stone of uniform colour, as at Binny, Uphall. The highly siliceous, massive, grey 'liver rock' of Craigleith may contain dark grey carbonaceous wisps, seen to advantage in the fine columns of the **National Monument** [140], Calton Hill (Figure 2.8) and **St Andrew's** and **St George's Church** [110], George

Street. Light coloured sandstones, worked at Ravelston, sometimes contained ironstone concretions which, as well as being unsightly, weaken the stone when they weather out. In some modern quarries colour mottling, due to the presence of limonite is a feature of stone, seen for example in the light yellowish grey sandstone quarried from the recently reopened Newbigging Quarry, in Fife (Chapter 8). Clashach Quarry, Elgin currently yields excellent stone of colours ranging from orange to mottled brown for major developments in Edinburgh.

Both the red sandstones from the Kinnesswood Formation (formerly 'Old Red Sandstone') of the Edinburgh district and the Permian 'New Red Sandstone' of Dumfries & Galloway and Cumbria owe their colour to the oxidising regime of the semi-arid, desert conditions under which the sediments were originally deposited. Aeolian quartz arenites are often red through the presence of finely disseminated ferric oxide (haematite) which coats the grains. Only 1-2% iron is enough to produce strong colours.

Other types of sandstone (not seen in Edinburgh's buildings) include arkose (feldsarenites) and greywacke. Arkosic sandstones have a high percentage of feldspar grains that impart a pink or red colour to the stone. Greywacke is a hard, dark grey rock composed of principally of feldspar and lithic grains with a high percentage of clay matrix. Greywacke, commonly used in buildings of the south of Scotland and the Borders, owes its hardness and strength to low grade metamorphism that has affected the strata. These rocks can be durable but fracture irregularly. Such hard, dark stone has been commonly referred to as 'whin in northern England and southern Scotland. Although whin is not used as a petrological classification, it was employed formerly by geologists as a field description for dark, compact, igneous rocks such as basalt and dolerite.

The strength of a sandstone is dependent largely upon the pore cement that binds the grains together. Generally, during the process of sedimentation, the pores (spaces) between the grains become partially or wholly filled by silica, calcite, clay minerals or iron oxides. In siliceous and calcareous sandstones silica and calcite respectively form strong bonds, although carbonate cements are liable to corrosive weathering, particularly in town atmospheres. Argillaceous sandstones cemented wholly by clay minerals are generally too weak to be used as building stone. Sometimes the sand grains remain virtually uncemented and the rock may be crushed in the fingers.

| Specific rock name | Mineralogical characteristics | Bedding and colour | Building sandstone characteristics |
|---|---|---|---|

| | | | |
|---|---|---|---|
| Quartz-arenite | Fluvial and marine sandstones: dominantly sub-rounded to sub-angular quartz grains; qualifiers define the cement content of the sandstone; siliceous sandstone (silica), ferruginous sandstone (iron-rich cement), calcareous sandstone (calcite or calcium carbonate cement). Argillaceous sandstones have a high clay content. Carbonaceous sandstones have a coal (organic) content. | May be massive (unbedded) or parallel bedded, planar and trough cross-bedded or laminated. Micaceous, laminated sandstones are referred to as flagstones; some sandstones are soft on working and harden on exposure; sandstones with calcite and silica cements are white or pale grey; ferruginous sandstones are brown and yellow; argillaceous and carbonaceous sandstones and flagstones are grey and brown. | Massive sandstone hard to work, may produce durable ashlar; bedded sandstones, particularly laminated stones including flagstones, may split easily; micaceous and carbonaceous laminae may enhance delamination especially in face-bedded blocks; iron-rich impurities may produce yellow and brown patterns; iron or carbonate nodules may give the stone a non-uniform appearance. |
| Quartz-arenite | Desert sandstones: rounded quartz grains coated with hematite. | Prominent dune bedding; often thickly bedded; shades of red; sometimes black laminae and streaks of manganese oxide may be present. | Spacing between bounding surfaces determines thickness of block; often soft to work, these sandstones produce ashlar blocks which harden on exposure. |
| Litharenite | Dominantly lithic (rock) grains. | Colour dependant on constituent rock fragments | Loss of surface skins and veneers may occur in sandstones with high clay content, leading to progessive weathering. Some clays absorb water leading to the decomposition of exposed faces. |

**Weathering**

The definition of weathering varies according to its usage in geological or masonry description. However, the geological make-up of a stone including its texture and grain and cement composition are important factors to be considered in both the natural and built environment. These characteristics may be observed both in a hand specimen and in larger structural units, for example quarry faces or ashlar masonry.

