Chapter THREE

Geological Matters

Peter del Strother

A repaired lion

[RMS]

Building stones: an introduction

If you were designing a building with pinnacles you would need to select very carefully what stone to use. You would certainly be considering colour, appearance, texture, strength, ease of carving, durability and cost. Limestone changes colour with weathering so that would have to be taken into account too. You would also want to be certain that stone of the requisite quality was available in sufficient quantity. When building commenced in 1840 transport cost was a not insignificant issue. The railway line to Birmingham (The London and Birmingham Railway) was opened in 1838, the Midland Line in about 1840 and the Great Northern Railway from King's Cross not until 1850.

Sandstone is generally less attractive than limestone and is not necessarily durable. These notes will mainly deal with limestone. Four different limestones will be described, three of which were probably considered by the Houses of Parliament architects. The fourth, Clitheroe's local limestone, is described for contrast.

Limestone, calcium carbonate, consists of the hard parts of once living organisms cemented together, i.e. glued together. The cement which glues the hard parts together is also calcium carbonate, dissolved and precipitated from solution. If you visit an area where limestone is forming today you will see a wide variety of depositional environments including reefs with mud flats behind them, often several kilometres wide. Reefs are damaged by storms, so erosional debris from the reef is also incorporated into limestone. In high energy areas, such as those regularly swept by tides, shoals of ooids may form. Ooids, from the Greek for egg, are spheres of limestone 0.5 to 2mm diameter, formed by some combination of direct precipitation from sea water and algal activity. Oolitic limestone is a favoured building stone, an example of which is illustrated in the notes about Ketton freestone below.

Consequent to a wide variety of depositional environments and a propensity for diagenesis[1] there are many types of limestone, from hard Carboniferous

1 The alteration of sediment and rock by pressure and temperature but but not to the extent that it is transformed into a different rock type - that would be metamorphism.

limestone of Derbyshire to soft Cretaceous chalk. Even limestone from a single quarry may not be of the same type throughout.

Durability is not easy to assess but some building stones have been used for centuries and their performance, good or bad, is known.

Four building stones:

Limestone from Ketton Quarry (Rutland) and similar quarries nearby, such as Clipsham.

The pale brown Jurassic limestone found at Ketton and nearby quarries was formed about 170 million years ago when England was located about half way between the equator and its present position. The Gulf coast of Florida and the Florida Keys would be a reasonable modern analogue for the depositional environment of the Jurassic at Ketton. Ketton freestone, which is an oolitic limestone, has been widely used for building stone for hundreds of years. Many buildings in the centre of Stamford and several Cambridge colleges are built from it. The close up picture of this freestone shown here reveals that it consists of unimaginable numbers of ooids without much cement holding them together. If you look carefully you can see small scars on the surface of each ooid marking the points where this piece of stone was fractured. Despite this lack of cement the stone is strong enough for most building applications. Ketton's limestone, and other similar oolitic limestones, is called freestone because it has no preferred planes of weakness along which to fracture. This makes it easy to carve. In contrast consider roofing slate, which preferentially splits into parallel sheets, would be almost impossible to carve with hammer and chisel.

Left: Clipsham
Centre: New Anston
Right: Pinnacle Anston

[RMS]

In Ketton quarry the limestone is 20 metres thick, barely two metres of which is freestone. Freestone was mined in the past, but the quantity available may have been too restricted for extensive use in the Houses of Parliament. Clipsham stone is oolitic, just like Ketton stone. Both have such high porosity that water entering the pore space can readily drain out. This improves frost resistance.

Clipsham stone has been used as a replacement in parts of the Houses of Parliament, York Minster and a number of college buildings in Oxford. Both Clipsham and Ketton stone are suitable for copings, cornices and for monumental work.

Oolitic and other porous limestones have self-healing properties. When they become wet a tiny fraction of limestone dissolves. The solution, brought to the surface by capillary action as the rock dries out, leaves a skin of limestone behind as the water evaporates. The process of stalactite and flowstone formation is similar.

