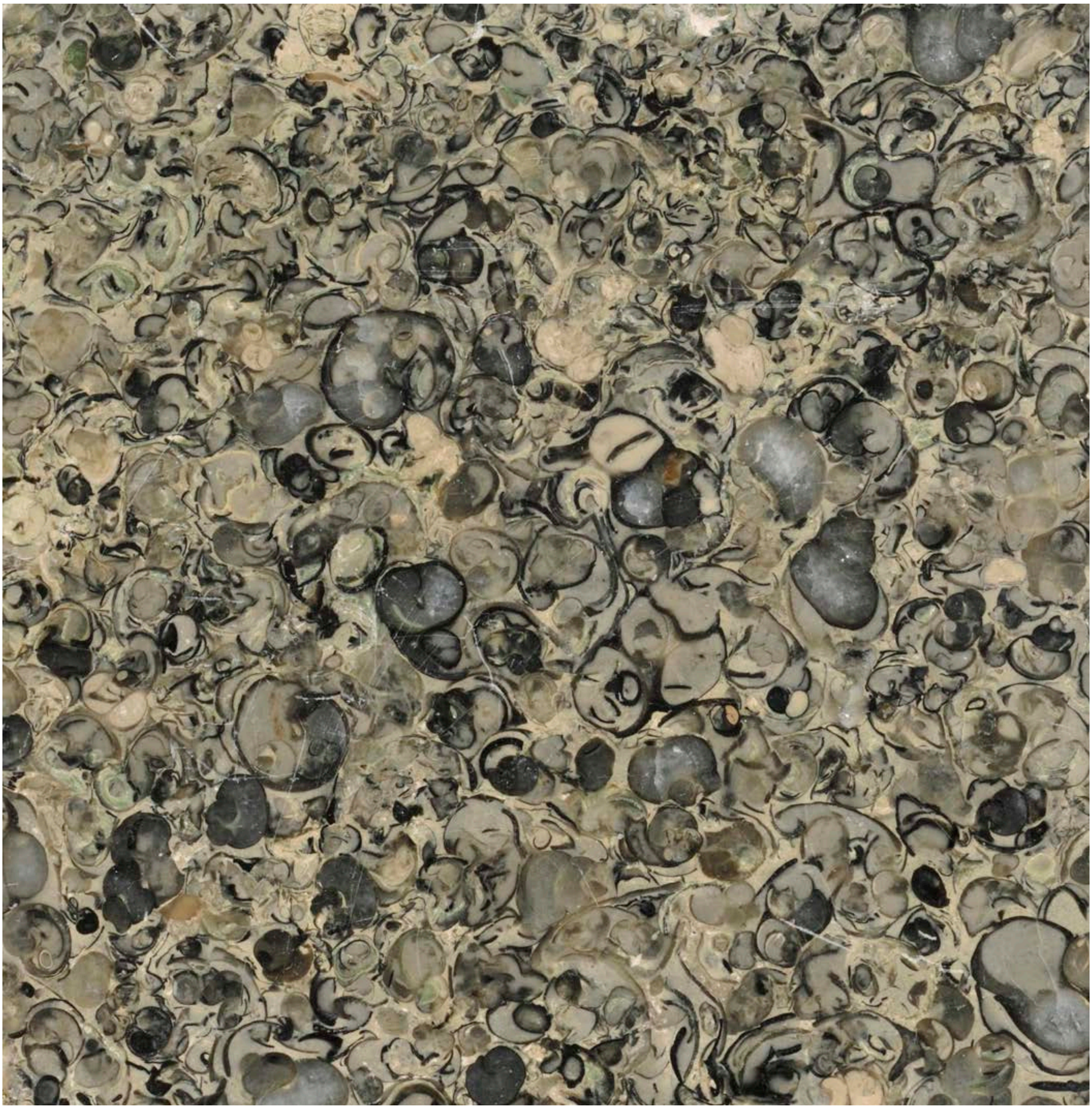
Historic England

Purbeck Marble

Conservation and repair



Summary

The unique shelly appearance and subtle colour variations of Purbeck Marble made it the foremost decorative stone of the English medieval period. It was used extensively for architectural features, including columns and pillars, string courses and sculpture in high-status buildings such as cathedrals, abbeys and palaces, as well as more sparingly in many other churches. Over the centuries, layers of now-discoloured waxes and coatings have obscured much of the characteristic splendour of Purbeck Marble, but originally its polished surface would have had an opulence that mimicked true marbles and contrasted with surrounding stonework.

Unfortunately, the composition of Purbeck Marble makes it especially vulnerable to deterioration caused by moisture. This can be a particular problem when it is exposed to external environmental conditions or when it is in sheltered locations, such as cloisters, where there are high levels of condensation. As with all heritage assets, deterioration is often exacerbated by lack of maintenance. In the past, attempts at treatment have tended to be piecemeal and inconsistent, but recently there has been an increased understanding of Purbeck Marble and progress has been made in developing methods to combat its decay.

This technical advice note looks at the many complex issues that affect Purbeck Marble, the causes of decay and past interventions. It provides best practice advice for care and repair of this important stone including surveys. This guidance is intended for architects, surveyors, conservators, other conservation professionals and anyone who is interested in or responsible for the care of buildings that contain elements made of Purbeck Marble. It will aid specifiers and practitioners in making informed decisions about conserving and maintaining this type of stone.

This guidance has been prepared for Historic England by David Odgers, Clara Willett and Alison Henry.
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Front cover: Typical polished surface of Purbeck Marble showing distinctive gastropods.

Contents

1 Introduction

Purbeck Marble is not a true marble, but rather a hard, dense limestone that can be polished to a smooth, shiny finish. During the Romano-British period, it was primarily used for inscription plaques, architectural mouldings, and mortars and pestles. There seems to have been little use of it after then until the 12th century. During the English medieval period, it became very popular for sculptural and architectural details in cathedrals and churches, perhaps due to its distinctive rich, dark colour and lustre finish. It was also used as an alternative to Tournai Marble imported from Belgium. Some of the greatest examples of works in Purbeck Marble are St Edward's shrine (1269) at Westminster Abbey and the abundant columns within the interiors of Ely, Exeter, Lincoln and Salisbury cathedrals.

Although Purbeck Marble is a hard stone, it is not a durable one. It is particularly susceptible to deterioration as a result of the bed orientation and environmental conditions (especially fluctuations in humidity) in which it is used.

Since the 19th century, this problem has been commonly acknowledged: remedial works were often carried out with varying success and generally at a cost to the aesthetic values of the stone. At a meeting of the Cathedral Architects Association Conference in 1984, specific concern was voiced about the condition of Purbeck Marble in many English cathedrals, most notably at Durham (especially the Galilee Chapel), Lincoln and Norwich. Five-yearly surveys revealed that deterioration of the Purbeck Marble was serious and disfiguring in many cases, causing disintegration to the point of destruction. Although conservation architects were urged to find ways to protect Purbeck Marble, there seemed to be no up-to-date advice on safe and acceptable methods for doing so.

Since then, more research has been carried out on the treatment of Purbeck Marble and other hard-to-treat stones. This includes the polishable limestones project carried out by English Heritage (now Historic England) in conjunction with the Building Research Establishment in the 1990s (see Teutonico 1995). This investigation classified polishable limestones, examined their physical and chemical nature and observed their decay processes. It was also intended to provide guidance on treatment. Unfortunately, there was insufficient evidence to produce detailed recommendations for treatment and repair. This began to change after a joint Institute of Conservation/English Heritage conference in 2007, when English Heritage started compiling and researching information on hard-to-treat stones, including Purbeck Marble. A review of treatments recently applied to Purbeck Marble showed that there has been, and still is, a wide range of approaches to dealing with deterioration. These vary from managed neglect to re-tooling, re-waxing, repair and replacement. There is still little consensus on best practice.

After a survey of the Purbeck Marble at Lincoln Cathedral in 2014, Nicholas Rank (Surveyor of the Fabric) wrote of the need 'to consider how best to implement a conservation policy to arrest the gradual loss of surface of the stone which is becoming increasingly a disfigurement to the building. This will require a nationwide investigation into the problems of conservation since this problem is not unique to Lincoln but can be found in a number of medieval cathedrals.'

This document aims to address this deficiency. Within it, the results of recent research and the performance of previous treatments are examined, and recommendations set out for the conservation, repair and maintenance of Purbeck Marble.

2 Properties and use of Purbeck Marble

2.1 Geology of Purbeck Marble

Purbeck Stone is the general name given to limestones of the late Jurassic/ early Cretaceous Purbeck Group (152 to 140 million years old), quarried as building stones on the Isle of Purbeck in Dorset. The climate during this period was relatively warm and southern England was covered with freshwater and brackish deltas and lagoons adjoining a shallow inland sea. These environments supported a rich marine and land flora and fauna, consequently Purbeck Stone often contains abundant fossils, especially bivalves, gastropods and ostracods. Purbeck Stone varies in colour (from blue, green, reddish-brown to shades of grey) and there are more than 20 different named beds of it, each with its particular characteristics, qualities and uses.

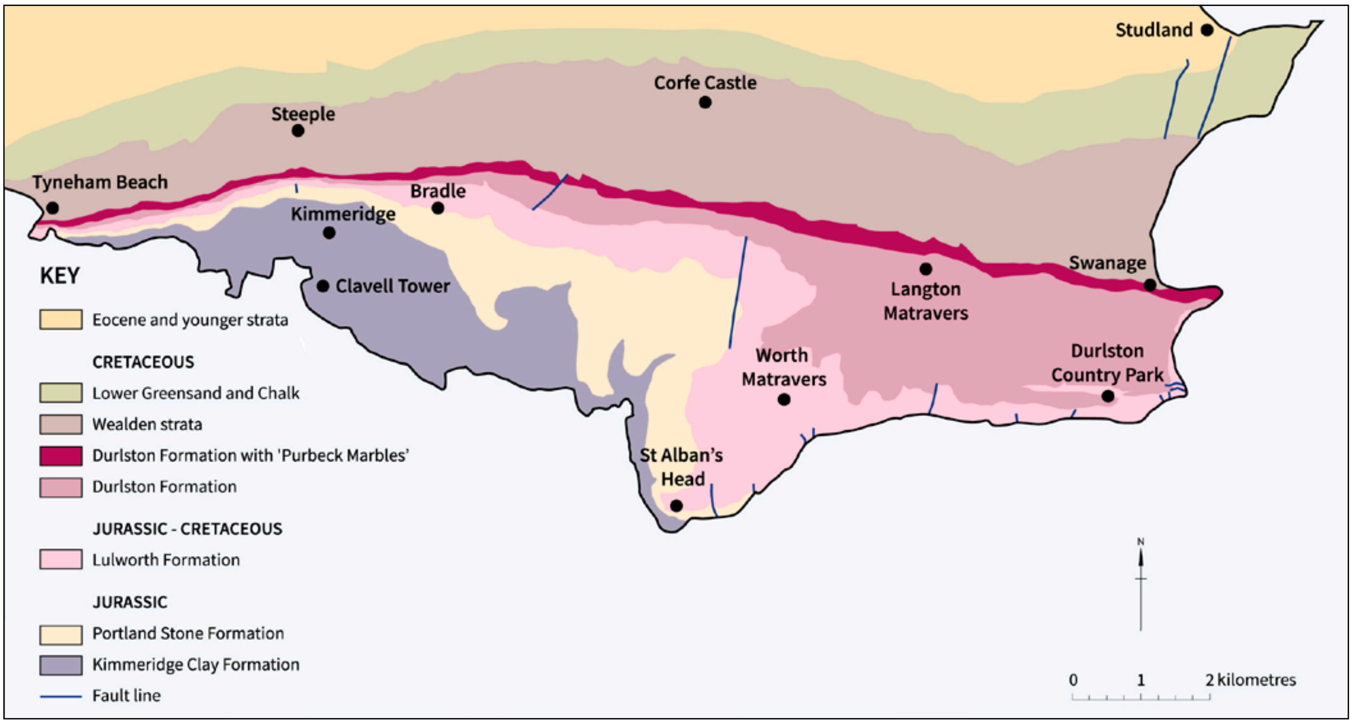


Figure 1: This geological map shows the distribution of Jurassic and Cretaceous strata (including Purbeck Stone) on the Isle of Purbeck, Dorset. The geological strata generally become younger from south to north, with the layers of 'Purbeck Marble' occurring within the upper Durlston Formation. This formation comprises mainly shales and clays, the harder 'Purbeck Marbles' occur as limestone bands which crop out between Tyneham Beach and Swanage.

Purbeck Stone is sourced from the Lulworth and Durlston formations. The Portland Stone Formation also occurs on the Isle of Purbeck, but is mainly worked from quarries on the Isle of Portland, located to the southwest.

Purbeck Marble is found near the top of the Purbeck Group (in the Peveril Point Member of the Durlston Formation) and typically occurs as thin beds in outcrops at or near the ground surface. Individual Purbeck Marble beds range from around 300mm to 600mm thick and are interspersed with layers of shale and clay. The outcrops all occur within the Dorset Area of Outstanding Natural Beauty, large sections of which are owned by the National Trust.