In the ground, a rock may undergo a series of weathering changes which can be classified according to the degree to which the strength of the material and the rock's mineral constituents are altered. Both physical disaggregation and chemical alteration may take place. The rock may be affected by changes in climate, burial, temperature and percolating solutions either from the surface or from depths in the earth's crust. The groundwater regime of circulating salt-bearing waters is critical. Movement of groundwater facilitates the transfer of chemicals in solution which in turn may interact with the rock constituents, affecting the strength and chemical composition of pore cements. Such processes may have acted on the body of rock for time spans of millions of years or over much shorter periods.

The relative hardness of interbedded sedimentary rocks can be observed in natural sections or quarry faces. Concentrations of flaky minerals such as micas on particular planes in the rock or variations in grain-size may reveal the natural layers or bedding formed during deposition which in turn may be exploited in winning the stone. Equally, internal planes or laminations within a single bed may be more prone to erosion. This may produce differential weathering of rock surfaces in quarry faces, natural sections and in masonry stone faces, particularly if stone is laid with beds 'on cant' (with bedding vertical).

In the built environment, stone is removed from its place of origin and regional groundwater setting and placed in an artificial position, either on the ground surface or at higher elevations. Freshly quarried stone is generally wet and full of 'quarry sap' and it is usually necessary to allow it to dry and season before it is used in a building. 'Stone that is quarried one day and built the next is in a green state, and unfit for use.'" Sometimes it is considered desirable to dress freshly quarried stone which is generally softer than its seasoned equivalent. The hardening which seasoning brings to a stone may be attributed to the movement, in solution or suspension, of small amounts of siliceous, calcareous, clay or iron-rich material. This material is drawn to the surface by capillarity and deposited when the 'quarry sap' evaporates"' and is thought to produce a kind of skin on the exterior of the seasoned stone affording some protection against weathering. However, there may be more to be said for firstly allowing stone to season, thereby allowing potentially damaging salts to be drawn to the surface before being removed by dressing." Some local stone e.g. from Redhall, was soft when first quarried. This quality was noted for rendering the stone 'very fit for the chisel and delicate carving, and the more so as it hardens on exposure to the atmosphere and retains its polish long'. Likewise Cullalo stone was particularly soft and friable but soon hardened on exposure."

Although one stone type is often used, stone of different origin, texture and composition can be employed in wall courses. However the potential for chemical interaction between stones thus placed and between stone and mortar also needs to be considered in assessing the likely performance. Commonly occurring weathering of building stone includes the development of granular dissolution where surface grains become detached to effect a loss of sharpness in tooled faces and polished ashlar. Erosion patterns around edges of the stone may develop if there is interaction between the stone and lime mortar. Delamination may occur where stone is laid 'on cant' due to the development of subsurface salt crystallisation or clay mineral expansion. Sub-surface salt crystallisation is particularly noticeable in stones subjected to total saturation where zones of salt precipitation cause efflorescence on drying out. Surface veneers and contour scaling may occur irrespective of the natural bed alignment.

## Limestones

Portland Roach stone with Jurassic fossil bivalves and gastropods. Ramp parapet to the west of the University of Edinburgh library.