Ketton freestone - close up showing ooids, each about 0.5mm diameter

United Reformed Church
Moor Lane, Clitheroe

[RMS]

You can see the results of self-healing on the Clitheroe pinnacle. The skin largely hides the true texture of the limestone, which is not oolitic. You have to search very diligently to locate an example of the original texture and you will need a magnifying glass to see any of the small number of shell fragments.

Salthill limestone, Clitheroe

The Carboniferous limestone at Salthill is 350 million years old. It was formed when England was located just south of the equator. One has to be wary about modern analogues of the Carboniferous because a large number of genera living at that time, including all the corals, became extinct at the end Permian mass extinction event. The end Permian mass extinction, 250 million years ago, was much more severe than the better known end Cretaceous event 65 million years ago which saw the demise of the dinosaurs.

Despite these reservations, the Trucial coast of the Arabian Gulf is considered to have a similar depositional environment to the limestone of the Chatburn quarries.

Limestone found at Salthill is of two principal types, one coloured a uniform grey and devoid of fossils large enough to see without a microscope and the other replete with fossil crinoids.

The strong grey uniform rock type could be carved with difficulty but the crinoidal variety could not because crinoids fracture along cleavage planes and therefore unevenly. The crinoidal limestone is attractive when used in blocks because the crinoids stand proud on a weathered surface. The calcite in crinoids has a well-ordered molecular structure, making it more resistant to dissolution by rain /acid-rain than the limestone matrix.

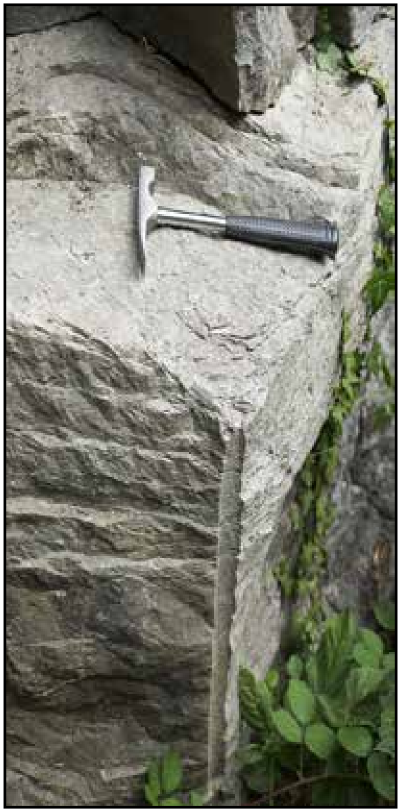
The front of Clitheroe's United Reformed Church, located near the top of Moor Lane (see image shown here), has been built with limestone from Salthill. You can see spectacular examples of crinoid stems in the limestone blocks of the façade (see images overleaf). If there is any carved crinoidal limestone in Clitheroe it is very scarce. Despite their popular name of 'sea lilies', crinoids are animals related to sea urchins. Colour doesn't immediately come to mind when you look at fossil crinoids, but modern crinoids are very colourful and some even walk. Crinoids feed by catching small organisms as they float past their arms on the current.