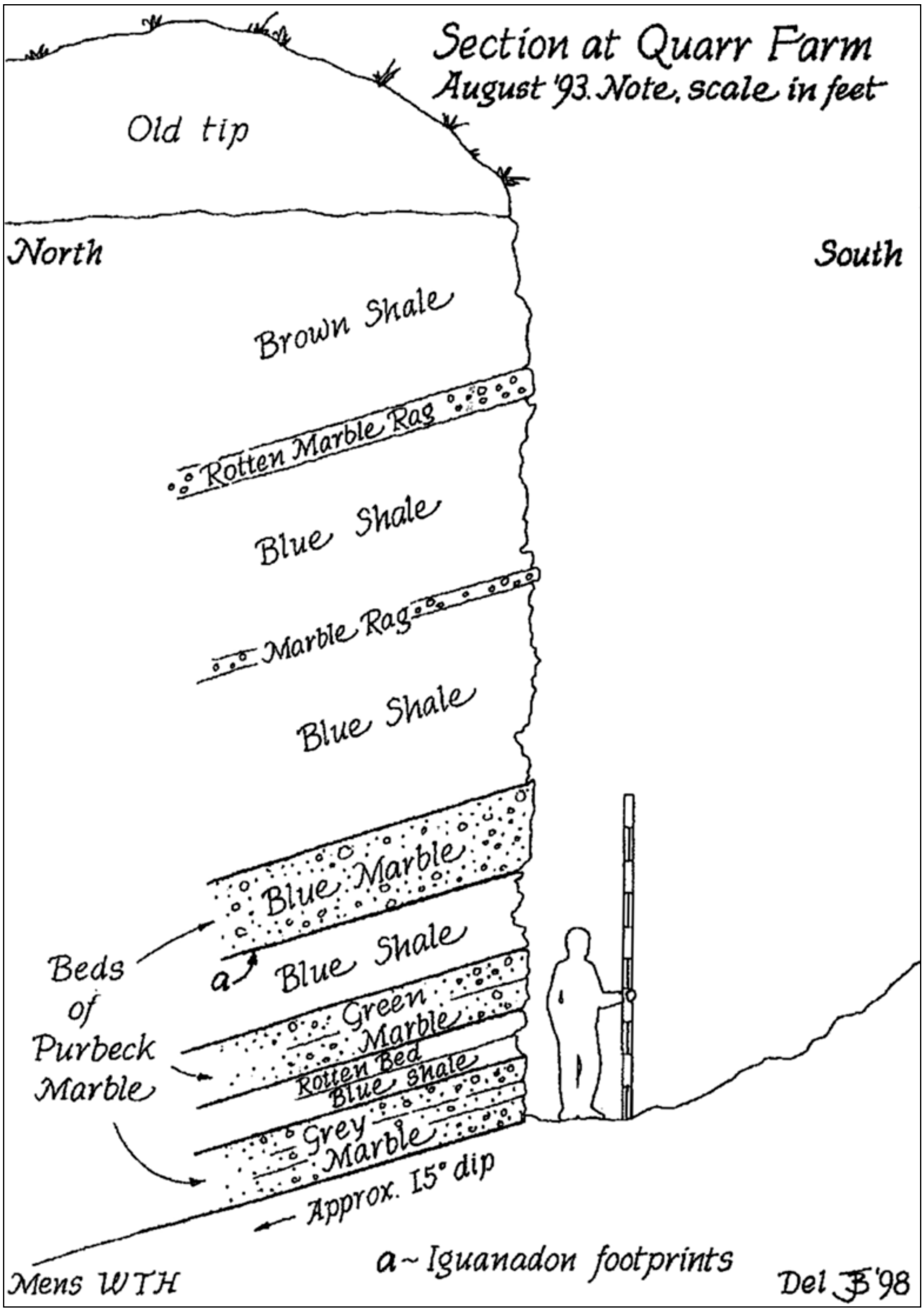


Figure 2: A typical outcrop of Purbeck Marble showing thin beds interspersed between beds of shale and other stone.

Despite its name, Purbeck Marble is a sedimentary rock and not a true metamorphic marble. Classified as a biomicrudite limestone, Purbeck Marble is a dense stone with low porosity (less than five per cent), low absorption and high compressive strength (over 100 MPa) perpendicular to the natural bed.

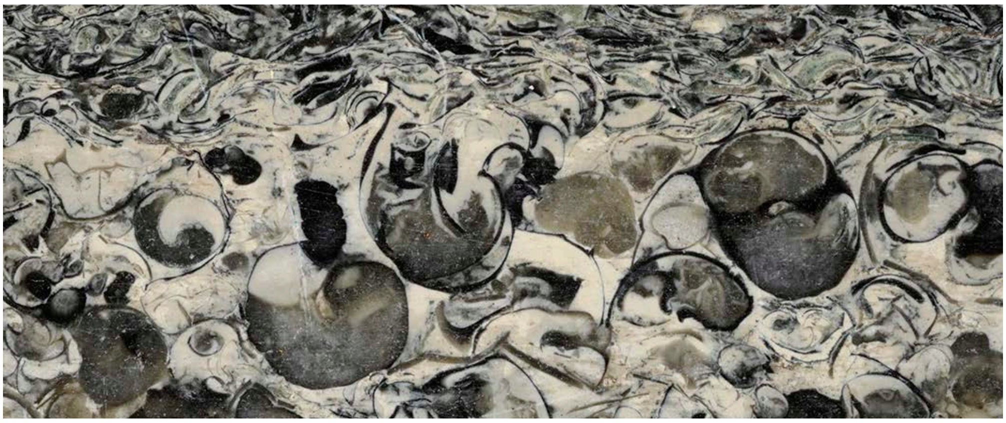


Figure 3: The polished finish of Purbeck Marble showing the detail of *Viviparus carinifer* (the freshwater snail).

Purbeck Marble contains a distinctive fossil fauna characterised by pale-coloured, closely-packed masses of the freshwater snail (*Viviparus carinifer*) set within a darker coloured, fine-grained limestone mud matrix. The mineralogy of the stone is predominantly calcite (90 per cent), with significant amounts of clay minerals (mainly smectite) and smaller amounts of other minerals, such as feldspar and pyrite.

2.2 Extraction and working of Purbeck Marble

In Roman and medieval times, it was easy to extract Purbeck Marble because it was found so close to the surface. Quarrymen simply removed overburden from outcrops and cut out the stone. Eventually, however, accessing the stone from the surface became more difficult. Purbeck Marble mines were then dug out (for example, at Seacombe and Winspit) with columns of stone left standing to support the roof. Purbeck Marble was excavated in this way from the 17th century until the early 1960s, when increasing mechanisation enabled large amounts of overburden to be removed with ease, thus allowing the stone to be dug out from the surface once again. Quarrying of Purbeck Stone continues to this day and it is used mostly for flooring. However, there is currently very little extraction and supply of Purbeck Marble.

Figure 4: Fragments of the Verulamium (St Albans) forum dedicatory panel, dated to 79CE, were found in excavations at St Michael's School, St Albans, Hertfordshire in 1955. Here, a reconstruction with the five fragments shows the entire inscription which was originally formed from one piece of Purbeck Marble.

Cutting and carving Purbeck Marble requires great skill. From the 12th century, these skills were developed in two main centres of ‘marbling’ at Corfe Castle in Dorset, and in London. The stone’s hardness made it laborious and expensive to work, and distinct tools, generally drawn out to finer points than those used for working other softer sedimentary stones, were required. The high shell content meant it was not ideal for carving fine detail. Despite this, effigies and capitals of great beauty were made, incorporating bold detail that allowed polishing to take place.

The restricted bed height of the stone also limited its use. If greater height was required (such as for the sides of tombs or for columns), the stone had to be turned on end so that the bedding was vertical. However, due to the stone’s tendency to split along the bedding planes, this made it less durable.

Much of the early commissioned work using Purbeck Marble was carried out in the marbling yards at Corfe Castle. With the rebuilding of Westminster Abbey in the mid-13th century, many craftsmen moved to London, where a court school of marblers and polishers was set up under the patronage of Henry III. During the years that followed, the London school was responsible for creating such ‘mass-produced’ items as ledgers, tomb slabs and columns. After the 16th century, however, Purbeck Marble became less popular. This was partly because there were few new buildings requiring the ornament of Purbeck Marble after the Dissolution of the Monasteries (1536–41) and partly because other real imported marbles became more readily available.

Figure 5: The monument to Richard II (1367–1400) and Anne of Bohemia (1366–1394) in Westminster Abbey is constructed from large slabs of Purbeck Marble set on edge. The nature of the stone means that carving is intricate but does not have fine detail. Discolouration is due to a conservation treatment, known as 'induration', applied in the 19th century.

2.3 Use of Purbeck Marble

During its heyday (between the 12th and 16th centuries), Purbeck Marble had many advantages. Not only was it hard, colourful, interestingly textured, easily polished and cheaper than real marble, but also the quarries were close to the sea. This meant that the stone could be easily transported and widely distributed, mostly in England but occasionally further afield (for example, to Normandy).

Despite these advantages, the cost of working Purbeck Marble made it expensive and so it was rare for it to be used as a general building stone. There are exceptions, though, such as the Grade I listed town cellars in Poole, Dorset which is built of Purbeck Marble.

The main uses for Purbeck Marble were as follows:

Architectural elements

The most common and widespread use of Purbeck Marble was for architectural elements, such as columns/shafts, capitals and string courses. Almost all of the medieval cathedrals of England contain some Purbeck Marble: Lincoln Cathedral, for example, has more than 1,000 Purbeck columns. The stone's colour range and deep hues also meant that Purbeck Marble played an important role in overall architectural design, particularly as a contrast to adjacent paler surfaces, such as other limestones or plastered walls. A contemporary account of the building of the choir at Lincoln Cathedral refers to 'precious columns of swarthy stone, not confined to one sole colour, nor loose of pore, but flecked with glittering stars and close-set in all its grain. Of this are formed those slender columns which stand around the great piers, even as a bevy of maidens stand marshalled for a dance.' (see de Noiers 1860).

Figure 6: The town cellars building in Poole, Dorset (now the Waterfront Museum) is a rare example of where Purbeck Marble features as a building stone. Constructed in the 15th century as a storehouse for wool and cloth, it has undergone various uses and is now the local history centre.

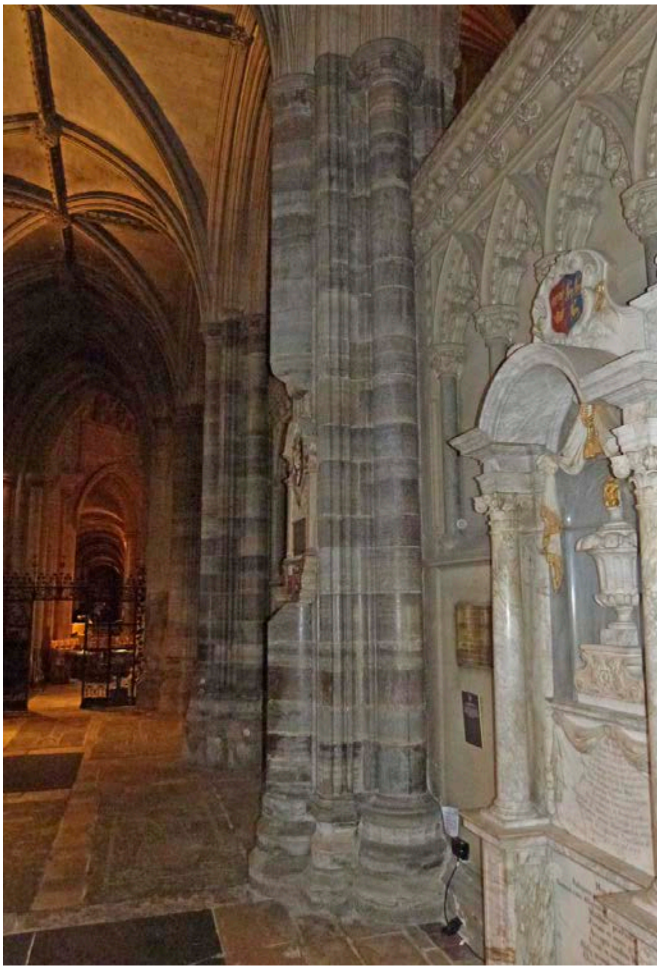


Figure 7 (above): At St James' Church, Kingston, Dorset, Purbeck Marble has been used for columns, abaci, string courses and hood moulds to provide contrast with the pale Portland Stone ashlar and arches.

Figure 8 (right): A compound pier in Ely Cathedral, Cambridgeshire is composed of shallow sections of Purbeck Marble laid in their natural bed; variations in the composition of the beds are clearly visible.

Figure 9 (left): A typical 13th century font at St Nicholas, Brushford, Somerset is constructed entirely from sections of Purbeck Marble laid in their natural bed.

Figure 10 (right): An 18-inch effigy of a knight from the 13th century thought to be of Robert de Roos. Now at St Mary's, Bottesford, Leicestershire, it was brought to the church from Croxton Abbey. The effigy would have originally lain on top of a chest tomb. Though detailed, it is flatter than comparable alabaster effigies because of the difficulty of carving Purbeck Marble.

Fonts

Purbeck Marble fonts are widely distributed across southern England, south of a line running from the Bristol Channel to the Wash. There is some consistency of design: bowls are generally square or octagonal, cut from stone in its natural bed, and supported on a stout but low central column, sometimes surrounded by smaller columns. Any decoration is usually restricted to relief carving on the sides of the bowl. Some of the earliest examples of the use of Purbeck Marble in medieval times are as fonts. The stone was cheaper than the imports from Tournai, and the colour, texture and ability of Purbeck Marble to take a polish made it more desirable, too.

Effigies

Early Purbeck Marble effigies tend to be found close to the source of the stone in Dorset, but later ones occur as far north as Durham. The largest collection of such effigies is the 13th-century knights at Temple Church in London. Purbeck Marble effigies often lack the finely carved detail of alabaster ones of a similar age. Furthermore, the fashion for painting effigies meant there was little point in using a hard-to-carve, polishable stone if it was then going to be painted.

Figure 11: A monument to Edward II (1284–1327), dating from the 1330s, in Gloucester Cathedral. The base is carved from Purbeck Marble in exquisite detail. The dark brown appearance is due to discolouration from repeated applications of beeswax.

Tombs

The decorative possibilities of Purbeck Marble can be seen in the large number of elaborate tombs found in many areas of England. The most common design was the chest tomb, in which carved Purbeck Marble panels were set upright and either fixed to a central core or secured to the adjacent panels. The top slab or 'lid' might support effigies or a canopy.

Ledgers, coffin or tomb lids

The bed height of Purbeck Marble lent itself to the production of (often very large) ledger stones, which were then incised with lettering. In the 14th to 16th centuries, slabs were cut to take monumental brasses.

Floors

The limited bed height and ability to take a polish made Purbeck Marble an ideal flooring material. However, its high cost meant that it was commonly included as part of a decorative pattern alongside other (usually cheaper) stones.

Figure 12 (right): A 14th-century memorial ledger slab to Elias of Beckingham (died about 1307) at Holy Trinity Church, Bottisham, Cambridgeshire. It originally had a brass depicting Beckingham in clerical robes, but this is thought to have been stolen during the English Civil War.

