

**LEARNING FROM THE PAST – A REVIEW OF TREATMENTS
CARRIED OUT TO CLUNCH IN 1985 AND FURTHER FIELD AND
LABORATORY INVESTIGATIONS INTO THE DECAY MECHANISMS**

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Abstract

Clunch is a sedimentary limestone (chalk) from the Lower Cretaceous period. When first quarried it is greenish-grey in colour (due to the presence of glauconite) and contains an abnormal amount of small fragments of the fossil bivalve '*Inoceramus*'. It has a significant porosity (more than 30%) and most of these pores are very fine as they consist of the gaps between very small grains (about 0.01mm diameter). The stone, which was widely used in the south and east of England since the 14th century, can be subject to significant and severe deterioration principally through a characteristic lamination of the surface; the decay mechanism has never been fully explained.

In Chapter 11 (Case Studies) of the first edition of *Practical Building Conservation: Vol 1 Stone Masonry* (1988), John Ashurst described a series of comparative treatments that were undertaken on the clunch of the west elevation of the south stable block at Woburn Abbey in August 1985. One-half of this elevation had been dressed back to behind the decay zone and the other had not. The same treatments were applied to both types of surface; they included an alkoxy silane consolidant (Brethane), hydrophobic treatment (microcrystalline wax, boiled linseed oil) and lime treatment (lime poultice, limewater and lime-casein shelter coat).

It is rare that the opportunity arises to carry out a complete assessment of such a variety of treatments but in 2010, a thorough investigation of the treated elevation was carried out and this paper will describe the results and put them into context with past, current and possible future treatments of the stone. The results were also used to support further investigations into the decay mechanisms; these included simple field techniques such as permeability measurements and decay mapping as well as laboratory analysis of core samples with EDX.

Keywords: Clunch, decay, treatment trials, permeability, options

1. Introduction

Chalk from the Upper Cretaceous beds has played a significant part in the historic architecture of Southern England. Most chalk is soft and weathers easily but is still found in some building interiors. The harder beds within the chalk are generally referred to as 'clunch'. The scarcity of good building stone in the area meant that this was extensively used for external walling as well as more decorative elements of carving and vaults. The decay of clunch is generally more pronounced than other limestones with significant loss of surface and it has always been assumed that this close-grained texture and fine pore structure of the stone has been a significant contributor to its decay.

There have been many interventions carried out over the years to mitigate the causes and deal with the effects of decay. These have included the use of limewash (often as part of a maintenance programme), oils and waxes as surface treatments. Historically repairs often involved the tooling back of the affected surface or the replacement of the stone (sometime using a different stone) and more recently repairs using lime mortars, grouts and shelter coats have been widely used.

In order to test these various approaches in the field, the Research and Technical Advisory Group of the HBMCE (now English Heritage) undertook some trials at Woburn Abbey in 1985. Soon after their completion, conclusions were drawn as to which had been the most successful. Although there have been some informal inspections in the intervening years, there has been no detailed review of the trials. As part of a general review of the treatment of stone at Woburn Abbey, an opportunity arose in 2010 to assess the trials carried out 25 years previously and, at the same time, to look in more detail at the nature and mechanism of the decay of clunch.

The assessment was mostly site based and was set up to include detailed visual recording, simple techniques for objective measurement (such as permeability tests and USB microscope) and backed up by some laboratory based tests.

2. Geology and properties of the stone

Clunch exists as a well-marked bed within the Lower Chalk; it is a thin bed in Berkshire, continues through Oxfordshire and Buckinghamshire and reaches between 15 – 25 feet (4.6 – 7.6 m) thickness through Bedfordshire, Hertfordshire and Cambridge (Dimes 1990). Clunch was quarried in two distinct areas – Tottenhoe in Bedfordshire and near Cambridge. When first quarried it is greenish-grey in colour (due to the presence of glauconite) and contains an abnormal amount of small fragments of the fossil bivalve '*Inoceramus*'. This results in it having a gritty feel which has led to the stone being incorrectly described as 'sandy'. Its texture is compact and fine-grained and it is usually worked as a freestone (i.e. the bedding plane is not obvious so the stone can be worked in any direction). In this paper we are principally concerned with stone from the Tottenhoe quarry.