Limestones are used as a major building stone in southern Britain. In England, south of the Humber, Jurassic limestones occur in thick beds and have been extensively worked for dressed stone in the Cotswolds, the Bath area and Isle of Portland. Inevitably, high transportation costs and local availability of good quality sandstone has precluded common usage of limestone in Edinburgh. Portland Stone, a white shelly limestone of Upper Jurassic age is commonly used in many English cities. A rare example of its use in Edinburgh is the extension of the **Royal Society of Edinburgh**, No. 26 George Street (formerly Commercial Union Insurance) 1931 at the junction with Hanover Street. Fossiliferous Carboniferous limestone from England has been used as cladding of some buildings. Polished Derbydene shelly limestone from Derbyshire has been used to clad the upper courses of **No. 9 St Andrew Square** [178].

In Scotland, limestone beds are generally too thin to be quarried economically for dimensioned stone but have had a long history of usage, in the Lowlands and parts of the Borders and Highlands, as lime for agricultural purposes, in mortar and as a flux for iron smelting. Limestone was occasionally used locally in rubble construction with sandstone dressings and harling on vernacular buildings. Limestone has been mined and quarried in the past locally at Burdiehouse, Middleton and Pencaitland in the Lothians. Currently it is quarried in conjunction with shale at Dunbar for cement manufacture.

Limestone is formed by the accumulation of shells or the calcareous hard parts of marine organisms, or by the precipitation of calcium carbonate as calcite, or the evaporation of water rich in minerals depositing crystalline calcium or magnesium carbonate. During the Carboniferous Period, some 280 to 360 million years ago, the climate and topography of the Edinburgh area were very different from that of today. A sub-tropical climate and repeated invasion by shallow seas provided the environment for limestone to form. Typically limestones and associated marine mudstones are fossiliferous, making these rocks valuable for stratigraphical correlation.

The term marble, traditionally used by the building industry for any decorative limestone that will take a polish, is geologically restricted to recrystallised limestones. The latter contain new minerals formed in response to burial and heating of the rock at depths of several kilometres in the earth's crust (see Metamorphic Rocks - Marble).

## Igneous rocks

Igneous rocks, formed from hot molten source material known as magma, possess an essentially crystalline texture and are composed of small interlocking crystals of silicate minerals. Extrusive igneous rocks such as basalt are formed from volcanic or fissure eruption in which magma emerges through weaknesses in the earth's crust, producing irregularly layered lava flows that cool quickly in contact with the earth's surface and atmosphere. Locally, good examples of ancient basalt lava flows can be seen on Whinny Hill, Arthur's Seat. These rocks, together with tuffs and agglomerates (the pyroclastic products of the volcano), provided a ready source of building stone for the rubble work in buildings such as **St Anthony's Chapel** on Arthur's Seat, the boundary walls of **Holyrood Palace** [146] and in the oldest walls of the City **Observatory House** [138] (built 1776-1792, to the specification of James Craig, designer of the First New Town).

Intrusive igneous rocks of volcanic origin, such as dolerite, are the product of magma which fails to reach the earth's surface before solidifying. Some magma cools in pipes which feed volcanoes, forming plugs. Erosion of the earth's crust over millions of years exposes such rocks at the surface. The spectacular crag on which **Edinburgh Castle** [9] is built is an example where the surrounding sedimentary rocks have been eroded to deeper levels by ice-sheets. Magma also intrudes into natural planes of weakness within the existing rocks of the crust, forming thin sheets that are known as sills and dykes. A sill is an intrusion that lies parallel to the bedding planes of the sedimentary rocks which lie above and below it. The dolerite sill of Salisbury Crags, the prominent escarpment overlooking Holyrood Palace in Holyrood Park (Figure 1.1a), is a magnificent local example. It was here that James Hutton, (1726-1797), who inspired modern geological thinking, was able to show how the once molten magma had been injected into the surrounding sedimentary layers.'" Dykes are planar bodies of igneous rock which have intruded across the principal bedding planes of the pre-existing rocks. When exposed by erosion, they often form wall-like features and are commonly relatively narrow bodies of rock, a maximum of only a few metres in thickness. Rapid cooling produces closely spaced joints, a characteristic which enables easy extraction but which limits the potential for using these rocks for dressed stonework. Such rocks are typically hard and intractable and thus are difficult to dress. Nevertheless, large quantities of durable dolerite were once extracted from Salisbury Crags both for `calsey staves' for roadmaking and for rubble work.