Figure 13 (below): Purbeck Marble used as part of a decorative floor at Ely Cathedral. Here, some of the polished surface of the stone has delaminated. A later replacement slab in a polished carboniferous 'marble' is clearly apparent.

3 Deterioration

The first step in the deterioration of Purbeck Marble is usually the loss of the original polished surface; this may be accompanied by discoloration. Subsequent deterioration will depend on the environmental conditions in which the stone exists, any treatments applied to it, the mineralogical and chemical composition of the stone and the particular way it has been used.

Typically, the result of decay is the spalling and flaking of the surface. Writing in 1855, Sir George Gilbert Scott accurately described the Purbeck Marble shafts in Westminster Abbey as 'decayed from 1/4" to 1/2" from the surface and so scaly and tender that it can scarcely be touched without portions coming off'. (Jordan 1980)

Decay is often exacerbated by lack of maintenance, treatments such as harsh cleaning methods or the application of an inappropriate surface coating. Although this is not unique to Purbeck Marble, the special characteristics of the stone make it particularly vulnerable.

In 1994, English Heritage's polishable limestones project studied Purbeck Marble in five cathedral sites (Chichester, Lincoln, Norwich, Rochester and Salisbury). The fieldwork included a stereo-photographic survey of Purbeck Marble at the sites, which revealed a range of environmental conditions, different degrees of decay and variations in levels of maintenance. Environmental monitoring was also carried out at each site, and samples of stone taken for petrological and thin-section analysis.

This research and more recent observations by conservators (notably at Ely Cathedral) have suggested that there are a number of overlapping causes of decay. These are described below.

3.1 Variations in environmental conditions

Purbeck Marble contains a number of clay minerals, such as illite and smectite. They are distributed both as very thin layers within the stone and also around individual fossils. Although illite is a non-swelling clay, smectite has a layered structure that allows and even encourages moisture to be absorbed between the layers. As a result, the clay expands and later contracts as it dries out. These processes are usually driven by variations in relative humidity and resultant condensation on the stone surface. When this fluctuation is repeated regularly (as in a cloister), it can lead to spalling or larger scale cleavage along bedding planes. The latter is often evident in columns and shafts where the clay strata run vertically.

Figure 14: Monument to Archbishop William Greenfield (died 1315), St Nicholas Chapel, York Minster showing localised flaking of surface.

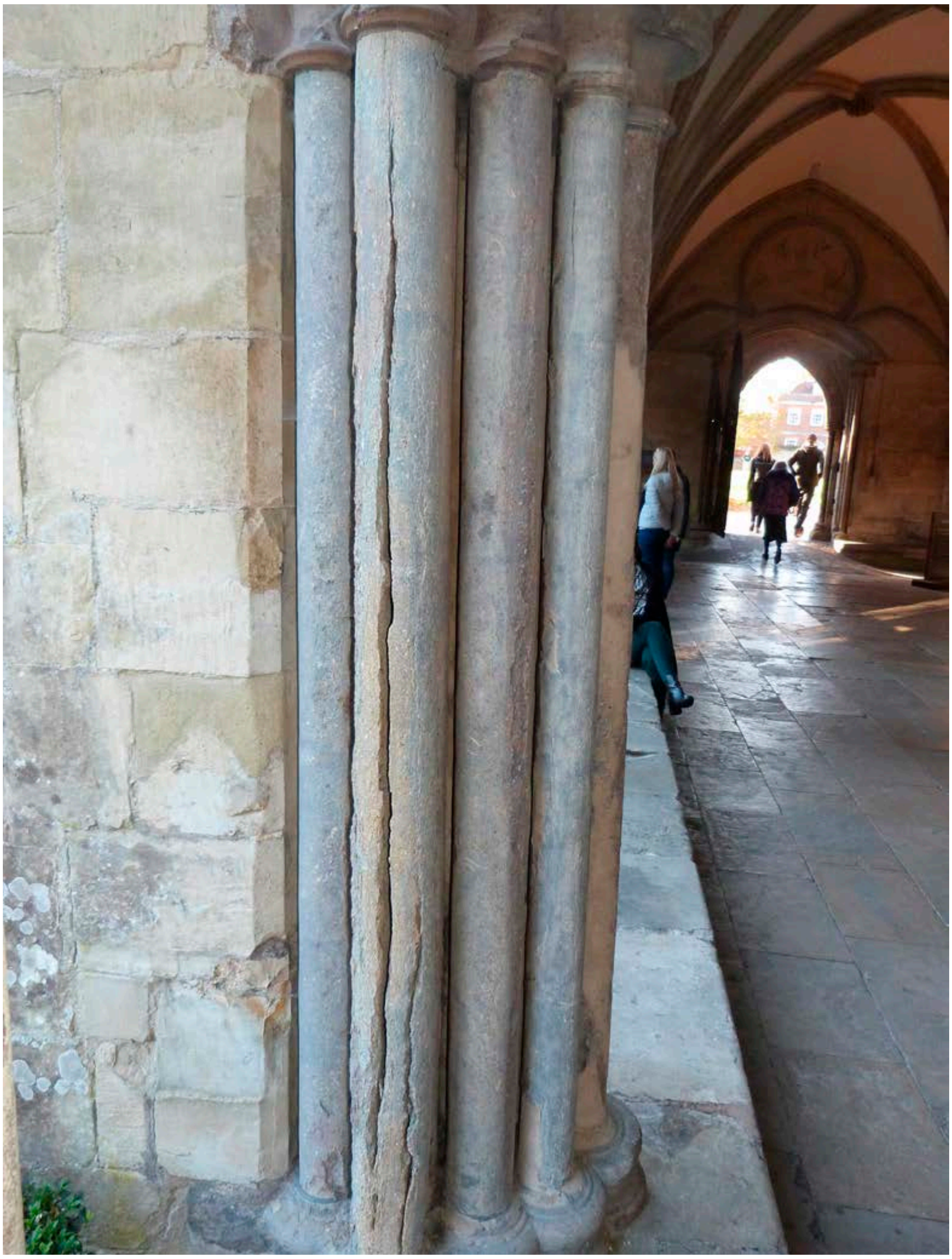
3.2 Separation along bedding planes

Most Purbeck Marble elements are monolithic (for example, capitals, bases, effigies, floor slabs) and are laid in the natural bed of the stone. Some larger columns, such as those in Lincoln Cathedral, are made from bands of smaller stones laid in their natural bed. In all of these cases, the variation in the composition of the strata of the stone is shown by the erosion of weaker beds. Delamination along these weaker beds is the principal cause of decay of Purbeck Marble used for paving or ledger slabs.

Purbeck Marble naturally occurs in a shallow bed. When it was used for columns, shafts, pillars and other tall structures, it had to be laid with the bedding planes orientated vertically. Although these architectural elements were often decorative, rather than load bearing, the expansion of the stone frequently resulted in cleavage along the bedding planes. This was sometimes exacerbated by the traditional use of lead (as opposed to softer lime mortar) as the bedding material for shafts. Lead does not allow the same degree of expansion of the stone as lime mortar, and so any expansive forces can only act perpendicular to the shaft, thus encouraging separation of bedding planes.

Compressive forces due to applied load can also cause the stone to split along the bedding planes of face-bedded elements, such as the sides of tombs.

Figure 15: Within the Salisbury Cathedral cloisters, the variable environment and the vertical bedding of the stone have caused cleavage along the bedding planes. The separated sections can become very distorted and will eventually fall away.



3.3 Oxidation

Purbeck Marble contains the mineral pyrite. When the relative humidity exceeds 60 per cent, pyrite oxidises to form ferrous sulphate and sulphuric acid. The extent of this oxidation is usually apparent from the way in which the surface of the Purbeck Marble discolours to brown. The sulphuric acid also reacts with the calcite binder in the stone to form gypsum. This not only leads to loss of binder but also disrupts the surface, as it is an expansive reaction.

Similarly, glauconite, an iron-silicate mineral that gives Purbeck Marble its characteristic green colour, readily oxidises and may also react with acid. The products of oxidation are slightly soluble in water and can cause the stone to disintegrate.

3.4 Sulphation

Purbeck Marble has a predominantly calcitic matrix. When sulphur dioxide (from general pollution) mixes with moisture and settles on the surface, sulphurous acid is formed, which then reacts with the calcite to form gypsum. Gypsum is 200 times more soluble than calcite. If Purbeck Marble is repeatedly wetted by direct rainfall, the gypsum will usually wash off as it is formed and will not accumulate on the surface. This will cause erosion of the surface. If, however, the stone is protected from direct rainfall but is subject to condensation, the sulphate will form a surface crust that tends to darken and blister. This crust can also affect the moisture-transfer characteristics of the surface.

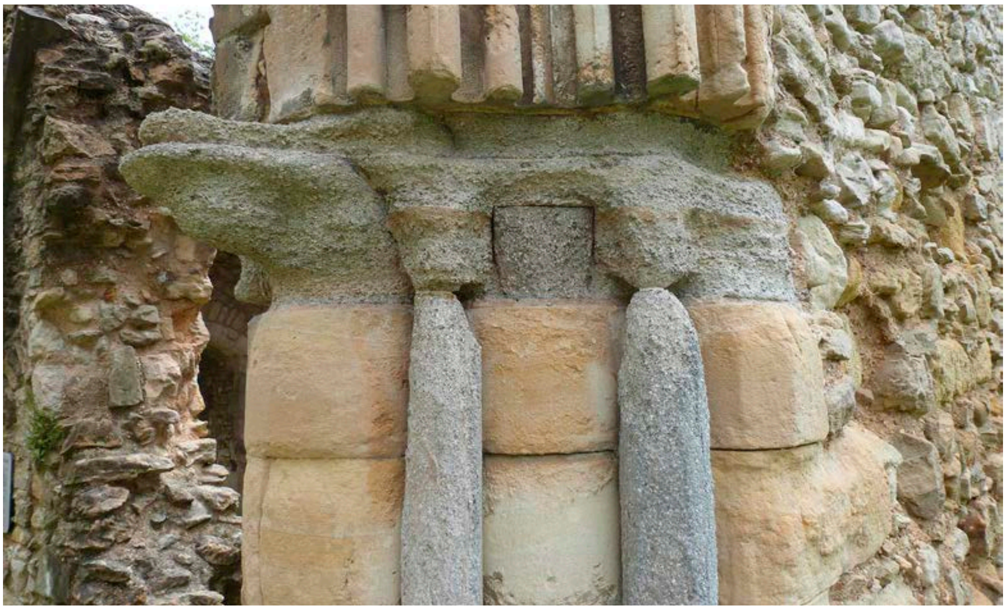


Figure 16: Significant deterioration to the Purbeck Marble at Netley Abbey, Hampshire, due to exposure to pollution from the power station and oil refinery downwind of the site. The deposition of sulphur dioxide combined with water run-off has dissolved the calcite binder of the stone.

3.5 Salt crystallisation

Despite the limited porosity of Purbeck Marble, dissolution, migration and re-crystallisation of soluble salts can contribute to its decay. Sources of salts can naturally occur in the stone itself, derive from groundwater, result from applied treatments such as cements or accumulate from de-icing salts put down on roads and pavements.

Liquid water dissolves salts as it travels through stone, transporting them and depositing them wherever the liquid flow is broken. This may be either at the surface (efflorescence) or, as is usually the case with Purbeck Marble, at the interface between bedding layers (cryptofluorescence). The expansion of salts as they crystallise causes disruption, blistering and flaking of the surface.

Purbeck Marble situated at a low level (such as floors, ledger stones and plinths) is particularly susceptible to damage from salts in rising groundwater. Where there is an impervious layer (for example, lead or cement joints), salt crystallisation may cause preferential decay on one side of the layer.

Figure 17: A compound pier built of blocks of Purbeck Marble in Lincoln Cathedral laid in their natural bed. The blocks at low level have suffered damage as a result of rising ground water. This will have been exacerbated by the sealing of the surface of the stone with wax.

Figure 18: Localised damage due to sub-surface crystallisation of salts on the side panel of a medieval monument.

Figure 19: Damage to low level external Purbeck Marble as a result of salting of the adjacent roadway next to Norwich Cathedral cloisters.

3.6 Previous treatments

The regular treatment of Purbeck Marble with natural waxes, oils and resins was assumed to be beneficial to the stone's long-term preservation. Unfortunately, although these treatments provide some protection, they may also cause aesthetic changes and a reduction in permeability. The darkening of surface treatments, especially from the cross-linking of polymers contained in these materials, will turn the original grey/green of Purbeck Marble to dark brown. These surface treatments also become brittle with age, leading to micro cracking. When this happens, moisture can penetrate behind the coating and set off humidity-driven decay mechanisms, causing the surface to blister and take on a milky appearance. The 'tackiness' of waxed surfaces can also attract dust, dirt and pollution, which may change the original colour of the stone.

Figure 20: The deterioration of the wax coating here is a result of environmental factors. Fluctuations in humidity affect the stone behind the coating leading to the deterioration of both.

Figure 21: The detachment of shellac coating reveals the original colour of Purbeck Marble behind.