Examination of the Tottenhoe stone shows that much of it is generally of poor quality. It has up to 8% clay content and a microporous structure. Results from the BRE classification show that it has a porosity of 31.4% and water absorption of 14%. There is however a bed in the lower 4.7m succession at Tottenhoe (which has a quarry face of 46m). This seam is 0.7m in height and is both coarser and appears to have less microporosity as well as being slightly greyer in colour; it can be identified by the inclusion of phosphatic nodules (Sanderson 2010).

Photomicrographs of the two different types of Tottenhoe clunch are shown below (Figs 1-2). The images represent 1.22mm wide areas of the stones. The clearer and more colourless parts are crystalline pieces of shell and the darker indistinct material is lime mud. The Tottenhoe Grey (more durable) stone has a much smaller proportion of mud. A difference in particle size of the larger fractions, between the two types is clear to see. The grey variety is coarser but apparently the matrix is more compact and opaque, while the white shows a greater degree of bright speckling due to micrite particles which seem to be less closely packed than those of the grey. Although at the present magnification pores are not discernable (they are considerably smaller than the thickness

of the section, and thus obscured by overlapping grains), it would seem that the softness of the white variety could be attributed to less contact adhesion between grains and consequent greater permeability.

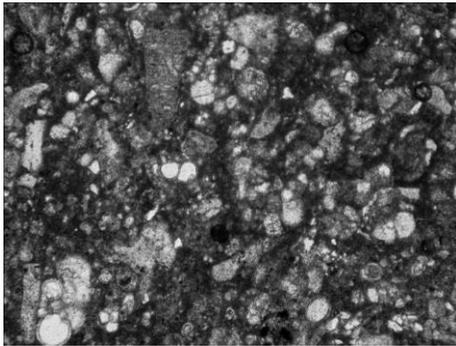


Fig 1. Photomicrograph - Tottenhamhoe (grey)

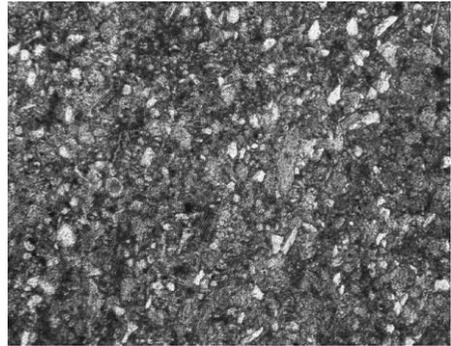


Fig 2. Photomicrograph of Tottenhamhoe (white)

3. Historic use of clunch stone

Although chalk has been used since Roman times for construction including the traditional rammed chalk walls found in the East Anglian region, Clunch appears to have been used since the Norman period (eleventh century). It particularly found favour because it was easy to work and ideal for carved detail.

The lack of transport meant that small local quarries provided much of the clunch used. However larger quarries such as Tottenhamhoe were used to supply stone to important buildings such as Windsor Castle and Westminster Abbey.

Clunch stone was extensively used in the construction of many churches in the medieval period up until the dissolution of the monasteries (1535-40) when all monastic building stopped. The demand for stone declined until in the middle of the eighteenth century, when the revival of classical architecture, enabled Tottenhamhoe and other quarries to flourish. For nearly a century, the stone was much in demand as wealthy landowners built or remodeled houses (such as at Audley End, Woburn, Ashdown, Southill and Ashridge). The material continued in localised use for more modest projects (for example the Swan Hotel in Bedford) up to the last quarter of the nineteenth century, by which time its limitations had become apparent and the transport network had developed so that other stones and building materials became accessible.

When first quarried, the clunch is very soft and prone to damage during transport. For this reason, it was customary to leave a block of clunch to season over a winter or two. During this time, the 'quarry-sap' moved to the surface and the stone became harder. As it dried out, it also became much more permeable to moisture to the extent that any mortar applied to the face would dry out so quickly that effective bedding of the stone was compromised. In order to overcome this, there are references to coating internal faces of ashlar blocks with materials (such as linseed oil and even bitumen) that would reduce the suction of the stone.

4. Mechanisms of decay – current understanding and recent investigations

It has been well recorded that the decay of clunch can occur quite quickly. Archive records at Woburn suggest that within 40 years of construction, some of the clunch stonework was being ‘dragged and cleaned’. The BRE tests on the building limestones of the British isles showed that Tottenhoe clunch had the lowest durability rating of any limestone tested although it was also noted that some of the stone after many years weathering acquired remarkable toughness and resistance to deterioration.