Portland Stone on the walls of Manchester
Central Library, St Peter's Square

Portland Stone

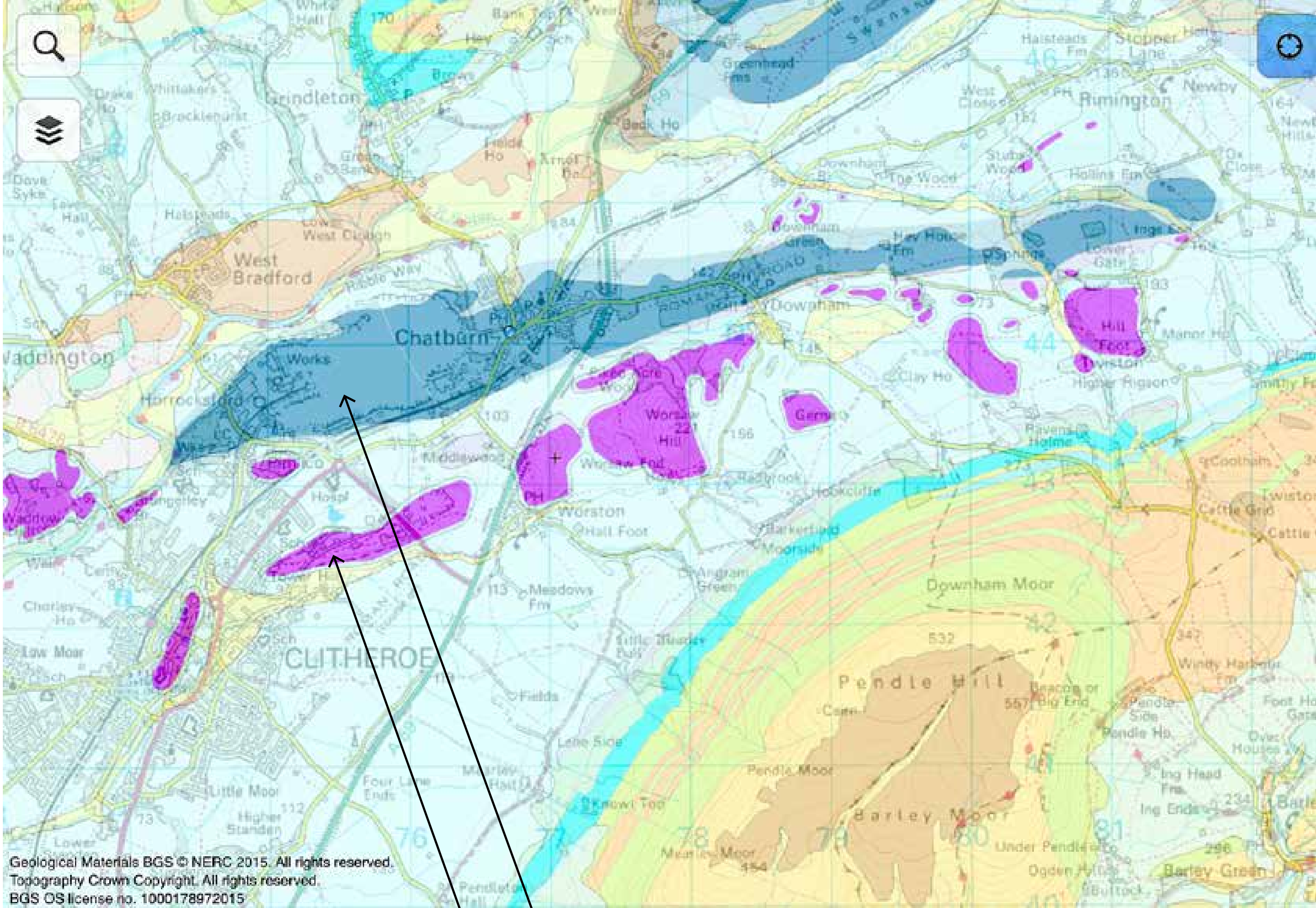
The 145 million year old Jurassic limestone from Portland Bill was also deposited in an environment similar to that of Florida. It weathers almost white. Portland Stone has been used throughout the country in a huge number of high status monuments and buildings. The cenotaphs in London and Manchester are made from it. The Central Library (St Peter's Square, shown here), Ship Canal House (98 King Street) and several other central Manchester buildings are either built or faced with it. Most Portland Stone is oolitic and like Ketton freestone is readily carved. In Portland stone fossils also tend to weather out, so what starts as rather a dull texture becomes more attractive with age. The fossil illustrated is a bivalve. In Portland stone you can usually see individual ooids. You can certainly see them at the Library, but you have to look closely.

Top and left:
Crinoids and other fossils in the wall of the United Reformed Church, Moor Lane, Clitheroe.



Left:
Crinoidal limestone in Salthill Quarry, Clitheroe.

Right:
Non-crinoidal limestone in Salthill Quarry, Clitheroe.



Geology of the Clitheroe Area.

The blue represents limestone that is quarried for cement production.