3.7 Other causes of deterioration

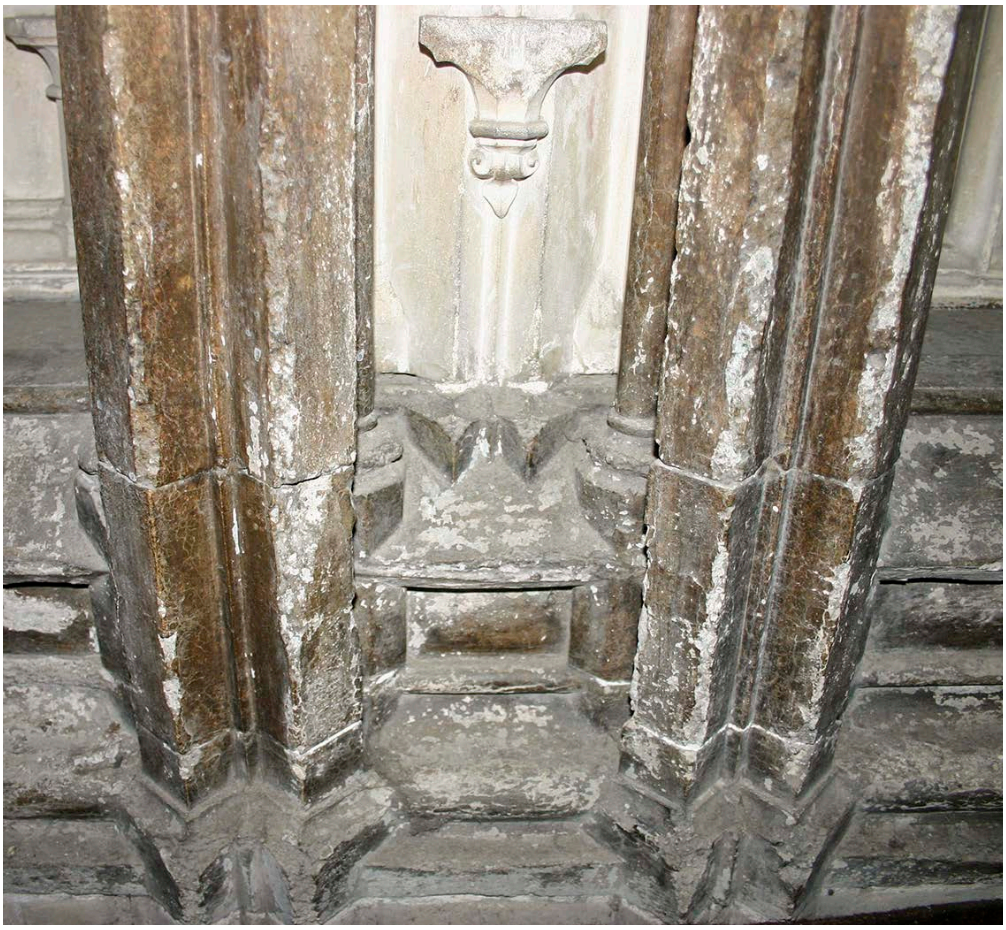
Like other stones, Purbeck Marble is susceptible to the effects of both the environment and human interaction. Visitors to buildings that contain Purbeck Marble may unintentionally harm the fragile stone by scuffing column bases or scraping other elements with bags and rucksacks. Abrasive material may be carried in on the soles of shoes, or visitors may step on pieces of flaking stone that have fallen from the columns, which will then be ground into the floor. Visitors and occupants will often pick at loose fragments, too. Although human touch actually creates a protective greasy layer, it does not prevent the surface from spalling.

There are a number of ruins that contain elements of Purbeck Marble. These may experience additional problems, caused by plant growth and frost damage, for example.

Iron was generally only used to fix elements of a chest tomb together, or as pins for securing columns in place. Iron will corrode in the presence of air and moisture. This corrosion causes the iron to expand, which, in turn, leads to splitting or damage to the stone.

It has also been reported that the original working of the stone causes micro cracking, bruising and consequent weakening of the surface. However, the implications of this on the durability of Purbeck Marble has not been evaluated.

Figure 22: A monument to Edward II (1284-1327), dating from the 1330s, in Gloucester Cathedral. Low-level abrasion and surface deterioration due to combination of visitor action and rising moisture.



4 Historic treatment of Purbeck Marble

4.1 Polishing and surface treatments

Polishing is the traditional way to prevent decay in marble. As early as AD77, Pliny the Elder advocated this method as a protective measure. While polishing alone will not completely prevent or stop decay, it plays an essential role in protecting both Purbeck and 'true' marble. This is because polishing closes the pores of the stone, which helps to minimise water penetration. Rough surfaces also have a greater surface area than smooth ones of the same dimensions. Polishing the stone will reduce the area that is exposed to moisture.

Early texts indicate that, after polishing, Purbeck Marble was originally protected by a layer of linseed oil, beeswax or goose grease. Any protection this provided was only temporary; it did not remove the need for appropriate maintenance. It is evident that there were attempts to reapply protection over the centuries, but unfortunately the materials and methods used are not well recorded.

In many cases, maintenance did not occur frequently enough, or even at all. Eric Benfield wrote (in 1940) (see 2011 reprint):

> *The durability no less than the beauty of Purbeck material is proven by survival in forms which are still a delight to look upon. In those cases where Purbeck Marble shows signs of deterioration, particularly the cylindrical shafts forming clustered columns in churches, the fault can be attributed to consistent neglect. It was not realised that the polished marble needed attention. Had these finely wrought features been waxed from time to time and protected from damp, decay would not have set in.*

4.2 Surface consolidation

A process known as 'induration' is perhaps the most widely used and earliest well-recorded method of surface consolidation. Sir George Gilbert Scott described it in 1855 in reference to his attempt to repair the Purbeck Marble of the royal tombs in the sanctuary at Westminster Abbey, which had begun to disintegrate:

> *I wish to cement together the disintegrating particles as both to prevent them from coming away and also to exclude the humidity which causes the decay. For this therefore I make a weak solution of white shellac in spirits of wine [ethyl alcohol, later replaced with methylated spirits as a cheaper alternative]; this I inject by means of a gardener's syringe the end of which is perforated with numerous holes so small that jets of water have not force enough to wash away the loose particles of stone. The weak solution soaks in as far as the decay has proceeded and the resinous matter is deposited six times with a day's interval to each for drying. The last injection is stronger than the othdvers – the necessity for penetration being less. I find that the process secures the loose particles and hardens the decayed stone and I have no doubt will effectually arrest the decay. Such parts as have scaled off are firmly re-attached by strong shellac cement.*
> (from Jordan 1980)

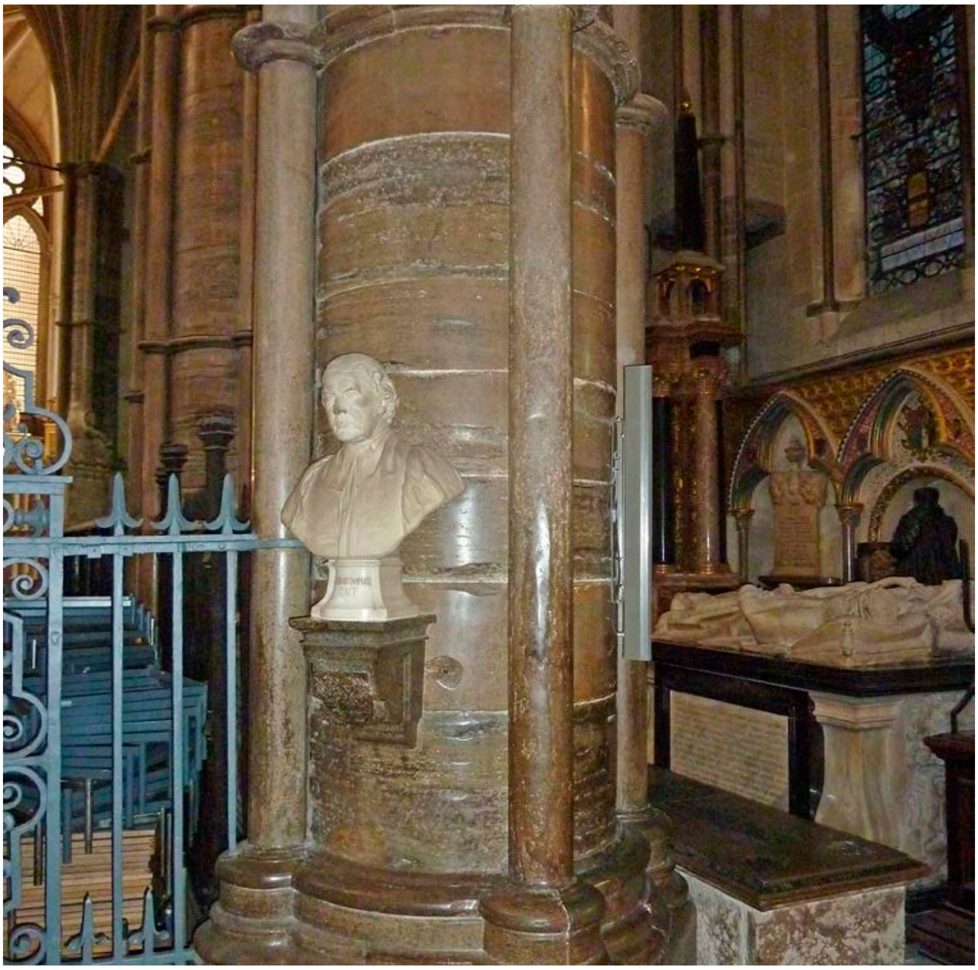


Figure 23: Brown colouration of Purbeck Marble as a result of 'induration' with shellac carried out on all the columns and monuments at Westminster Abbey under the direction of the Surveyor of the Fabric, Sir George Gilbert Scott, during the 1850s.

This 'induration' proved highly successful in reducing ongoing decay: the shellac remains in place, although there is some localised blistering. It is less successful in aesthetic terms, though, as the surface colour has changed from the green/blue hue of the original Purbeck Marble to a deep chocolate brown.

Many other materials have been used with varying degrees of success. Attempts in the 1970s to consolidate and protect the surface of the decayed Purbeck Marble at the church in West Walton, near King's Lynn, with polyurethane varnish resulted in failure, the surface yellowing and flaking in both external and internal locations. Another recommended treatment, used in the 1990s, was a mix of cosmolloid wax, ketone 'N' resin and white spirit. There has been no evaluation of its success.

Shellac

Shellac is a natural material consisting of tree sap digested and excreted by the lac bug. Chemically, it comprises a mixture of aliphatic resins. It is obtained by scraping the bark of the tree on which the 'sticklac' has been deposited. These scrapings are purified by heating and filtering. The liquid shellac is then allowed to form a hard crust on a flat surface. This crust is broken up into flakes, which is the form in which shellac is usually available. Colours range from colourless to deep brown, depending on the sap of the tree from which the shellac was collected.

Shellac is readily soluble in ethyl alcohol (among other solvents). It has been used widely in that form since the 17th century, not only as a varnish (particularly in French polishing) but also mixed with fillers as a mortar. Medieval craftsmen used it as glue between stones.

Over time, in the presence of ultraviolet light, shellac will oxidise, darken and cross-link, forming a material that is brittle and almost insoluble.

4.3 Surface repair

Mortar, plaster of Paris, resin and shellac have all been used to repair the surface of Purbeck Marble. They have been used to create repairs of all sizes, which can be coloured and finished to replicate Purbeck Marble.

Precise criteria for the success of mortar repairs do not exist, but it is best to consider them in terms of the original principles underlying any repair: protecting decayed stone and being compatible with the form, texture and colour of the original surface.

Unsuccessful repairs may alter the appearance of the original structure, as was the case with the columns, bases and capitals of the cloister at Norwich Cathedral. Repairs were crudely carried out in Roman cement mortar, which did not visually match the Purbeck Marble and obscured the detail of the underlying mouldings. Other unsuccessful examples include where repairs to a circular column have been faceted or where repairs have been found to sound hollow when tapped, thus indicating a degree of detachment from the substrate.

At both Ely Cathedral and York Minster, cementitious and plaster of Paris repairs were applied after decayed Purbeck Marble had been removed. In some places, these repairs were then painted and waxed to resemble the adjacent Purbeck Marble; in others, aggregates were chosen to make the repair mortar resemble the stone. There is also evidence of synthetic resins being used as a binder for plastic repairs at Chichester Cathedral. Whether measured in material or aesthetic terms, there have been successes and failures with all these options.

In the late 19th century, John Bacon (Clerk of Works at Ely Cathedral) used shellac as a binder for a plastic repair, rather than as a surface coating (see Kennedy 1995). His method was described as follows:

> *Where only the surface is broken, a piece of sound Purbeck Marble is crushed to the size of small shells or stones of which it is composed, and a fine sieve used to separate the dust. The aggregate is mixed well with shellac and resin and heated over a fire. The decayed parts of the pier are removed and the mix applied to the surface which has been heated by the application of burning charcoal with the aid of a pair of bellows.*

Figure 24: Cementitious repairs to columns carried out using the Bacon method at Ely Cathedral. Although they achieved a fairly good match in colour, the repairs show the difficulty of obtaining the correct surface texture and finish.

The repair is then rubbed with a piece of hard York stone, then with second grit then with snake stone reducing it to a complete smooth surface after which when perfectly dry it is rubbed over with linseed oil which after standing for a night is rubbed clean. Then a paste of spermaceti [a waxy substance from the head cavity of the sperm whale] and beeswax in equal parts dissolved in oil of turpentine over a fire is applied to the surface and well rubbed in with rags.

In general, these repairs have survived well, but they are in a stable, warm, dry environment.

Another method of repair was attempted at Canterbury Cathedral, where a technique referred to as 'scagliola' (pigmented gypsum plaster mixed with animal glue) was used in the mid- to late-19th century. In fact recent investigation has revealed that this treatment was not true scagliola, but a simpler homogenous mortar repair. It comprised lime and sand, with linseed oil probably incorporated into the mix and also applied to the surface of the repair.

Although this initially made the repair hydrophobic, the mortar softened on prolonged contact with water, presumably because the linseed oil degraded and was no longer acting as a hydrophobic agent. The mortar also included iron oxide pigments to match it to the brown Purbeck Marble (although this was not the colour of the original stone, but a product of the cross-linking and darkening of an applied coating). As the extant original Purbeck has either decayed or been cleaned (by removing the applied coating), the repairs, though remaining generally sound, now stand out because of the colour difference.