4.1 Decay characteristics

Typically, clunch has been observed to deteriorate in the following ways:

- a) Multi-planar cracking due to loads acting on inherent fissures and faults in the stone
- b) Despite its wide acceptance as freestone, incorrect bedding can reduce the load-bearing capacity of clunch which has a low shear resistance. Exposure to the weather of any fine fissures between bedding planes may lead to rapid deterioration.
- c) Discolouration through various factors including soiling, sulphation and accumulation of biogrowths.
- d) Lamination of the surface to a depth of 2 - 5mm (Fig 3). Some stones are susceptible to lamination but others immediately adjacent (which are subject to the same environmental conditions) appear to be completely sound. Once lamination starts, it will tend to develop over the whole stone.
- e) Once the surface has been lost through lamination, the underlying stone that is revealed has powdered as a continuing part of the same decay process; only in a few cases does the surface revealed beneath a lamination then stabilise and not shown further decay.



Fig 3. Typical lamination of surface of clunch

4.2 Investigation of decay mechanisms

The decay mechanism of clunch has never been fully identified and explained. It has a significant porosity (more than 30%) and most of these pores are very fine as they consist of the gaps between very small grains (about 0.01mm diameter). It has been suggested that the fundamental causes of decay of clunch (and particularly the type of Tottenhoe stone used extensively at Woburn) ‘relate to moisture rhythms and thermal

cycling and the microporous nature of the stone' (Ashurst 1991). The blocking of the surface pores and the consequent reduction of the permeability might occur due to movements of minerals to the front of the stone or by the rubbing of the stone face during the construction process (and so clogging up the pores with fine dust known as slurry); it may also be attributed to 'quarry-sap'. Any or all of these are thought to lead to the observed laminations.

Like all stones, the decay of clunch will also depend on factors such as design, orientation, exposure, use and previous treatment or repair. During the investigations at Woburn Abbey, two parts of the elevations of the North Court were studied. These were the north facing courtyard elevation (Fig 4: E03) and the west facing external elevation (Fig 4: E04).

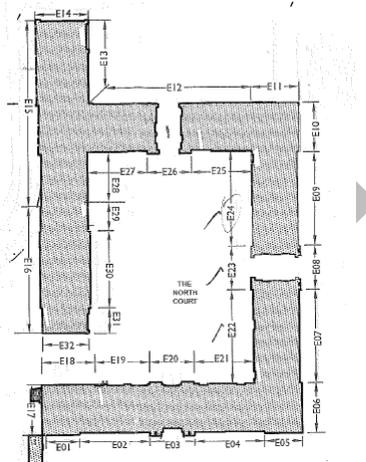


Fig 4. Plan of North Court of Woburn Abbey

4.3 Decay mapping

There are great benefits in overlaying notations of decay and surface changes on elevation drawings or photographs; patterns of decay become discernible and help direct the investigation. Decay mapping was carried out to indicate areas of lamination, powdering and to record previous repairs that had involved either tooling off the surface (to a depth of about 8mm) or replacement of the stone. This mapping revealed that the elevations could be divided into four zones (Figs 5 and 6):

Zone A – At low level and consists almost entirely of stone where the original surface has been lost and decay continues to underlying stone through spalling and powdering.

Zone B – Up to lintel level of ground floor windows; this has most of the stone showing either current or historic (often tooled off) lamination but with only individual stones exhibiting on-going spalling.

Zone C – Up to just above cill level of upper window; in this zone, the stone is mostly sound but with some individual stones having a laminated surface and localised decay beneath.

Zone D – Up to cornice level; this area is almost all sound and the more protected stone has original surface intact. This is also the area where surface coatings (limewash) are found.

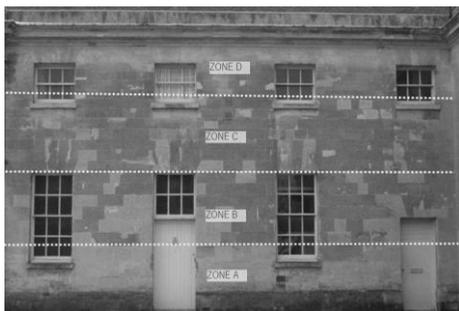


Fig 5. Elevation E22 of North Court



Fig 6. Elevation E04 (external) of north court

The difference between the two elevations is that in the more exposed elevation (E04), zones C and D are much narrower with Zone B being predominant. This reflects the greater exposure of this west facing elevation to rainfall and more regular regimes of wetting/drying and heating/cooling.