The purple areas are generally where the fossils occur.
This is where Salthill Quarry was located.

This is now an industrial estate with an excellent geology trail.

Magnesian limestone

The late Permian Magnesian Limestone, about 255 million years old, was deposited on the margins of what is known as the Zechstein Sea. At that time England was located within the supercontinent of Pangaea in an environment similar to that of the Sahara Desert. This limestone is pale, not brown like the Ketton freestone. The Zechstein Sea, isolated from the ocean on at least five occasions, was repeatedly evaporated, perhaps even to dryness. Salt and gypsum /anhydrite accumulated up to 100m thick. Such evaporative events are not unique in earth history. About 6 million years ago the Mediterranean Sea was cut off from the ocean on several occasions. As a result of evaporation, more than a million cubic kilometres of salt, 600 to 1000 metres thick, accumulated (Ryan, 2009). Much of it remains under the present day sea floor.

Magnesian limestone formed in reefs and in large shallow lagoons behind the reefs of the Zechstein Sea shore.

'Normal' limestone is composed of calcium carbonate. If half the atoms of calcium are replaced by magnesium atoms the rock is known as dolomite, named after the mountains in northern Italy close to the Austrian and Swiss borders. In magnesian limestone rather less than half the calcium atoms have been replaced by magnesium ones. The chemical reactions which convert limestone to dolomite or magnesian limestone to dolomite are not completely understood. Geologists refer to it as the 'dolomite problem'.

Much of the calcium carbonate in the Magnesian Limestone was originally aragonite, a form which is less stable than calcite, and tends to dissolve and re-precipitate as calcite. Some calcium carbonate has been dolomitised. Some dolomite has then been de-dolomitised. The story of magnesian limestone is a complicated one and the processes of diagenesis tend to destroy evidence of the original depositional environment. They also change the physical properties of the rock, especially its permeability. The example shown (right) was once an oolitic limestone, but the (aragonite) ooids have dissolved and left voids. This makes it a potential reservoir for oil or gas. York Minster was built from magnesian limestone, (Selby Abbey too) most likely from Jackdaw Crag Quarries, near Tadcaster. At the time of its construction stone transport would have been by horse and cart, so local stone would have been preferred.

Jackdaw Quarry, Tadcaster

[RMS]

Example of magnesian limestone from Sunderland showing voids

This piece is 50mm wide

The weathering of building stone

Quartz grains are virtually indestructible, but sandstone rarely consists of silica-cemented quartz alone. Arkoses are immature sandstones with a substantial proportion of feldspar, which is less chemically resistant. Sandstones may also contain micaceous fine partings which lead to lamination and spalling.

Salts can damage building stones through a number of physical mechanisms, such as differential thermal expansion, osmotic swelling of clays, hydration pressure and enhanced wet / dry cycling caused by deliquescent salts, (Doehne 2000). Salts arising from Portland cement mortar are an important source of decay to historic building materials, (Moropoulou, 2002).

It is the matrix, cement and proportion of feldspars which most influence sandstone's durability. Calcite cemented sandstones are especially vulnerable. Some clay minerals are expansive, i.e. expand and contract through wet and dry cycles. The forces generated may exceed the strength of the intergranular cement.

Thermal expansion and contraction was thought to be a contributor to weathering in desert environments, but that is no longer considered a viable process. More likely it is the impact of wet / dry processes arising from dew. The sandstone used in St. Ann's Church, Manchester, must have been of particularly poor quality. Its walls are a patchwork of repairs, the latest phase of stone replacement still in progress.

The impact of air pollution has changed over time, (Grossi & Brimblecombe, 2007). In the C19th the dramatic increase in burning of coal in urban areas and consequent liberation of SO_2 (sulphur dioxide) made a significant impact on calcareous building stones. Monitoring of atmospheric quality was very limited so it is not possible to relate concentrations to modern values. However it is clear that SO_2 concentrations have been falling for many decades. The deposition of soot, from diesel engine exhausts, has increased markedly. Soot is responsible for most stone blackening.