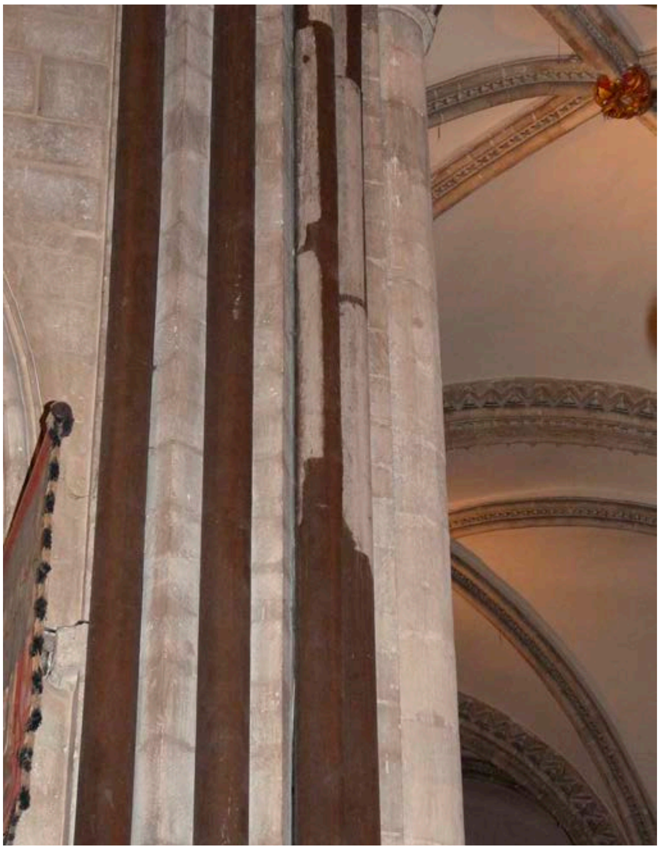


Figure 25 (left): Scagliola repairs at Canterbury Cathedral were applied to match the dark brown surface of the Purbeck Marble as a result of discolouration of a wax surface coating. However when the surface coating was removed, the repairs now appear in stark contrast to the original pale colour.

Figure 26 (below): A cut-away detail of the scagliola repairs which reveals the original deteriorated surface and the extent of the repair.

Figure 27: An example of multiple repairs to a capital in Norwich Cathedral cloisters using perhaps three different mortars, none of which provide a good aesthetic match. Note the unrepaired capital behind.

4.4 Structural repair

Structural repair was usually restricted to vertical splits along bedding planes in shafts and columns. It generally involved either pointing up the fissure or applying some form of collar as a brace against further splitting.

Both approaches proved problematic. Pointing up the fissure only temporarily solves the problem, as the splits often continue to grow. Applying a collar or brace prevents further splitting, but is visually obtrusive.

4.5 Repositioning stones

Another approach was to hide the decaying Purbeck Marble, rather than try to repair it. The outward-facing elevation of a column is more exposed to moisture, environmental fluctuations, pollution, potentially damaging remedial treatments and general wear and tear than the inward-facing elevation, which most occupants and visitors never see. Rotating the damaged column hid the decayed side. This, of course, is not a treatment that can be repeated, but it has been used to good effect at Norwich Cathedral.

Figure 28 (above): An example of using a copper band to provide medium to long-term security for a column at Ely Cathedral. Signs of cleavage are evident.

Figure 29 (right): An example of using cable ties to provide short-term stability for splitting column. A stainless steel bar has been incorporated to provide rigidity.

4.6 Restoring surface polish

Although there have been many attempts to restore the polish of Purbeck Marble, most of the specific ingredients used in past treatments have been unrecorded. Architect Bernard Fielden's intervention on the Walter de Gray tomb and other Purbeck Marble in the 1970s at York Minster is an exception. Fielden's method consisted of stripping surface treatments with dichloromethane paint remover, rubbing down the stone with 'cream grit' and then 'snake stone', and finally polishing it with putty powder (containing tin oxide) and oxalic acid crystals. (Unfortunately, the constituents of 'cream grit' and the nature of 'snake stone' are not described). This approach was broadly successful in that the lustre and appearance of the Purbeck Marble were restored and still remain intact (The Sir Bernard Fielden Archives, York Minster Archives).

In some cases, decayed material is removed and the surface buffed to a high polish with no attempt to retain the cylindrical shape of the shafts. Although this preserves some of the desired qualities of the Purbeck Marble, the variable topography of the surface can be visually disturbing.

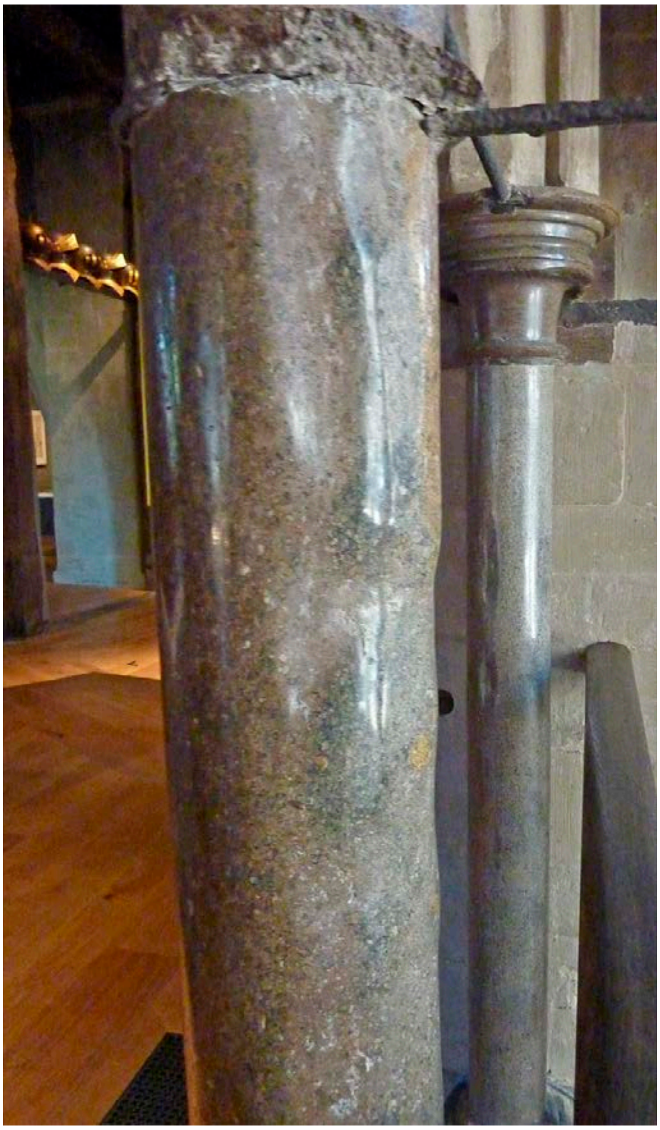


Figure 30 (left): Deteriorated material has been removed and the surface polished, but this has left the column with an undulating topography that is very obvious in reflected light.

Figure 31 (above): A Purbeck Marble column base in Canterbury Cathedral reworked (in the 1930s) to remove decayed material and then polished. The surface is now sound but the detail of the form has been lost.

4.7 Replacement

In the past, decaying Purbeck Marble columns were often replaced. Ideally another column made of Purbeck Marble was installed (for example, in the choir of Ely Cathedral), but other stones were used, too, either due to cost or lack of availability of the original stone. Examples include the extensive replacement (using Bath Stone) of columns in the cloisters of Norwich Cathedral and the widespread replacement of Purbeck Marble (using Chilmark Stone) on the exterior of Salisbury Cathedral. The use of different stones has a significant effect on both the design and overall aesthetic appearance. However, Alwalton Marble (another polishable limestone from Cambridgeshire) was used at Lincoln Cathedral in the 19th century; visually, this is quite a good match and it has generally weathered well.

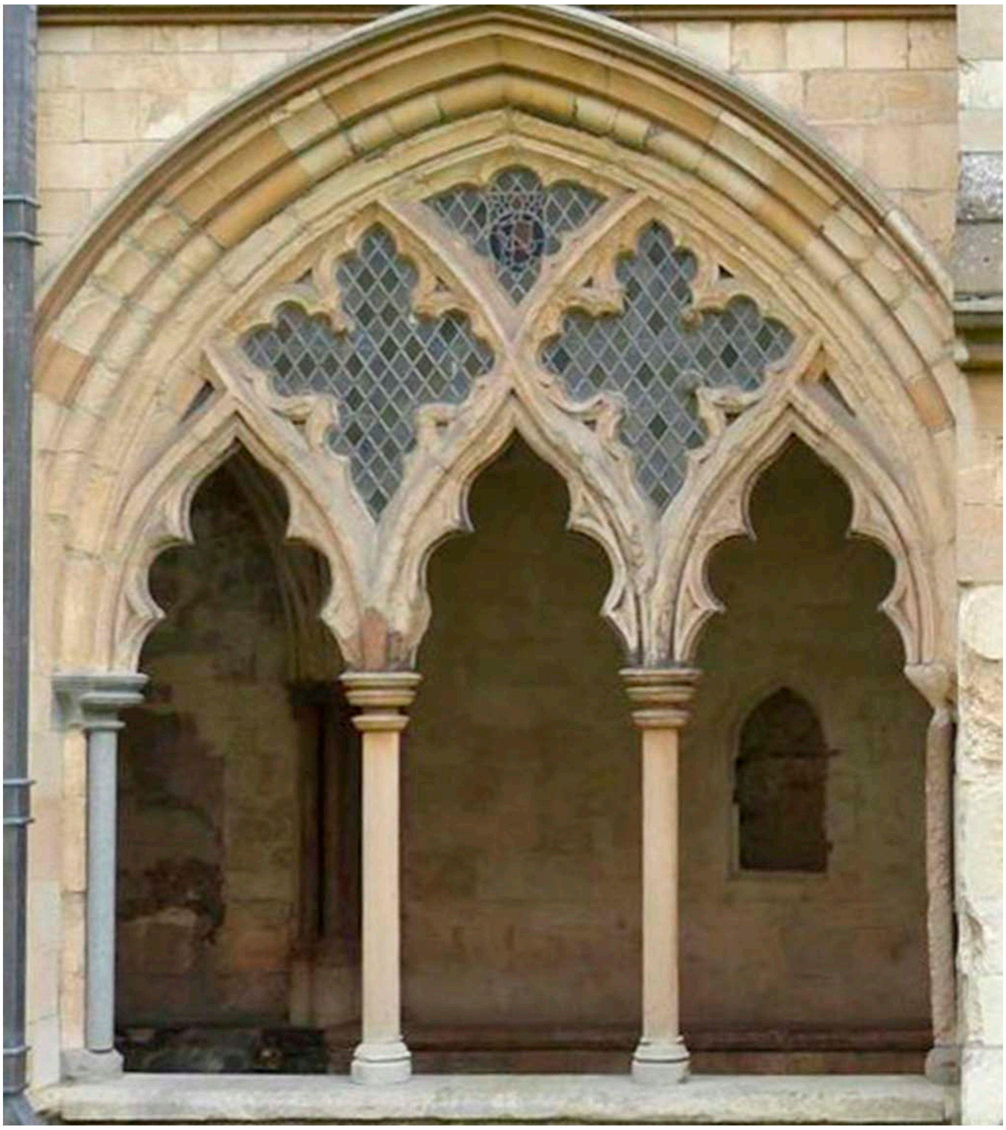


Figure 32: A single bay of Norwich Cathedral cloisters showing an original Purbeck Marble column (right), a replacement Purbeck Marble column inserted in 2001 (left) and two Bath Stone columns (centre) which are 19th century replacements for original Purbeck Marble columns.

If new Purbeck Marble is not available for replacement, limestone columns can be painted to resemble Purbeck Marble. This solution was used in the north transept and Zouche Chapel in York Minster. It was so skilfully done, it is hard to see the difference.

Figure 33: Zouche Chapel, York Minster: a polished Purbeck Marble column cluster (left) and replacement Bath Stone column cluster painted to look like Purbeck Marble (right). The painted stone has a good colour match, but lacks the depth of sheen which a polished Purbeck Marble surface provides.

5 Assessment

Effective solutions to any problem require a sound understanding of the causes. This involves identifying the material, assessing its condition and understanding the environment in which it exists. It is only after a detailed assessment of the condition and causes of deterioration of Purbeck Marble that appropriate treatment can be proposed.

Figure 34: Capitals of a column cluster in Salisbury Cathedral showing a variety of issues including ongoing decay, poor previous repairs and (repaired) damage from the expansion of an iron bar.

5.1 Identification

In general, Purbeck Marble is easily recognisable, although it is rare to see it in its original state because much of it is now obscured behind layers of discoloured coatings. Examining the surface of a replacement stone with a x10 magnifying hand lens will reveal if it has the typical shelly matrix of true Purbeck Marble; it may be necessary to scrape away a small area to reveal the underlying surface. Examination is best carried out in undercut or hidden areas, where coatings tend not to have been so easily or heavily applied.

Creating a Purbeck Marble inventory

Recording the location of all Purbeck Marble within a building will provide a useful baseline for subsequent assessment. An inventory should include ground plans and elevations and should identify types, for example, column, capital, floor, monument. All these elements should be recorded and photographed.