4.4 Permeability tests

A number of stones were selected for permeability measurements using a Karsten tube – the locations are shown in Fig 7. This covered all of the zones identified in the condition survey as well as different types of face (e.g. weathered, laminated, re-dressed) of individual stones.



- No 1: Decayed stone from Zone A
- No 2: Sound surface (with brown biogrowth) in Zone B
- No 3: Tooled back surface in Zone B – adjacent to No 2
- No 4: Sound surface at top of Zone B
- No 5: Sound surface in Zone C
- No 7: Sound surface with coating in Zone D
- No 8: Laminated section of stone in Zone C

Fig 7. Location of porosity measurements in Bay E22

Although conclusions are somewhat limited by the number of tests carried out, some useful interpretations can be made:

- Most stones show a typical permeability curve with the absorption of water tailing off with time.

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- No 1 (decayed stone with no intact surface) is the most permeable.
- Nos 2 and 3 show little difference suggesting that a tooled back surface eventually establishes a similar low permeability as stones where the surface remains intact.
- The stones at higher level (for example No 7 with surface coating) have higher permeability than others lower down; this suggests that the mechanism by which pore blocking takes place has not occurred to the same extent – either due to the protected location of the stone or the presence of the surface coating.

4.5 Microbiology

Where the surface is intact, the stone generally has a brown and white patchy appearance with considerable cultures of algae and lichen. The two elevations of the North courtyard were inspected by Professor Mark Seaward and his comments can be summarised as follows:

- The extent and nature of colonisation has been dictated by the properties of the underlying stone; these vary even on a stone-by-stone basis.
- Various treatments of the stone in the past (particularly with limewash) have influenced the colonisation.
- The extent of the grey lichen growth suggests that there has been a treatment over all the surfaces but it manifests itself stronger on certain stones perhaps due to mineralogical differences.
- The brown surface (examined using a Raman spectroscope) showed that there were organic residues present, but it seems certain that these were not metabolic products (i.e. derived from plant or fungal growths) but related to organic treatments of the stonework.
- No calcium oxalate was detected, so this confirms there were no lichens (at least growing in these sample spots in recent decades).
- Lichen biodeterioration was currently minimal or indeed insignificant.

From these conclusions, it seems highly likely that the brown surface seen on much of the stonework is an organic residue of linseed oil that is known to have been applied in the past. This residue seems to have caused much darker discolouration and also served to reduce the permeability of the surface.

4.6 Salts

It has long been assumed that salts played some part in the deterioration of clunch. If this were the case, then it would be expected that a decayed section of stone would contain salts, which (due to the movement of salts with moisture and the fact that most salt activity occurs within 20mm of the stone surface) might be expected to show a gradient from surface to the interior of the stone. A core sample (40mm deep, 20mm diameter) was therefore taken from Bay E04 (see Fig 8); this was divided into three sections and each section analysed (using BS standard for salt analysis) by Dr. Mike Schwar of Cliveden Conservation.

The full analysis showed the following:

Location	Front 0-10 mm	Middle 10-30 mm	Back 30-40 mm
Nitrate, NO ₃ :	0.002%	0.01%	0.02%
Sulphate, SO ₄ :	0.5%	0.3%	0.4%

Fig 8. Salt analysis from Bay E04

There was generally therefore a very low level of salts (with chlorides all less than 0.01%) and no clear gradient (particularly sulphates) through the sample. The change in nitrate level was not thought to be statistically significant.

4.7 Cross sections of core samples

In order to try and understand further the way in which laminations develop, a further two core samples were taken from Bay E04. These were mounted in resin at the Interface Analysis Centre at University of Bristol and were examined using SEM/EDX. Scanning Electron Microscope (SEM) produced higher magnification images at intervals along the prepared cross sections and Energy Dispersive X Ray analysis (EDX) produced information on the elemental composition and distribution at various regions on the cross section.

One of the core samples came away in two sections – the main bulk and the lamination of the front face - but the pieces fitted together well and so were then set together into resin. The x1.8 photograph of the cross section of this sample (see Fig 9) is very instructive. The break between the front lamination and the main core can be seen as a white line running across the section but there are also multiple minor laminations in the stone behind. Perhaps more significantly, the area of the main bulk has a light colour and the dark area towards the front face shows that there are some differences. NB the slight darkening around the edge of the whole sample is due to penetration of the organic solvent for the resin in which the samples were set.