No. 60 George Square, built from local dolerite and pink Craigmillar sandstone. Columns are of grey micaceous sandstone.

In Edinburgh the widespread use of stone of volcanic origin in rubble walling testifies to its local abundance and availability. Typically the common varieties of basalt and dolerite are dark grey to black rocks, composed of small interlocking crystals of feldspar and magnesium- and iron-rich silicate minerals. Andesite (found in the Pentland Hills), although similar in texture to basalt, varies in colour from pale pink to red. Dolerite produces typically tough but aesthetically uninteresting stone. Rarely, it has been used in the construction of old buildings such as at **No. 82 Nicolson Street** [40] and in **George Square** [43, 45]. Dolerite together with Scottish granite (see below) was quarried extensively in the past for use as setts for paving carriageways. Although granite setts are making a welcome return to many streetscaping projects it is important to emphasise the use of appropriate base materials to prevent settlement and rock fracture. In modern times both dolerite and granite have been quarried extensively for crushed roadstone aggregate that provides rough-wearing surfaces.

Relatively slow cooling of bodies of magma at depths of several kilometres permits the formation of intrusive igneous rocks composed of large interlocking crystals of minerals (visible to the naked eye). Granite and black gabbro are common Scottish examples of these medium- to coarse-grained rocks. Traditionally, granites were exploited in Aberdeenshire (e.g. Peterhead quarries — pink; and the quarries in and around Aberdeen - grey and pink) and Galloway (e.g. grey granites of Creetown and Dalbeattie). Granites from these sources have been used in buildings throughout Britain and have been exported widely.' Even in Edinburgh, the 'Sandstone City', there are fine examples of Scottish granite work in buildings, plinths and monuments. The capability of granite to withstand large loads and ability to weather well has been utilised in the construction of plinth courses and for functional works such as bridges and docks. In Scotland granite is currently worked at Tormore Quarry, Ross of Mull and at Easter Delfour, Kincraig.

Greyfriars Bobby, Candlemaker Row. Bronze sculpture sits on a plinth of polished Cumbrian Shap Granite with prominent pink feldspar crystals.

A general (geologically sensu lato) definition of granites embraces all medium- to coarse-grained, light-coloured igneous rocks with at least 5% quartz. Individual crystals should be discernible with the naked eye. Compositionally, granites contain between 55 to 75% silica. The mineralogy of the granite group comprises quartz and silicate minerals including orthoclase and plagioclase feldspar, muscovite (white) mica, biotite (black) mica and amphibole. The crystal size has a direct bearing on the purpose to which the stone will be used. Thus fine-grained varieties may weather better and be less liable to spilling in monumental and building work than coarse grained types. Porphyritic textures, in which large crystals, usually of feldspar, occur in a fine-grained groundmass tend to be of less value for setts and roadstone but can be used to striking effect in ornamental work. The large crystals display the variation in the natural colours of the rock's constituent minerals, a characteristic utilised to advantage in monumental work and for decorative purposes in buildings. Colours vary from grey to pink according the proportion of pink feldspar in the rock. An example is pink granite from Shap, Cumbria which can be seen in the columns of the portico of **St Mary's Cathedral**[69], Palmerston Place. Black biotite and dark green minerals such as amphibole may give a variegated appearance to polished granites.

Black Scandanavian Larvikite forms cladding round the base of the University of Edinburgh library.