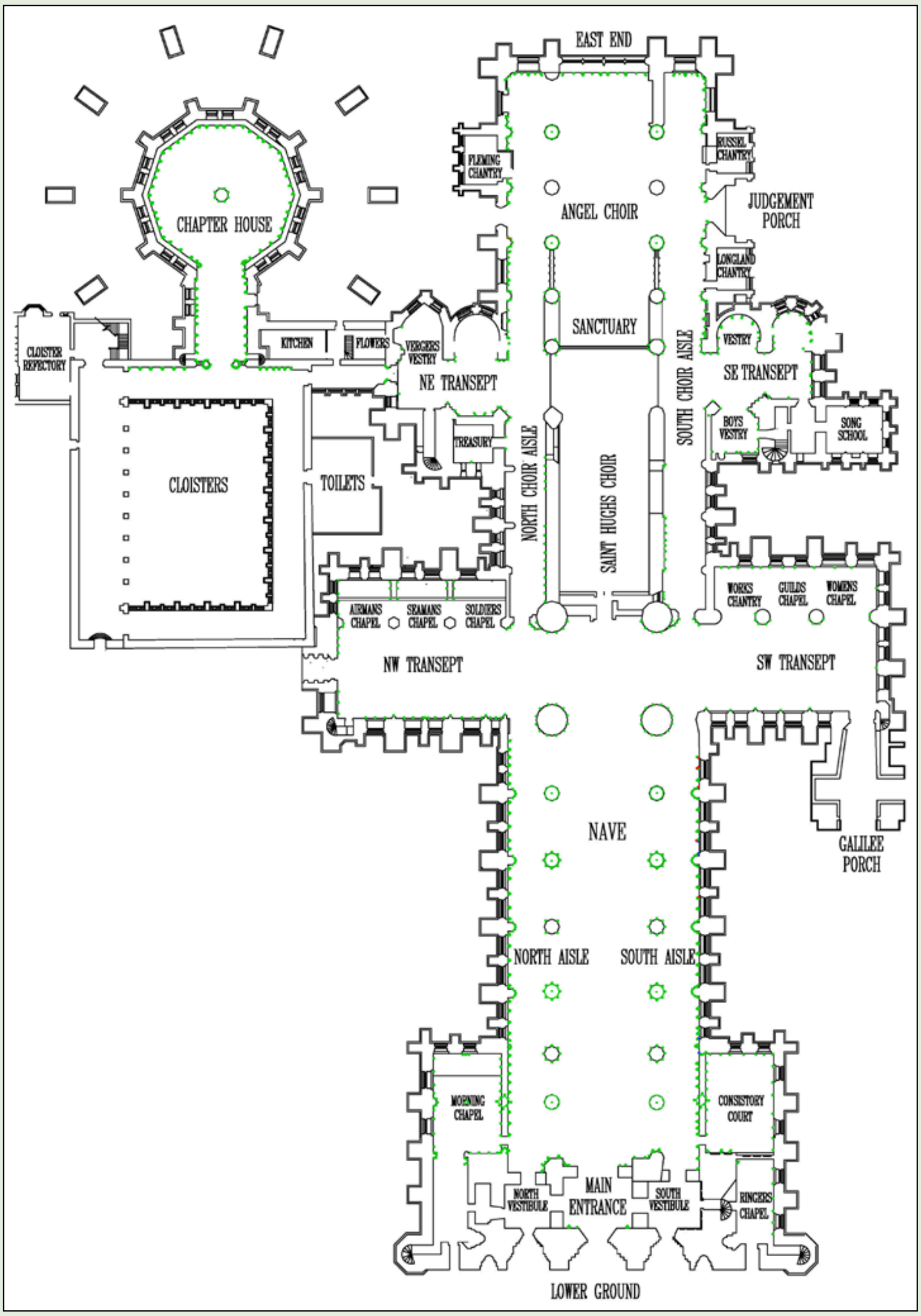


Figure 35: A ground floor plan of Lincoln Cathedral showing the location of Purbeck Marble elements.

5.2 Condition survey

For Purbeck Marble, there are significant interrelationships between the various agents of decay. It is important to understand the nature and extent of this decay and to record any observations (including general and local environment) on a drawing or annotated photograph. This provides useful information regarding patterns of decay.

The polishable limestones project created a method to map the decay (see Appendix A); it is particularly useful for structures that contain many significant Purbeck Marble elements. In cases where there are only a few pieces of Purbeck Marble, especially if they are not highly significant, it will usually be sufficient to simply categorise the condition using the criteria below:

- **Stable**: little or no ongoing decay visible. Condition not expected to deteriorate within the next 10+ years
- **Deteriorating:** noticeable active loss or damage. Condition likely to deteriorate within five years
- **Poor:** considerable loss of material or major break/fissure, which may endanger stability. Deterioration in condition imminent
- **Missing**: element no longer present

It can be difficult to make reliable assessments from a single condition survey. It is generally more useful to compare the current survey with earlier surveys or photographs. This will help to establish the rate of decay.

For more massive composite elements (such as the arcading in the nave at Lincoln Cathedral), there may be a variation in the condition of individual stones depending on their location and nature. This may require a more complex process of recording that takes a holistic approach and also identifies localised issues.

5.3 Further investigation and analysis

Where there is obvious decay (for example, elements that have been categorised as 'deteriorating' or 'poor'), a conservator or other experienced professional should carry out a more detailed survey. This will involve a visual inspection to record the condition in detail, and possibly some or all of the activities described below.

5.3.1 Assessing structural condition

Tap testing with a small chisel will normally reveal the structural condition of a Purbeck Marble element such as a shaft or column. In sound condition, this would normally produce a distinct sharp sound, but discontinuities will be revealed by a muffled hollow sound. Increased resonance or ringing will indicate that the stone is under stress, usually as a result of compressive forces. Discontinuities can also be mapped using ultrasound, which passes sound waves through from one side and measures them on the other. A structural engineer should always be consulted if there are any obvious structural defects.

5.3.2 Locating embedded iron

Iron is most likely to be found in the form of dowels and cramps in shafts and monuments. Its presence is usually indicated by staining, cracking, detachment or disruption of the stone adjacent to a joint. A cover meter can be used to locate iron, but the accuracy of the results will depend on how deeply the metal is embedded. The presence of lead or the proximity of other ferrous materials can cause misleading results. A possible (but more expensive) alternative is to use radar.

5.3.3 Environmental monitoring

Environmental data loggers can be used to record ambient temperature and relative humidity. This provides information on environmental fluctuations that may be affecting the Purbeck Marble. In some situations (for example, in cloisters), recording of surface temperature is also beneficial because it allows condensation events to be identified.

5.3.4 Identifying surface coatings

There is no easy way to establish the nature of surface coatings. However, it is sensible to start with simple, cheaper investigations. Such a process might involve:

- visual examination with a x10 magnifying hand lens
- archival research to find out if there are records of historic treatments, such as the induration with shellac of the royal tombs at Westminster Abbey
- examination with a USB microscope; this can reveal the presence of surface coatings, although it is unlikely to identify them
- small-scale trials with white spirit on cotton swabs to determine the presence of beeswax or other waxes
- portable X-ray fluorescence to identify the elemental composition of the surface
- taking a small sample and carrying out polarised light microscopy on a thin section to identify layers
- analysis of organic binder using Fourier transform infrared spectroscopy and/or gas chromatography/mass spectrometry

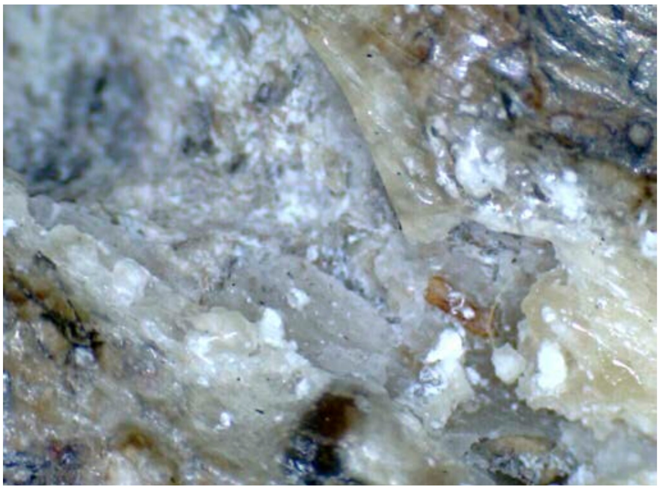


Figure 36: USB microscopic image (x50) showing resinous coating which has previously been applied to the Purbeck Marble. This has now dried, contracting away from the surface.

All investigations are open to interpretation. Even if all of the above are carried out, it may still be difficult to identify the coatings, particularly as they may have changed over time. Commissioning more involved and more expensive investigations may be necessary.

5.3.5 Identifying surface repair materials

It can be hard to determine where repairs have been carried out because they are often hidden beneath subsequent coatings. It is important to distinguish between information that is required to help assess deterioration and that which is simply of historic interest. As with the analysis of surface treatments, procedures need to start with the simpler, cheaper methods and move on to more detailed examinations. This process might involve:

- visual examination with a x10 magnifying hand lens
- archival research to find out if there are records of historic treatments
- examination with a USB microscope; this can reveal the presence of aggregates and may give clues as to the binder
- analysis of mortar samples using simple disaggregation analysis
- analysis of samples using techniques such as scanning electron microscopy, energy dispersive X-ray, X-ray diffraction and infrared spectroscopy

6 Conservation and repair

Since the polishable limestones project in the 1990s, there have been a number of trials of the repair of Purbeck Marble. Some of these are summarised in the table of methods in Appendix B. This is not a comprehensive record of all the trials, but highlights the diverse approaches to problems that are superficially similar but may differ in the degree of decay or the range of previous treatments applied.

Figure 37: This column cluster in Salisbury Cathedral cloisters was subject to a variety of trials in 1993, but assessment of the results has been limited because there has been a subsequent programme of replacement and re-coating with microcrystalline wax.

The processes described below present a coherent strategy for the effective maintenance and repair of Purbeck Marble. As with any stone conservation, all interventions carry a risk to the original fabric and should only be undertaken after thorough assessment. Because of the complexity of Purbeck Marble, it is essential that the work is carried out by a suitably qualified and experienced conservator.

6.1 Mitigating causes of decay

Usually the decay of Purbeck Marble is caused by a combination of factors interacting in a complex process. Many of the causes have their roots in the mineralogical make-up of the stone, the location and environment in which the stvone is set, or the previous treatments to which it has been subjected. Few of these factors can be changed or controlled, but it is important to try to understand them and to take steps to mitigate decay where possible.

Preventive measures are always beneficial. Maintaining roofs, gutters and drainage will ensure that they work efficiently and do not leak. It may also be possible to regulate the internal environment by using heating or ventilation systems to reduce condensation. If a surface coating is known to be a major cause of decay, it may be necessary to reduce or even remove it (see 6.3.2).

6.2 Repair trials

It is essential to trial repair techniques (including cleaning) before work begins. These trials will determine what is achievable within the constraints of suitable conservation techniques, established conservation principles and budgets. There are a large number of methods for conservation outlined in Appendix B. An experienced conservator can narrow these down by assessing both the results of the condition survey and information about previous treatments.

Figure 38: Cleaning trials on a Purbeck Marble column on the north choir aisle at York Minster involved a variety of methods including sponges, poultices and solvents.

Trials should always be carried out on representative areas, and, if possible, on surfaces hidden from view. They should be reviewed both immediately after treatment and several weeks later, when the stone and any consolidant/mortar/coating will have had a chance to establish equilibrium with the substrate and local environmental conditions.

6.3 Conservation and repair

There is no unique specification for the repair and conservation of Purbeck Marble. Like any other stone, its treatment can only be established after assessing its condition and mitigating any causes of decay. In most cases, treatment will include some or all of the following:

- cleaning
- removing or reducing previous coatings
- structural repair
- grouting splits or fissures
- consolidating decaying surface
- surface repair
- surface protection
- repositioning
- replacement

6.3.1 Cleaning

Cleaning refers to the removal of surface dust, dirt and any accumulated deposits such as sulphation. Although it is quite rare to find polychromy on Purbeck Marble (except on a few effigies and monuments), it is important to establish whether the surface deposit is obscuring any original paint.

The choice of cleaning method will depend on the condition of the substrate and the type of dirt, and also the effect on any underlying surface coating. Small-scale trials are essential. Possible methods include:

- wiping with white spirit or 'V&A mix' (50:50 water/white spirit with <1% Synperonic A7) to lift surface dirt
- wiping with damp melamine or microporous sponge; this uses minimum water and removes surface dirt without damaging the surface

- dry steam cleaning (usually >150°C) and catching run-off with a clean sponge; this loosens surface dirt, but prolonged dwell time may lead to some roughening of highly polished surfaces

- applying a natural latex poultice, with or without ethylenediaminetetraacetic acid (EDTA). As it cures, the latex adheres to and retains the surface dirt; it can then be peeled off. However, it is not suitable for friable or rough surfaces, as loose sections of the substrate will also be removed and fragments of latex can be left behind in cracks and crevices. Latex containing EDTA should be avoided on highly polished marble as it will tend to etch the surface

- applying an ammonium carbonate poultice on areas of sulphation. The concentration of the poultice, type of medium and dwell time can all be manipulated to provide the desired effect. A typical poultice might contain an 8% solution (weight/volume) of ammonium carbonate combined with a 50:50 mix of paper pulp (usually short-length cellulose fibre) and fumed silica

- using micro air abrasion to remove sulphate deposits from carved areas of Purbeck Marble. It can be used very sensitively at low pressures (1–2 bar) and with a range of aggregates (usually calcite or dolomite)

Figure 39: At Norwich Cathedral cloisters, the heavily soiled and coated columns were cleaned using a poultice of synthetic latex and EDTA. Dwell time had to be carefully controlled to avoid over cleaning and all the poultice material had to be removed using dry steam.

6.3.2 Removing or reducing previous coatings

In some cases, it may be necessary or desirable to remove, or at least reduce, previous surface treatments or coatings in order to:

- prevent problems caused by moisture ingress through impervious or brittle cracked coatings
- improve adhesion of repair mortar
- reveal the condition and original colour of the Purbeck Marble

Trials are essential before any reduction or removal. They will reveal if the surface coating is hiding earlier repairs that once matched the soiled or darkened surface. Complete removal is often neither possible nor desirable, in which case partial removal may still allow for better assessment of condition and subsequent application of new surface treatments.

Figure 40: Removal of surface coatings can often reveal previous repairs beneath. These in the north choir aisle at York Minster may be inappropriate either in appearance or composition and will need to be re-done.

Suitable methods for removal are generally based on dissolving the coating. Solvents can be organic or inorganic. The choice will depend on the nature of the surface coating and the desired result. Possible materials include:

- ammonium carbonate
- ammonium bicarbonate
- EDTA (usually only for unpolished surfaces)
- organic solvents (white spirit, industrial methylated spirit and acetone)

All these solvents can remain in close contact with the coating for a prolonged period when applied as a poultice. The dwell time can be established through trials. To facilitate removal, particularly if there is a rough surface, the poultice can be applied over Japanese tissue. Poultice materials might be synthetic latex (especially for EDTA), paper pulp, sepiolite (especially for organic solvents) or a combination of these. Fumed silica can also be used as an alternative to sepiolite, and there are other conservation grade mediums available.

Minimal amounts of water should be used to rinse poultice residues. Rinsing is best carried out using a dry steam cleaner (>150°C) and sponges to catch any run-off.

Where solvents are ineffective or where the coating is close to a decorated surface that is incompatible with the solvent, it may be possible to remove waxes by melting them. Heated spatulas or low temperature-controlled heat guns, used in conjunction with blotting paper, can be effective. Brittle coatings can be removed with micro-abrasive methods using small diameter nozzles; these are not advisable on softer waxes, which tend to absorb the energy of the abrasive and remain in place.