Fig 9. Cross section through core sample showing lamination near face

Energy dispersive X-ray analysis (EDX) targets an area about 250µm in diameter and records the amount of each element present. The results of tests on the core sample not mounted in resin showed average content as laid out in Fig 10:

	Layer 1 (outer lamination)	Layer 2 (Secondary lamination)	Layer 3 (inside)
C	2.9	1.7	2.5
O	42.7	49.1	35.2
Na	0.3	0.3	0.2
Mg	0.8	0.6	0.7
Al	2.3	1.4	1.9
Si	10.0	6.6	8.7
P	1.4	0.9	1.3
S	0.2	1.7	1.3
Cl		0.1	0.1
K	0.3	0.1	0.2
Ca	38.1	36.8	47.1

Fig. 10. Table showing average % content of elements at various depths of core sample

The areas affected by pore blocking have higher oxygen and lower calcium content. Without a greater number of absolute measurements, it is not possible to make any firm conclusions. However it reinforces the idea that some sort of change takes place near the surface, which leads to the laminations seen in many of the clunch stones at Woburn.

5. Common established repair methods

On many buildings constructed of clunch, evidence survives of the common practice of stone being protected by limewash. On elevation E22 of the North Court of Woburn Abbey, traces of limewash were found and there is archive evince of the use of milk and water being applied. As was seen in the analysis of surface microbiological growth, there is also evidence of residues of linseed oil and this is thought to have had widespread use as a surface preservative for clunch.

The 19th century restoration of many of England's churches was well intentioned but, although clunch may have deteriorated due to long neglect, the methods of repointing, repair and rendering with cementitious mortars generally led to even faster decay. The replacement of clunch with other (generally harder) stones also led to accelerated decay of the adjacent softer clunch.

In recent years, the repair of clunch has been largely based on some well-established techniques of limited replacement, cutting back decayed surfaces, lime mortar pointing, repair and rendering, and sheltercoating or limewashing. The success of any or all of these treatments will depend on many factors not least the skills of the conservators. However inspection of a number of buildings allows some limited conclusions to be drawn.

- Although clunch is still available, stone from the more durable seam is hard to obtain so the replacement of stone has usually been restricted to structurally significant areas such as window mullions. In general these have survived well.

- Cutting back the decayed surface (either of individual stones or of whole facades) is effective at removing the laminated surface and providing an appearance that reflects the original architectural intention. However, it changes the relative dimensions of mouldings and other detail. The technique of rubbing back the surface also appears to fill the microporous surface with fine stone dust; this is particularly apparent if a wet 'spinning' technique is used.
- Once the surface has been tooled back, there is also good evidence that the decay mechanisms become re-established and the laminations start again.
- Render repairs of decayed surfaces have had mixed results with exposed feather edges failing and detachment of areas of render on stonework that is susceptible to regular wetting and drying.
- Patch render repairs of individual stones were not as successful as those where the whole face of a stone had been repaired.
- Repointing is generally effective although, on a practical level, the high permeability of the stone means that control of the drying of the mortars is difficult.
- Sheltercoats have been used to protect the stone and were always intended as part of a maintenance regime; they will last only a few years in normal exposure.
- Limewash has been used but on smooth surfaces with a closed pore structure, it has a tendency to detach within a short time particularly on exposed areas.
- In one location, many coats of limewater were applied after cleaning and levelling the stone. It created an effect similar to a clear varnish to the stone face.

6. Trials carried out at Woburn Abbey in 1985

Practical Building Conservation Volume 1: Stone Masonry by John Ashurst was published by English Heritage in 1988. Consolidation of Clunch in the South Court of Woburn Abbey was included as one of the case studies.

'During August 1985 a series of comparative consolidation treatments were undertaken on the clunch of the south stable block at Woburn Abbey. The stone had weathered and deteriorated, creating extensive areas of flaking. It had been decided that dressing back was the most satisfactory treatment for this deterioration. As this is a process which can seldom be repeated, requires all stones on a façade to be treated and is relatively labour intensive, it was decided that the Research and Technical Advisory Service of HBMCE should investigate alternative procedures'.