SO_2 oxidises to sulphuric acid. The reaction with calcite is then:

$CaCO_3 + H_2SO_4 + H_2O > CaSO_4.2H_2O + CO_2$

calcite + sulfuric acid > gypsum

A molecule of gypsum occupies more volume than a molecule of calcite so when this reaction takes place in pores the expansion pressure can physically destroy the surrounding carbonate rock.

When not heavily rain-washed, a hard gypsum skin forms, often blackened by soot particles. In areas where stone is frequently washed by rainwater the gypsum dissolves and there may be direct dissolution of carbonate.

The reaction of sulphuric acid with dolomite (and magnesian limestone) leads to the formation of $MgSO_4$ (magnesium sulphate) as well as gypsum. $MgSO_4$ is more soluble than gypsum and finds its way deeper into the rock, where damage can take place due to crystallisation, (Grossi & Brimblecombe, 2007).

Sandstones with calcite cement weather severely by the above mechanisms. Another process is bio-deterioration, (Siegesmund 2002). Colonisation of carbonate rocks by endolithic microorganisms such as cyanobacteria, chlorophycaceae, fungi and lichens is ubiquitous. In carbonate rocks Siegesmund found that under a residual protective layer on surfaces, photobiontic microorganisms occupied more than 60% of the dissolved rock volume. Bio-activity is more likely to be significant in areas of 'permanent' wetness, on the lee side of buildings in the North West of England for instance. The presence of soot increases the potential for bio-activity.

Pinnacles of the Houses of Parliament

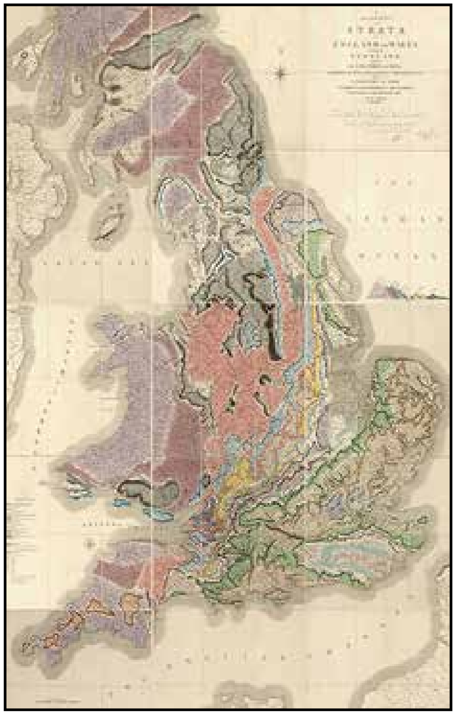
A Royal Commission was set up to oversee the construction of the new Houses of Parliament and a public competition held to invite designs, though it was stipulated that the new palace should be in Gothic or Elizabethan style, those being considered the only ones appropriate. Its report begins:

> *The RESULT of an INQUIRY, undertaken under the Authority of the Lords Commissioners of Her Majesty's Treasury, by Charles Barry, Esquire, H.T. De la Beche, Esquire, FRS & FGS, William Smith, Esquire, DCL & FGS, and Mr Charles H. Smith, with reference to the SELECTION of STONE for BUILDING the NEW HOUSES of PARLIAMENT.*
>
> *My Lord and Gentlemen London, 16th March 1839*
>
> *In conformity with your instructions, we have the honour to report that, in the months of August, September and October last, we have made a tour of inspection to various stone quarries in the kingdom, and visited numerous public buildings, with a view to the selection of a proper stone to be employed in the erection of the new Houses of Parliament.*