Figure 41: The Purbeck columns in Exeter Cathedral nave have been cleaned of dirt and surface coatings and left untreated.

The complete removal of surface coatings can make Purbeck Marble appear pale and sometimes bland. It is usually good practice, particularly in fluctuating environmental conditions, to apply appropriate new treatments to both protect the stone and improve its appearance.

6.3.3 Structural repair

It may be necessary to strengthen Purbeck Marble columns that have split along the vertical bedding, particularly if there is a risk of detachment. The brittle nature of Purbeck Marble means that drilling may lead to further fracturing, so inserting dowels across a split may not be possible. Instead, the best way to stabilise a split is to put retaining bands around the affected column. In the past, such bands consisted of copper, plastic cable ties or even duct tape; these last two are temporary options in emergencies and must be considered as a short-term fix only.

A neat method for stabilising a split is to use carbon-fibre ribbon (usually 25–50mm wide), which can be cut easily but is extremely strong in tension. This will not close up a split, but it will prevent it from developing further.

Figure 42: Canterbury Cathedral triforium: carbon-fibre tape provides stability for columns that may be splitting. The tape can then be disguised by covering with resin and crushed Purbeck Marble.

This repair should be carried out in the following way:

- apply an acrylic resin (for example, Paraloid B72 5% [weight/volume] in acetone) to the area of Purbeck Marble where the ribbon is to be located
- while the resin is still tacky, wrap the ribbon around the column with a minimum overlap of 100mm
- pull the ribbon tight and connect the ends with epoxy resin. It is helpful to secure a small length of timber with epoxy resin to the free end of the ribbon. This can be used to provide tension and then be cut off once the adhesive has set
- the ribbon can be disguised by applying epoxy resin to the surface and then covering it with Purbeck Marble dust or other aggregate/pigments while still tacky

The acrylic resin on the surface of the column will prevent the ribbon from slipping. If the ribbon is removed, the acrylic resin can also be removed, as it is reversible. An ultra-thin, flexible, carbon fibre tape (pre-bonded with an engineering-grade thermoplastic resin and coated on one side with adhesive) is currently in development. This will streamline the process described above.

Other structural problems may arise if the bases of slender columns degrade due to groundwater ingress and salt-driven deterioration. In such cases, the underlying cause will need to be addressed and additional stability provided. This might include:

- supporting the main column, cutting away the decayed section and indenting/replacing it with new Purbeck Marble
- providing rigid support at the base using stainless steel or another inert material

6.3.4 Grouting splits or fissures

It is not sufficient to simply secure splits and fissures in Purbeck Marble; it is also necessary to fill them to prevent moisture ingress causing further decay. Before this is done, it is important to ensure that the broken faces of splits and fissures are free from surface coatings. There will probably be a certain amount of debris in the voids, which must be removed for effective grouting. Do not use lots of water to flush out debris, as moisture may set off decay mechanisms. It is better to use a mixture of isopropyl alcohol or industrial methylated spirits (IMS) and water.

Figure 43: Completed grouting of a split in a column in Salisbury Cathedral cloisters.

Once cleaned out, voids should be grouted using the following technique:

- plug the outer part of the fissure with a removable sealant, such as cotton wool or clay
- insert small diameter (3–4mm) plastic tubes through the sealant at intervals (perhaps 100mm) along the fissure
- use a syringe (with a hypodermic needle to fit the tube) to inject grout into the lowest tube, and continue until the grout appears in the tube above
- remove the syringe, plug the lowest tube and repeat the process on the tube above until the fissure is filled
- once the grout has set, remove the tubes and the temporary sealant and make good with mortar to match the Purbeck Marble

Materials for grouting need to be free-flowing and have very low drying-shrinkage. There are proprietary conservation-grade grouts available, which usually contain modified hydraulic lime and surfactants. It is also possible to make up grouts using dispersed lime injection mortar (which is already formulated with surfactant), modified by adding finely ground pozzolan (such as trass) in a 50:50 ratio.

6.3.5 Consolidating decaying surfaces

Many materials, generally based on oils, waxes or shellac, have been used in the past to consolidate the decaying surface of Purbeck Marble. They provided some protection if used in a stable environment, but often discoloured the stone and failed in variable conditions.

There is a range of organic stone consolidants available, but little work has been done to understand the long-term effect of such consolidants on Purbeck Marble, particularly in environments susceptible to varying humidity levels (such as cloisters). However, there are a few examples of consolidants being used or tested on Purbeck Marble. Silane (Wacker OH) was used as a consolidant at Salisbury Cathedral, and trials at Ely Cathedral used other materials such as acrylic silane (Racanello), limewater, barium hydroxide and acrylic resin (Paraloid B72). The long-term effect of all these consolidants on Purbeck Marble is not yet understood. Visual inspection suggests that none of them seem to be causing deterioration, but further analysis and monitoring are necessary before any particular consolidant can be widely recommended.

For securing spalling surfaces, the most appropriate proven methods are:

- securing individual spalls with dispersed lime injection mortar. Dispersed lime is a natural lime putty (not synthetic like nanolime) with a very small particle size. For the injection mortar, it is mixed with a surfactant to allow good flow characteristics. Because of the small size (and therefore high surface area), dispersed lime is very reactive. It is normally mixed with a small amount of water, pigments and perhaps a powdered pozzolan (such as trass) and injected behind and around the friable sections, using a hypodermic syringe with a 2mm needle. Excess mortar can be removed with a small spatula once it has set. This material may not adhere well to surfaces that retain hydrophobic coatings, such as wax. Consequently, such coatings should be removed beforehand if possible.

- securing individual spalls using acrylic resin (such as Paraloid B72). This is a proven method for adhering small fragments, but it can cause problems in damp environments. It is, therefore, not suitable for use on Purbeck Marble exposed to high levels of humidity, or in external locations.

6.3.6 Surface repair

Mortars should be used primarily to protect the decayed surface, but they can also be added to make up missing detail where this is evident. In the past, Portland cement, Roman cement, plaster of Paris, epoxy resins, shellac and beeswax have all been used as binders to repair Purbeck Marble. Although these repairs may have been well executed, and only apparent on close inspection, few accurately mimic the texture and colour of the stone. As a result, they tend to rely on applied surface coatings to blend them in.

Mortar repairs based on lime binders are suitable for almost all environmental conditions and are preferable to other binders. However, the mortar will need to be trialled before it can be used, because the condition of the stone surface will affect how it should be applied and finished.

Figure 44: Using dispersed lime injection mortar (mixed 1:1 with trass) to secure spalls of an internal Purbeck Marble string course at York Minster.

Although the texture of an eroded Purbeck Marble surface can be replicated using selected aggregates, matching colour is far more difficult. However, recent work at a number of locations has shown that sensitive application of pigments to the surface of lime mortar can successfully mimic the overall appearance of Purbeck Marble.

Matching lime mortars to polished Purbeck Marble is more difficult and requires a subsequent application of wax. Some success has been achieved by incorporating casein into the mortar mix. Although this makes the mortar rather viscous and therefore hard to apply to vertical surfaces, it can be polished when set.

Generally, mortars will not adhere well to surfaces that have residues of coatings with hydrophobic properties, so removing such coatings may be necessary before any mortar is applied. In addition, the low porosity of Purbeck Marble makes adhesion to lime mortars more difficult. It is important, therefore, that suitably qualified and experienced conservators carry out the work.

In some situations, mortars may require additional support, which is best provided by using ceramic 'T' armatures. Ceramic is preferable to stainless steel (or other metal) because the mortar has better adhesion to a porous armature and the two materials have more compatible physical properties.

Mortars will usually be formulated specifically for individual projects.

Figure 45: The top of a chest tomb at Chichester Cathedral before (above) and after (right) consolidation of spalling Purbeck Marble with dispersed lime injection mortar.

Some recent examples include:

A Repair of Purbeck Marble in an internal environment

Lime putty or hydraulic lime (NHL2)	2*
Chievely sand	1
Purbeck Marble aggregate <300µm	1.5
Purbeck Marble aggregate <1.18mm–>300µm	0.5
Coarse white marble aggregate	1
Pigments (raw umber and terre verte)	1ml per 30ml mortar approx

*If using dispersed lime, the measure can be reduced to a maximum of 1

Surface matching can be achieved by applying casein mixed with pigment or using watercolours. To finish, microcrystalline wax is applied to both the repair and surrounding stone.

B Repair of columns in mixed internal/external environment (for example, cloisters)

Hydraulic lime (NHL2)	1
Purbeck Marble aggregate <150µm	1
Purbeck Marble aggregate <900µm–>150µm	1
Purbeck Marble aggregate <1.8mm–>900µm	1
Casein	2.5% (by volume of binder)

This mortar could be moulded and rubbed down, and the surface finally polished with microcrystalline wax.

C Repair of capitals and other decorative Purbeck Marble in mixed internal/external environment

Lime putty	1
Nosterfield river sand	0.5
Moreton Cullimore washed coarse sand	1
Crushed oolitic Bath Stone <1.18mm	0.5
Charcoal dust <1mm	0.5
Crushed Purbeck Marble <2.36mm	0.5

Dry earth pigments (raw umber, burnt umber, raw sienna, burnt sienna, yellow ochre, terre verte and ivory black) can be used to tone in repairs. While the mortar is still wet, small amounts of pigment are scooped onto a metal spatula and blown directly onto the surface to mimic the colouring of the stone. As the mortar cures, the carbonation of the lime fixes the pigments to the surface.

As an alternative to applying pigments to the surface (or in conjunction with this method), the underlying mortar may be made up of several mixes in varying shades. These can then be selectively worked in together to add a greater depth of variation, which helps to emulate the character and colour of surrounding original stone.

Other possible additives to mortars include glass beads, pozzolans and anti-oxidants (to reduce oxidation of pyrites and glauconite).

Figure 46: Repairs to the Cosmati pavement at Westminster Abbey were carried out using Paraloid B72 to consolidate the surface, and mortar repairs based on NHL2 hydraulic lime. The repair surfaces were then touched-in with watercolours, followed by a protective coating of microcrystalline wax.

Figure 47: Repairs to Purbeck Marble capitals in Norwich Cathedral cloisters:
(top left) A Purbeck Marble capital prepared for repair with loose material removed and ceramic armatures in place.
(top right) Repairs of a Purbeck Marble capital completed using mortar based on lime putty.
(bottom) Repairs to a Purbeck Marble capital completed with pigments blown onto the surface.

6.3.7 Surface protection

Surface protection has been and remains fundamental to the long-term survival of Purbeck Marble. Because microcrystalline wax does not go brittle or discolour, it is the best material available to protect the surface of Purbeck Marble.

An important reason for applying a protective coating of pure microcrystalline wax is that it facilitates cleaning because it is readily reversible in white spirit. Consequently, future surface soiling may be easily removed and the coating replaced, thus avoiding the need for a more intensive clean and the associated risks to the original fabric.

Microcrystalline wax comes in two forms: pre-made, such as cosmolloid wax, or beads that can be grated and mixed with white spirit to make wax of the required concentration. It is best applied with a cloth or brush to a clean substrate. The initial coat is usually applied quite thinly to allow the wax to get into all the small crevices. Alternatively, the surface can be warmed with a hot-air gun immediately prior to applying the wax; this will encourage even distribution. It is usual to apply up to three coats.

Wax can also be applied to surfaces that already have other existing treatments. Indeed, it can be effective at filling micro cracks in previous treatments. Other materials, such as linseed oil and goose grease, may also be appropriate if it is essential to use an authentic traditional treatment.

Although applying a protective coating is generally good conservation practice and will protect the stone against external influences, there are situations (particularly in damp environments) in which problems may arise if moisture gets behind the coating. This can cause the surface to become milky. It is also possible that existing mechanisms of decay, such as oxidation of pyrite within the stone, may continue and cause disruption to the surface.

Figure 48: Trials of various coatings in Canterbury Cathedral; including beeswax, microcrystalline wax, linseed oil and goose grease.

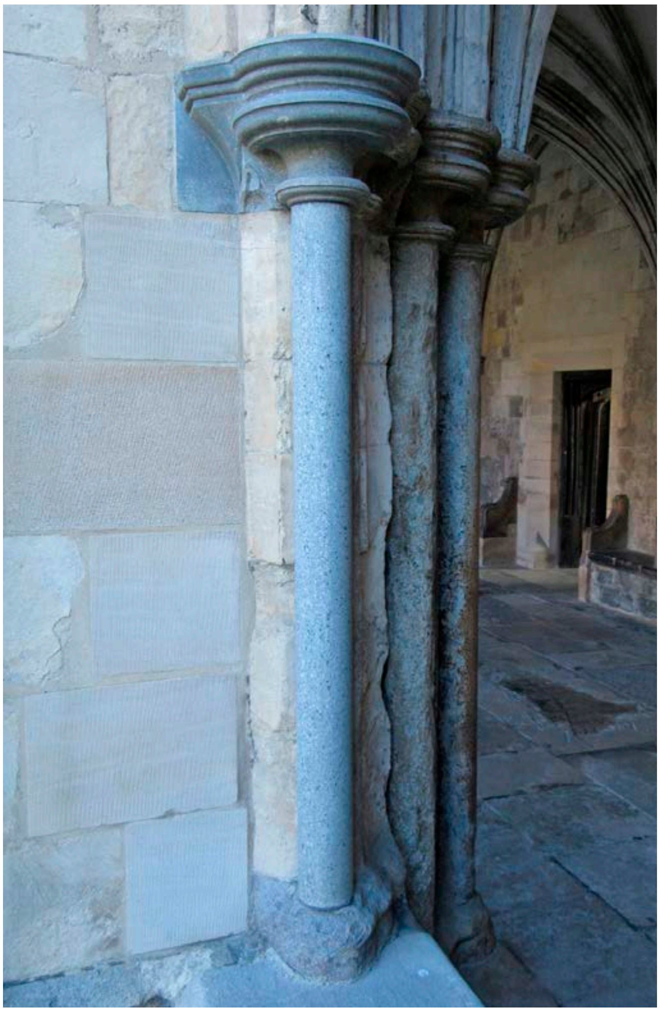


Figure 49: A new Purbeck Marble column and capital in Norwich Cathedral cloisters. The surface has been given a honed finish rather than polished. Microcystalline wax has been applied as a protective finish.