The series of treatments were undertaken on the west elevation of the south stable block. The treatments were chosen as being representative of the two sides of the debate over the suitability of traditional (and reversible) lime wash versus the modern and irreversible alkoxy silane treatments. Linseed oil was put forward by the house restorer at the time Cecil Rhodes and microcrystalline wax was chosen as a simple hydrophobic coating. One half of this elevation had been dressed back and the other had not. The same treatments were applied to both types of surface and the central pedimented bay was not treated.

A control panel was left within the dressed-back zone and the as-found zone. The weathered zone was first brushed down with phosphor bronze brushes, treated with quaternary ammonium biocide and then brushed down again. The treatment areas were to the internal west facing elevation of the South Court (Bays E33 - 35) as in Fig 11.

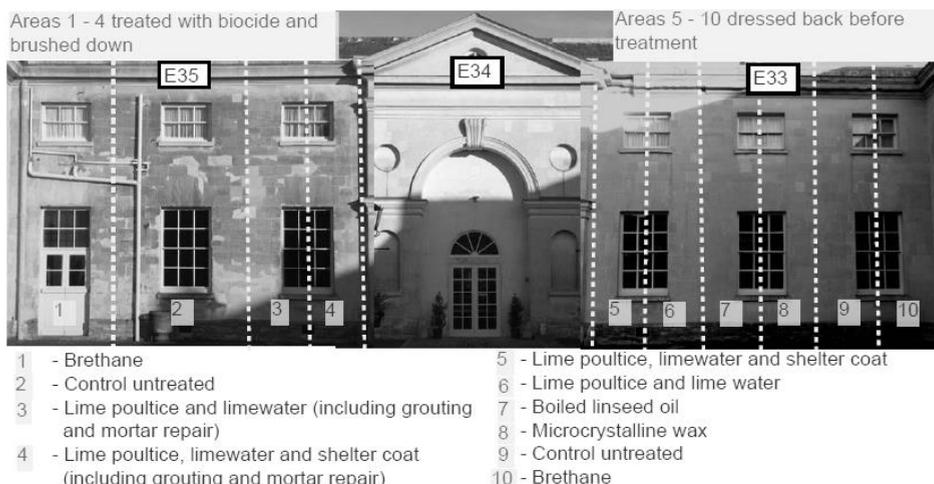


Fig 11. Diagrammatic representation of the trial treatments carried out in 1985

An appraisal of the treatment carried out six weeks after application (and included in Practical Building Conservation) concluded that:

- Brethane (Areas 1 and 10) – this was found to have some darkening but was considered insignificant when compared to the weathered stone adjacent. The surface felt very ‘tight’ and there was no dusting. It was felt that the simple dressing and chamfering of the skin was acceptable when coupled with consolidant in this way.
- Lime treatment (undressed surface) (Areas 3 and 4) – The techniques of grouting and filleting were considered very satisfactory in terms of appearance and that much of the original surface was retained. It provided a very sound surface compared to the untreated control.
- Lime treatment (dressed surface) (Areas 5 and 6) – These were significantly darker than the control – probably due to saturation during treatment. Only a small amount of dusting was found on the surface.
- Boiled linseed oil (Area 7) – This had darkened but the surface was exhibiting very little dusting.
- Microcrystalline wax (Area 8) – Some accentuation of the redressing marks was recorded and some blotchiness where the wax had been applied full strength. Generally better where the wax was dissolved in white spirit.
- Control area (Area 9) – The surface was found to dust readily.

In 1985, it was concluded that: ‘the most satisfactory treatment for weathered clunch surface was considered to be limewatering, filleting, grouting and mortar repair to the as-found surface followed by the application of shelter coat’.

It was intended that appraisals should be carried out each year but the next recorded appraisal was by Malcolm Starr of English Heritage in 2006. He wrote:

‘The response to this (original) recommendation was that the technique relied too much on maintenance, and that this approach of what might be termed “total” conservation tended to change the original ashlar character and precise architectural detailing of classical buildings. It was never adopted at Woburn.

All the chemical treatments had discoloured the faces, although material that had been exposed after brushing off looked more natural in colour. The discolourations, and unknown long-term effects, were felt to militate against chemical treatments, in addition to the cost of some of them. Where original ashlar faces had been retained on the lime method panel, large-scale delamination had continued. Small-scale delamination had continued on most of the brushed back areas, and the mortar fillets had begun to detach in place’.

The paper then goes on to speculate that: ‘much of this deterioration might not have occurred if the work had been maintained. The time span suggests that two further shelter coats might have been needed during the 23 years since the trials were carried out’.