William Smith, considered to be the father of modern geology, was the man who created the first geological map, 'The map that changed the world' (Simon Winchester, 2001). Its 200th anniversary was celebrated in 2015. In 1808, seven years before the publication of his map, Smith invited a small delegation from the Geological Society of London to see his fossil collection and a preliminary edition of his map. The delegation was less than friendly. Smith was not of the right social class. That he was a working geologist and dependent for his living on the practical application of geology was not gentlemanly and he was clearly not fit to be part of the social and dining club which characterised the Geological Society at that time. Worse for Smith, Sir James Hall and George Bellas Greenhough embarked on a plan to produce their own version of the map, heavily plagiarised from Smith's. The first edition of Smith's map was published in 1815 and Greenhough's map came out in 1819. Smith was already close to bankruptcy and spent time in a debtor's prison. By 1831, though, the Geological Society had changed. Smith, then aged 62, was showered with honours including the first award of the Wollaston Medal, presented to him by the new president Sir Roderick Impey Murchison. In 1865, long after Smith's death the Society went some way further to restoring Smith's precedence. All further editions of the map were to appear with the words, 'A Geological Map of England and Wales, by G.B. Grennhough Esq., FRS (on the basis of the original map by Wm. Smith, 1815).'

The report of the Royal Commission was comprehensive and included physically testing cubes of rock. Granite and similar rocks were ruled out because of the enormous expense of working them. It was also recognised that suitable sedimentary stone found in a quarry might be covered by a large amount of lower quality rock which would have to be removed, providing a temptation to use poorer quality stone.

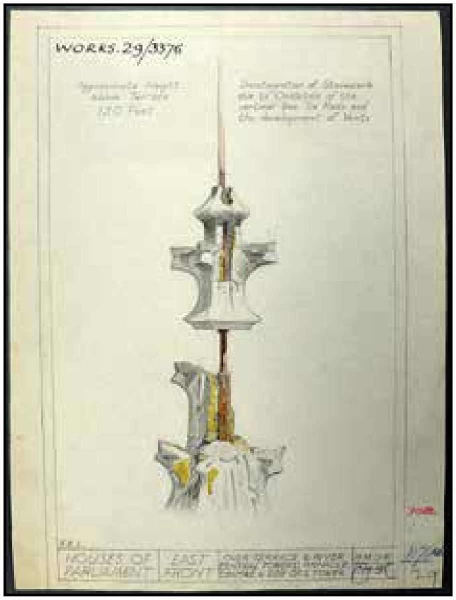
The report's authors found that the durability of sandstone used in historic buildings was variable, even in a single



William Smith’s first geology map.

Southwell Minster.

[RMS]



A watercoloured drawing used to illustrate the damage in the 1920s.

[National Archives: SR]

building. The sandstone used in Haddon Hall was in particularly good condition while that used in Durham Cathedral was poor. Magnesian limestone was found in perfect condition, with carvings still crisp in the Norman portions of Southwell Church. However that used in York Minster was so decomposed that the carvings were effaced.

Buildings constructed of oolitic limestone, both Ancaster and Portland, fared well.

The report concludes:

> *If, however, we were called upon to select a class of stone for the more immediate object of our inquiry, we should give the preference to limestones, on account of their more general uniformity of tint, their comparatively homogeneous structure, and the facility and economy of their conversion to building purposes; and of this class we prefer those which are most crystalline.*
>
> *In conclusion, having weighed to the best of our judgement the evidence in favour of the various building stones which have been brought under our consideration, and freely admitting that many sandstones as well as limestones possess very great advantages as building materials, we feel bound to state that for durability, as instanced in Southwell Church, etc., and the results of experiments, as detailed in the accompanying Tables; for crystalline character, combined with a close approach to the equivalent proportions of carbonate of lime and carbonate of magnesia; for uniformity in structure; facility and economy in conversion; and for advantage of colour; the magnesian limestone or dolomite, of Bolsover Moor and its neighbourhood is in our opinion the most fit and proper material to be employed in the proposed new Houses of Parliament.*
>
> *We have the honour to be,*
>
> *My Lord and Gentleman*
>
> *Your very humble and obedient servants*
>
> *(signed)*
> *Charles Barry*
> *H.T. De la Beche*
> *William Smith*
> *Charles H. Smith*

[reproduced from Houses of Parliament Papers Online, 2006]

Crystalline magnesian limestone was favoured because of its resistance to chemical attack. As a result the 1830s pinnacles were constructed used magnesian limestone from Anston in the West Riding of Yorkshire.