Figure 50: A new Purbeck Marble column in Salisbury Cathedral cloisters inserted and treated with pigmented wax.

6.3.8 Repositioning

Many columns have sides that are hidden from view and are protected from numerous environmental threats. These hidden sides will often be in better condition than the visible ones. Conservators can take advantage of these differences in decay by repositioning the element. In the case of a column, the mortar and any other fixings are removed from the joint and the column is rotated. In some cases, the decayed areas may first need to be faced up with Japanese tissue to prevent further loss. A similar process of reversal might be possible for floor slabs, but only if the underside has been finished to a smooth surface.

The natural 'aged' look will be lost, and since conservation should never seek to make areas 'new' again, decisions on repositioning will normally only be appropriate where safety issues, such as trip hazards, are the dominant issue.

Figure 51: Insertion of new Purbeck Marble into the framework of the Cosmati pavement at Westminster Abbey.

6.3.9 Replacement

If the stone is beyond repair, there may be no alternative but to replace it. However, even though the new Purbeck Marble may match the older stone geologically, it usually will not match it visually. All new Purbeck Marble should be treated with microcrystalline wax.

Visual contrast will be a problem with any replacement material, but the disparity between old stone and new seems particularly obvious with Purbeck Marble. In situations where visual harmony is more important than 'honest repair', small amounts of earth pigment can be added to the wax to reduce this disparity.

Purbeck building stone is still actively quarried by a number of companies and much of it is used for flooring. However, the latest edition of the Natural Stone Directory (2020/21) lists only a single source for Purbeck Marble: Quarr Farm. This is run by W J Haysom & Son, which is the oldest established supplier, dating back to the 17th century. The mine here is worked periodically as required. The stone is predominantly green or blue with a bed height of around 300mm. This remains the best match for the replacement of Purbeck Marble architectural details, columns and carved elements.

If Purbeck Marble is not available, other options for replacement include using a different stone, which is then either left as an 'honest repair' (that is, accepting the reduction in aesthetic heritage value) or painted to look like Purbeck Marble. Although such interventions have been used in the past, they should only be considered as a last resort.

7 Maintenance

Maintenance plays an important role in the conservation of any heritage asset. This is especially true with a material like Purbeck Marble, which has a propensity to decay. Maintenance routines will vary depending on the significance of the asset, its accessibility and its surrounding environment, but in all cases, some very simple procedures, such as monitoring, dusting and vacuuming, will help the stone's long-term survival.

It is important to keep Purbeck Marble clean because abrasives such as dust can be ground into the surface, harming the fragile stone. Monuments and effigies should be dusted regularly: perhaps once a year. Floors should be vacuumed using a soft brush attachment. If the floor is significant, this should be done frequently. The Cosmati Pavement in Westminster Abbey, for example, is vacuumed and then buffed with a clean lint-free cloth once a week. Less significant floors should also be vacuumed regularly; how often will depend on the amount of use.

Moisture is possibly the greatest threat to Purbeck Marble. Columns and shafts, especially those in areas where the environment is variable, may be particularly vulnerable to condensation and moisture damage. Although it may not be practical to remove condensation as it appears, any other sources of water should be investigated. The best form of maintenance is to carry out regular inspections and check that all drainage and rainwater goods in the area are working correctly.

If Purbeck Marble has lost its polish, it is more vulnerable to decay. Reapplying surface protection will not only restore the beauty of the stone, but also protect it from further deterioration. Regular inspection will enable conservators to check the condition of the surface and draw up maintenance plans for elements that may be vulnerable.

Simple steps can be taken to reduce the impact of visitors on Purbeck Marble. Doormats can be installed at entrances to reduce the erosion of Purbeck Marble floors, or pieces of furniture can be strategically placed to prevent visitors inadvertently touching vulnerable surfaces.

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A database of Romano-British inscriptions is available at romaninscriptionsofbritain.org

A database of Romano-British Purbeck stone archaeology by John Palmer is available at www.palmyra.me.uk/pur-preface.html

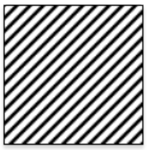
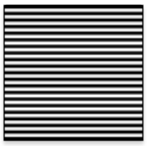
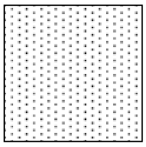
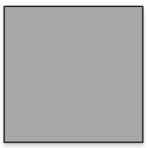
9 Appendix A

System for mapping decay of Purbeck Marble

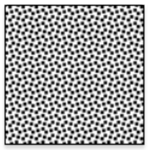
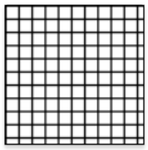
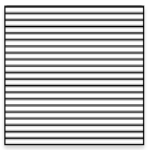
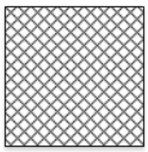
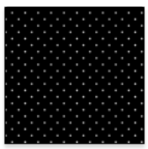
This table was prepared as part of the polishable limestones project carried out in the 1990s and reported at the 9th International Congress on Deterioration and Conservation of Stone in Venice (2000). Its purpose is:

- to assist in the understanding of decay trends
- to simplify and adapt existing surface decay mapping systems (for example, the Fitzner system, Normal system) specifically to Purbeck Marble
- to develop a simple reiterative system that can be used and repeated quickly and cheaply on site
- to devise a system that relies on simple graphic processes that can be digitised, overlaid and manipulated to form a permanent baseline for future recording

System for mapping decay of Purbeck Marble (Historic England, 2021)

Code	Classification	Suggested key	Characterised by
Type A: Detachment/disintegration (that is, effects involving breakdown or active decay of surface and structure)			
A1	Detachment		Separation and/or swelling and rupturing of a usually single thin uniform skin of <2mm, either across or parallel to the bedding planes. This includes blistering crusts and is often a prelude to exfoliation
A2	Exfoliation		Deterioration evidenced by lifting, followed by detachment of one or more surface layers of stone in parallel sheets or wafers at more or less even thickness
A4	Disaggregation		Lack of coherence characterised by detachment of regular granules, crystals, clasts or irregular splinters
A5	Spalling		Deterioration evidenced by total or partial detachment of fragments (spalls) that are irregular in form and thickness and vary in size
A6	Cracking		Narrow fractures, fissures, laminations or crazing, forming crevices of >0.5mm width and perpendicular to stone surface
A7	Loss		Loss due to vandalism, accidental damage, rusting cramps, structural intervention or unspecified cause

System for mapping decay of Purbeck Marble (Historic England, 2021)

Code	Classification	Suggested key	Characterised by
Type B: Staining/deposition (that is, effects mostly due to accumulation of material, causing changes in appearance or texture of surface)			
B3	Chromatic alteration		An alteration evidenced by variation in lustre/gloss/brilliance, change of colour or colour intensity (saturation), but without significant loss of material or significant deposition
Type C: Erosion/weathering (primarily alterations in surface profile where active detachment/disintegration may be slight)			
C4	Roughening		Loss of material leading to decreased gloss in polishable stones and/or weathering back to produce sound but uneven, lumpy surface
CX	New loss		Area of loss since last re-waxing treatment
Type D: Repair/restoration			
D1	Repair		Area of repair in the form of stone indents, piecing-in, mortar repair, and so on
D2	Surface coating		Old paint, limewash, wax or other surface treatment

10 Appendix B

Review of methods used in conservation of Purbeck Marble

The table on pages 58–61 was prepared in order to review methods used in conservation projects. It is not intended to provide specifications, but is included to show the range and variety of interventions that have taken place.

Review of methods used in the conservation of Purbeck Marble in cathedrals

Location	Canterbury Cathedral	Chichester Cathedral	Ely Cathedral
	Trinity Triforium	Monuments	South choir triforium
Date	2017		1995
Coating removal/ cleaning	■ IMS/acetone in water (chosen as most suitable) ■ Latex poultice ■ Monumentique latex paste		■ 10% ammonium bicarbonate applied as spray onto acid free tissue (contact time 3 hours)
Consolidation	■ Stabilisation with dispersed lime injection mortar but found not to adhere well to surfaces already having historic wax coating	■ Flush out spalls and laminations with water and ethanol ■ Grout and secure edges with dispersed lime injection mortar mixed with pigments	■ Gravity consolidation of splits with Paraloid B72 in acetone/alcohol (1:1) using vacuum technique ■ Filling of micro-fractures with microcrystalline wax
Repair		Flaunching mortar to protect laminations ■ Dispersed lime binder ■ Silver sand ■ Pigments Surface toned with water colour	■ Primal AC33 and water binder (1:3) ■ Sieved crushed Purbeck Marble stone dust (1.18mm, 600µm, 300µm) ■ Marble chippings ■ Calcite powder ■ Slate powder ■ Cellulose ether (to prevent slumping)
Protection	■ Goose grease (effect is short lived) ■ Linseed oil ■ Microcrystalline wax		■ Microcrystalline wax
Comments	■ Many areas already had substantial repairs applied (known as scagliola)		■ Account of this work in ASCHB Transactions Vol 20 (1995). ■ Other cleaning trials were V&A mix, white spirit in sepiolite, acetone and white spirit in sepiolite and 1% sodium bicarbonate solution

Location	Ely Cathedral North choir triforium	Ely Cathedral Galilee Porch	Norwich Cathedral Cloister Trial Bay No 17 columns, capitals and bases
Date	1999	2016	2002
Coating removal/ cleaning			■ TORC abrasive machine (with micro nozzle) ■ Poultices of ammonium bicarbonate and sodium dithionite to stabilise any decay of iron pyrites
Consolidation	■ Surface consolidation and stabilisation with Paraloid B72	■ Consolidation with Paraloid B72	■ Consolidation with Paraloid B72 in acetone/alcohol
Repair	No repairs carried out	Mortar used to build up to full profile: ■ Lime putty ■ Crushed Purbeck Marble stone dust ■ Brick dust	■ Lime putty mixed with glass spheres, quartz flour and other aggregates and pigments
Protection	■ Microcrystalline wax	■ Pigmented limewash	■ Microcrystalline wax
Comments		■ Columns were replacements in 1960s but suffering decay	

Review of methods used in the conservation of Purbeck Marble in cathedrals

Location	Norwich Cathedral	Salisbury Cathedral	Westminster Abbey
	Cloisters Bay 25-29 columns, capitals and bases	Cloister columns (Bay 26)	Cosmati pavement
Date	2015 to 2018	1994	2013
Coating removal/ cleaning	■ Monumentique latex paste (containing EDTA) (5 hours dwell time) ■ Pencil dry steam cleaner (150°C)	■ Ammonium carbonate poultice ■ V&A mix in a sepiolite poultice ■ TORC abrasive with piccolo nozzle	■ Initial cleaning with damp sponges ■ Poultice of Shellsol T (mineral solvent) in paper pulp
Consolidation	■ Crack/fissure filling with dispersed lime injection mortar and pigments	■ Crack filling with Primal AC33 and pigment ■ Consolidation of friable edges with Paraloid B72 ■ Wacker OH	■ 2% Paraloid B72 in ethanol/ acetone
Repair	■ Chalk lime putty **1** ■ Nosterfield river sand **0.5** ■ Moreton Cullimore coarse sand **1** ■ Oolitic Bath Stone dust sieved <1.18mm **0.5** ■ Charcoal dust sieved to <1mm **0.5** ■ Purbeck Marble stone dust **0.5**	■ Hydraulic lime **1** ■ Casein **0.5** ■ Purbeck Marble aggregate <150µm **1** ■ Purbeck Marble aggregate <900µm **1** ■ Purbeck Marble aggregate <1.8mm **1**	■ Repairs based on hydraulic lime (NHL2) and surface painted with watercolours
Protection		Various coatings including: ■ Cosmoloid/microcrystalline wax ■ Ketone resin ■ Colloidal silica ■ Beeswax	■ Repairs protected with Primal AC33 and then all surfaces treated with two coats of microcrystalline wax
Comments	■ Dry earth pigments were blown onto wet mortar to provide variation in colour	■ Cleaning with poultices caused opening of cracks so dry abrasive used instead ■ Some of the treated areas have subsequently been replaced with new columns and ■ All areas have been re-treated with wax	■ Floor is vacuumed once a week and buffed with cloth

Review of methods used in the conservation of Purbeck Marble in cathedrals

Location	Westminster Abbey	York Minster	York Minster
	Royal monuments	North choir aisle columns	North transept moulded string course
Date	2018	2013	2013
Coating removal/ cleaning		Various trials carried out. As a result two methods were tried: ■ Monumentique latex paste (2 hours contact time) ■ Benzyl alcohol paint softener (2 hours contact time) Both required rinsing with pencil steam cleaner	■ Dri-clean latex poultice ■ Benzyl alcohol paint softener ■ Ammonium carbonate poultice
Consolidation	■ Paraloid/glass beads and pigment used to secure laminations	■ Crack/fissure filling with dispersed lime injection mortar and pigments (terre verte and raw umber)	■ Cracks rinsed out with clean water and injected with dispersed lime injection mortar diluted with 5% water and mixed with pigments
Repair	■ Touched in with Gamblin paints mixed with ketone resin	■ Lime putty **1** ■ Nosterfield river sand **1** ■ Wood ash **0.5** ■ Portland dust **0.5** ■ Crushed Purbeck Marble stone dust (>300µm) **1**	■ Lime putty **2** ■ Nosterfield sand **1** ■ Portland Stone dust **1** ■ Crushed Purbeck Marble stone dust (>300µm) **1** ■ Wood ash (grey) **1** ■ Coarse slate **1**
Protection		■ Microcrystalline wax	
Comments	■ All of these were treated with 'induration' process in 19th century which has caused them to appear dark brown	Other cleaning trials were: ■ White spirit and acetone ■ Natural latex (Dri-clean), ■ Ammonium carbonate poultice, ■ Melamine sponge, ■ Hot air blower ■ White spirit	■ All of the cleaning methods, removed loose stone from very spalled area of Purbeck Marble

11 Acknowledgements

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