Granites and a wide range of other medium- to coarse-grained igneous rock types, including many imports from overseas, have been used in recent years as polished cladding to concrete structures. In coarse-grained igneous rocks the cohesive texture of interlocking crystals prevents the plucking out of grains during polishing and enables a brilliant finish to be achieved. This contrasts with the matt finishes of`polished' sandstone ashlar in which surface grains are more likely to be dislodged. The use of trade names, which may embrace many geologically different rock types, makes it a difficult task to determine the precise sources of these stones. An example is the Swedish black 'Bon Accord' granite which has been used quite commonly in the city. At **No. 9 St Andrew Square** [178] (see above) polished 'Bon Accord' stone may be seen at street level. Inappropriate use of imported inferior rock types (e.g. the Portuguese granite recently used in the **Waverley Market** development (1984) is exhibiting noticeable pyrite staining) should be guarded against but should not discourage the use of good quality materials of either indigenous or foreign origin. There are many examples of imaginative use of imported rock types such as polished larvikite (a Norwegian syenite exhibiting a brilliant blue sheen), as in the superb columns which frame the entrance to the **Scottish Life Assurance Company** [112] 2 North St David Street.

## Metamorphic rocks

When rocks are subjected to high temperatures and stresses deep within the earth's crust their physical characteristics may be changed. This process, known as metamorphism, produces crystalline rocks containing new minerals and exhibiting new textures. Although the rocks are often tougher and stronger than the original rocks they may be more brittle and susceptible to fracture. A wide range of metamorphic rocks can be formed according to the depth of burial in the earth's crust (in the order of tens of kilometres) and temperatures (up to 900° C) to which rocks are subjected. Although the texture and mineralogy of a metamorphosed rock are used to determine the degree (grade) of metamorphism, the mineralogy of the original material also has to be considered. The principal metamorphic rock type seen in Edinburgh's buildings is slate used in roofing. There are also many examples of polished marble for monumental and interior use.

### Slate

For roofing, slates are the most commonly used low grade, fine-grained metamorphic rocks. They have been extensively quarried in Scotland, principally at Easdale and Ballachulish, Cumbria and Wales. They commonly occur in varying shades of purple, grey and green and originate from mudstones (fine-grained sediments, which possessed natural bedding and lamination). When the mudstones are subjected to lateral compression and folded, new minerals, usually mica and chlorite form along planes normal to the direction of the compression and parallel to fold axes to develop slaty cleavage.

Slates usually split or cleave easily along this direction and sometimes the new minerals impart a sheen to the freshly cleaved faces. The process of metamorphism imparts a strength to the rock and the slaty cleavage, although rendering the material quite unsuitable for use as dressed stone, enables thin slabs to be split for roofing. Not all slates require to be cut to the same size and, in Scotland, a common practice was to use slabs of diminishing size on a roof, thus more fully utilising the available resource. Green and black slates are still available from Cumbria and are used for facing and paving as well as roofing. Despite a long and successful history of slate quarrying and the existence of suitable resources there are no currently operational Scottish slate quarries.

**Marble**

Other forms of metamorphic rock used for building stone, particularly for interior finishes include marbles. These rocks originate from limestones and their colour, mineralogy and texture are dependent on the composition of the original rock. In Scotland, marbles have been quarried on a small scale for ornamental and decorative purposes. 'Marble' has been used traditionally by quarrymen and stone masons to describe some limestones which are comparable as building materials to marbles, particularly in their ability to take a polish. True marbles are limestones which have been subjected to sufficiently high temperatures within the earth's crust to crystallise the rock, producing a tough, fine-grained stone which can be sawn and polished, providing an impervious and decorative surface.

Metamorphism of impure limestones has commonly resulted in the development of coloured marbles in which colourful silicate minerals such as serpentine minerals are present. Coloured marble, composed of serpentine and calcite, (the rock is geologically known as ophicalcite), was formerly quarried on Iona (the Iona Marble) and large quantities were sent to Leith and London.' Marble currently worked at Ledmore near Lairg (Ledmore North Quarry) is operated by Ledmore Marble Ltd. This stone commonly displays yellow, green and blue colour mottling, formed during metamorphism by the movement of mineral-rich fluids along small discontinuous joints. Block-size in the quarry is determined by the larger more continuous joints. Slabs can be cut to dimensions of a few metres, making the material suitable for panel work and interior floors. The floor of the entrance hall to **Longmore House** (Historic Scotland), Salisbury Place, is a fine example of polished Ledmore Marble.



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