7. Review of trial areas in 2010

It is unusual to have the opportunity to review a well-documented treatment but an investigation was carried out in 2010 to identify the effect of each of the treatment. The investigation used field techniques of observation backed up by permeability measurement using a Karsten tube.

7.1 Observations

Area no:	Treatment in 1985	Observation
1	All loose and flaking material was removed. Edges of all flakes were cut back to sound material using a chisel to form a neat splayed edge. Panel was thoroughly brushed down prior to treatment.	In the 25 years since application, there has been no further decay except under a x10 magnifier, it is possible to see very small flakes beginning to develop at low level. Because of the presence of a lead catalyst in the Brethane, there has been no microbiological growth on the surface.
2	Control – no treatment (except biocide)	Lamination and flaking has continued. Brown surface of biological growth indicates biocide had limited effect.
3	Lime poultice (lime putty applied to thickness of 15mm, sheeted in plastic and removed after two days), lime water (40 No applications) and lime	Although some laminations remain intact, almost all of the mortar fillets have detached or decayed. All laminations sound hollow indicating that grouting

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	mortar repairs and grouting (stone consolidated without redressing or removing surface; edges were supported with lime mortar fillets and voids grouted).	has not arrested the separation. Colour of surface slightly lighter than control.
4	Lime poultice, limewater, mortar repairs and grouting (all as area 3) plus lime casein shelter coat	Apart from tiny traces in protected areas, there is almost no evidence of any shelter coat remaining. Although some laminations remain intact, almost all of the mortar fillets have detached or decayed. All laminations sound hollow indicating that grouting has not arrested the separation. Colour of surface slightly lighter than control
5	Lime poultice, limewater, mortar repairs and grouting (all as area 3) plus lime casein shelter coat.	When compared to the control area, there is no obvious difference in appearance or extent of decay. Only very small traces of shelter coat remain in protected areas.
6	Lime poultice, limewater, mortar repairs (all as area 3)	When compared to the control area, there is no obvious difference in appearance or extent of decay
7	Boiled linseed oil applied by brush (similar to the treatment applied at that time to all new stonework at Woburn)	This bay has continued to decay at a faster rate than either the control area (area 9) or the area treated with wax (area 8). There is some surface discolouration when compared with adjacent areas.
8	Microcrystalline wax dissolved in white spirit and applied by brush. Then well rubbed in with a soft cloth and surplus removed.	There is no noticeable discolouration of this area although it still appears to retain a slight element of water repellence (see 'Permeability' section below). There appears to be less on-going decay than in the control area.
9	Control – no treatment	Lamination (albeit localised) continues to develop.
10	Brethane	There has been no deterioration of the surface at upper level where

		the stone remains clean but at lower level, the surface has darkened when compared to the adjacent control area.
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7.2 Karsten tube tests

Although conclusions are limited from the permeability tests, a number of trends are clearly shown:

- Permeability on the sections treated with Brethane showed no take up of water at all after 10 minutes; this showed that the hydrophobic qualities of the consolidant are still intact.
- All measurements taken in Bay E35 (areas 1 - 4 not dressed back) show higher permeability compared to those in Bay E33 (areas 5 – 10 dressed back).
- The control area (area 9) also has low permeability indicating that the dressing back serves to close the surface and reduce permeability.
- The most permeable samples are all on areas where the original surface has been lost (areas 2, 3 and 4).
- The least permeable stone (apart from that treated with Brethane) is that treated with oil.
- There is no discernible difference in permeability between the areas treated with lime poultice, limewater and shelter coat and the adjacent control area.
- The presence of lichen reduced the permeability of the surface.

7.3 Conclusions from the trials

The result of the detailed inspection of the trials showed that many of the assumptions of the decay mechanism were correct. After 25 years, dressed back areas show signs that the decay mechanism has been re-established. Lime treatment (limewater, mortar repairs and shelter coat) does not appear to mitigate the causes of deterioration but, in consideration of its use elsewhere, it can provide short-term stabilisation of the surface. If regularly repeated as part of a maintenance programme, then this stabilisation could reduce the extent of decay. Of perhaps most interest is that the areas treated with Brethane (that effectively prevent liquid moisture transfer into the stone) have been effective at slowing down the cycle of decay. Re-treatment would be problematic not only because Brethane is no longer available but it is not known how other treatments would interact with the hydrophobic surface. Other evidence suggests that any method that slows down (rather than prevents) the absorption or expulsion of water (e.g. oily film, possibly lichen, tooling the surface) will exacerbate the pore blocking effect and thus the cycle of decay will continue. A roughened surface, either from tooling (not spinning) or natural decay of surface lamination, provides a more permeable surface that is less susceptible to pore blocking.