In the 1920s it was evident that some pinnacles were in such a poor state of repair that they would need to be replaced. In 1928 the Department of Scientific and Industrial Research produced a comprehensive report, marked 'Strictly Confidential'.

> *The Selection of Building Stone in relation to its Weathering Qualities, with Particular Reference to the Proposed Repairs to the Houses of Parliament*
>
> *by*
>
> *R.J. Schaffer, BA, BSc, (Oxon)*

The report detailed the results of extensive work on weathering, both chemical and physical, and other factors influencing the choice of replacement stone. Some of the results were based on laboratory testing.

It concluded that use of sandstone to patch the damaged parts of the pinnacles would be disastrous as the universal experience was that contiguous limestone had a very negative impact on sandstone durability.

It identified the major problem at the Houses of Parliament had been the impact of sulphur dioxide gas from coal burning, the principal cause of the London smogs. The report also identified the negative impact on durability of rusting iron dowels. The report considered use of Ketton and Clipsham stone:

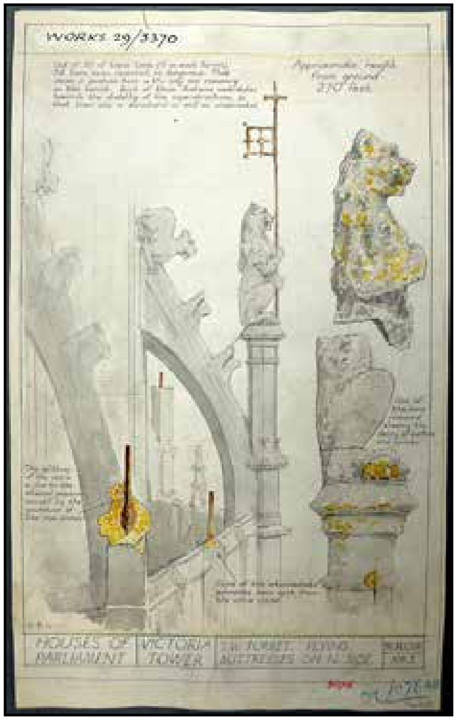
> *The suggested use of Ketton Stone and Clipsham Stone.*
>
> *Both Ketton Stone and Clipsham Stone, which are now under consideration, have been observed to exhibit good weathering qualities and there is much to be said in favour of the recommendation to use either or both these materials.*

Cement mortar was considered to present a risk of efflorescence, so it seems very likely that lime mortar was used. Although Portland Cement mortars appear to differ considerably in their tendency to form efflorescences, and, indeed, certain brands have been successfully used for jointing Clipsham Stone in Oxford, the danger exists and it is suggested that the use of Portland Cement mortar should be more fully investigated.

In the 1930s, following the recommendations of this report, some pinnacles were replaced using Clipsham stone from Rutland. Clipsham was chosen because its weathered colour was more similar to Anston than Ketton freestone.

Some considerable time was spent researching the most suitable stone to use to repair the 'Clitheroe' Pinnacle. Most of the recent repairs to the masonry of the Palace had been undertaken using Clipsham and this was the stone which was referred to in the tender documentation. However, in an article in the *Natural Stone Specialist* by Dr David Jefferson, Jefferson Consulting, it was indicated that there could be a detrimental effect if Clipsham stone was laid adjacent to the Anston Magnesian limestone. This persuaded the project team and their professional advisors that the better stone to use would be Magnesian Limestone sourced from the Jackdaw Crag Quarry near Tadcaster in North Yorkshire.

Though the 'new' stone is strikingly different in appearance the original weathered stone the project team, architects and contractors, Heritage Conservation Restoration Ltd, are all confident that, with time, the new stone will weather in. This belief is reinforced by the similarity of the new stone to cross sections of the original which were exposed during dismantling of the pinnacle and interventions during the indenting of new stones into old ones.



A watercoloured drawing used to illustrate the damage in the 1920s.

[Nationl Archives: SR]

Differential weathering between the pinnacle and an earlier repair using an unkown stone.

[RMS]

The new repairs using magnesian limestone from Jackdaw Quarry.

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