8. Options for treatment of decayed clunch

In the light of the review of the trials carried out Woburn in 1985, the field and laboratory investigations into current decay and observations of treatments to other clunch buildings, it is possible to set out the advantages and disadvantages of the various treatment options.

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Methodology	Advantages	Disadvantages
Consolidation	Although depth of penetration is likely to be limited, consolidation which results in a completely hydrophobic surface appears to be effective and the stone surface appears stronger to the touch	Hydrophobic surface means that other (water based) treatments cannot be carried out Re-treatment may be difficult and have little benefit
Repair with lime mortar	Use of compatible repair mortars can protect decayed sections and secure laminations More effective in areas which are more protected from wetting/drying cycle	Evidence suggests that mortars will tend to detach within a few years so repair should be seen as a maintenance activity Matching mortar with the fine-grained stone may produce a repair with a closed surface. Evidence suggests that an open textured permeable mortar is preferable
Surface treatment with limewash	Provides homogenous aesthetic appearance Provides short term protection to stone surface	No evidence that it slows down decay mechanisms Likely to require re-treatment within ten years
Surface treatment with shelter coat	Provides homogenous aesthetic appearance for short period	No evidence of any beneficial effect on decay mechanism Porous aggregates that are used to make shelter coat will have to be very finely ground to be able to fill the pores of microporous stone which may anyway be blocked
Surface treatment with linseed oil	A traditional treatment but mainly for reducing premature drying out of mortar used in fixing	Causes discolouration Evidence of slightly increased rate of surface decay In time, this may encourage certain types of lichen growth
Surface treatment with wax	Possible reduction in decay due to hydrophobic qualities	May cause some discolouration Will break down with exposure

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Removal of surface	Removes existing layer of decay Provides 'as new' appearance If surface is left rough or laitance removed from pores (for example by using dilute acid), this may allow better moisture transfer and reduce pore blocking	Affects relative dimensions of architecture Unsustainable as cannot be repeated Technique of spinning assists in establishing new 'pore blocking' cycle of decay
Replacement of stone	Reintroduces correct planes and profiles of masonry Reintroduces structural integrity Surface left roughly tooled may encourage moisture movement and reduce pore blocking	Removes historic fabric Durability of new stone may be no better than that removed Fine finishing of surface likely to encourage early pore blocking and lead to decay

9. Conclusions

The treatment of decay of stone must depend on many factors such as a sound analysis of the causes of decay and an assessment of the most suitable materials for conservation. It is often the case that there is no opportunity to review these treatments and, in most cases, the review will be superficial and subjective. In this programme of work at Woburn Abbey, it was possible to carry out a more complete assessment of the causes of decay through field observation and laboratory analysis and to conclude that pore blocking is the most dominant contribution to decay. The value of annotated survey was demonstrated and helped to establish how those areas exposed to more regular moisture movement suffered from a greater degree of lamination. Through consideration of permeability measurements, it was possible to establish that anything that closed up the pores of the stone (for example tooling off the surface and particle hydrophobic treatments such as linseed oil) also led to more loss through lamination. On the other hand natural decay of the surface to provide an open texture or interventions that protected the surface and yet allowed moisture movement (for example limewash) would seem to reduce lamination. Complete hydrophobic treatment (for example brethane and wax) also appeared to reduce the decay rate although there are significant doubts about continuing maintenance and re-treatment.

It would appear then that the centuries of the tradition of 'sheltercoating' a stone with lime wash to protect it from weather was well founded. It can only be speculation as to what the result would have been had the trials carried out in 1985 been maintained by regular limewashing. For the moment, the advice for the repair of clunch should be that it be kept clean and free of surface dust, grime and biogrowths and to undertake interventions that maintain a permeability rather than allow an impermeability.

The study of the trials at Woburn Abbey has shown the benefit of being able to look in detail at a variety of treatments and provide some objective field measurement, which will help to back up a comprehensive visual record. Although resources will often prevent such re-visits occurring, it can only be of benefit that what sometime seem like instinctive decisions on treatment can be supported by sound evidence.

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