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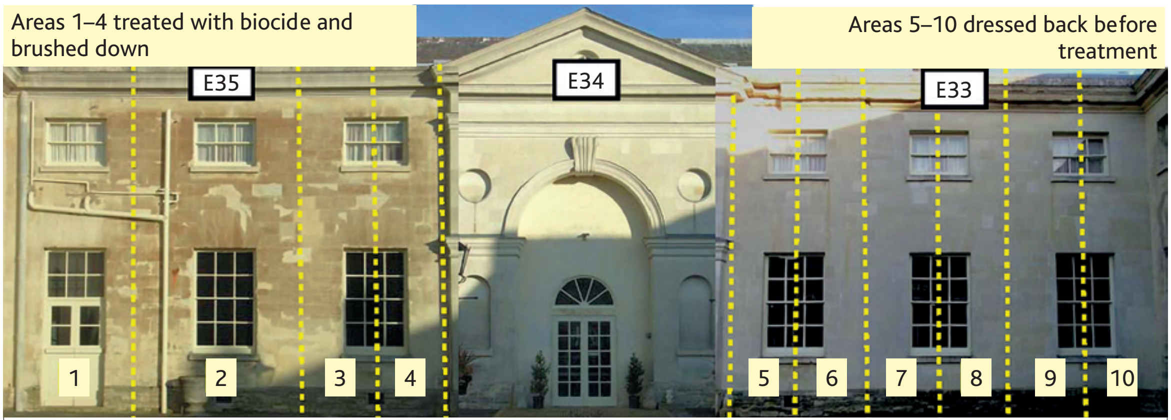
Progress with stone consolidants

Developments in stone consolidants show that they have a role as a treatment of last resort, to be used only after other options for slowing the rate of deterioration have been considered.



1 Brethane
2 Control untreated
3 Lime poultice and limewater (including grouting and mortar repair)
4 Lime poultice, limewater and shelter coat (including grouting and mortar repair)
5 Lime poultice, limewater and shelter coat
6 Lime poultice and limewater
7 Boiled linseed oil
8 Microcrystalline wax
9 Control untreated
10 Brethane

The south court of Woburn Abbey, showing areas treated in 1985

In an article in *The Spectator* in 1860, the writer was pondering the options for treatment of the recently constructed but already decaying Anston stone of the Houses of Parliament. 'There is however a dispute between rival preservers – a contingency at which we need not wonder considering what innumerable processes have been lauded as possessing the chemical properties for perfecting stone which has rotted by the decomposing action of the elements. There seems to be very little room for confidence in any of these processes'. Those words remain relevant, as the consolidation of external weathered stone mostly continues to be a frustrating exercise of hope over experience.

For many centuries stone has been treated with a variety of materials, including limewash, oil, waterglass, copperas and wax. Some were applied to provide an aesthetic effect and some to provide protection. They should all be considered as surface treatments and not confused with consolidants, which are intended to restore cohesion and give mechanical strength to deteriorated stone without adversely affecting the behavior of the stone, depositing by-products that may harm it or affect its appearance. To achieve this, they need to penetrate through the full depth of the decayed zone but not fill the pores of the stone; and as though all of this were not difficult enough to achieve, the consolidant should not prejudice subsequent treatment or affect future maintenance of the stone.

The search for a suitable consolidant has been going on for centuries. The synthesis of silicon-based compounds in the first half of the 19th century was largely unheralded but in 1861 Hoffman suggested a form of ethyl silicate (very similar to modern day silanes) for the consolidation of decaying stone. Since then many products have been proposed and used, including 'fluate' (fluorosilicate), 'Baryta water' (barium hydroxide), 'siassic liquid' (sodium silicate/arsenic acid), 'silicon ester' (a form of ethyl silicate), 'Zerelemy liquid' (sodium silicate) and even 'Bakelite' (phenol formaldehyde).

The government-appointed Stone Preservation Committee reported in 1927 that it was unable to recommend any stone preservative treatment. The Ministry of Public Building and Works carried out experiments in 1964/65 using a variety of silicon-based products and limewater. The application of these was well recorded and the effect of the consolidant was assessed over several years, and reported by Clarke and Ashurst in 1972. The results were largely negative. All of the work with silica-based consolidants acknowledged the fundamental fact that they are more compatible with siliceous stones (sandstones) and chemically incompatible with calcareous stones (limestones).

During the 1970s there were a number of developments in stone consolidation: first, the refinement of some of the silane-based materials (Wacker OH, for example) to improve performance and make them more compatible with limestone; second the extensive and generally successful treatments pioneered by Hempel and Larson at the V&A (and used for a couple of the external figure sculptures at Wells Cathedral); and, third, the development of limewater as a possible consolidant for limestone, as pioneered at Wells and Exeter Cathedrals under the direction of Robert Baker.

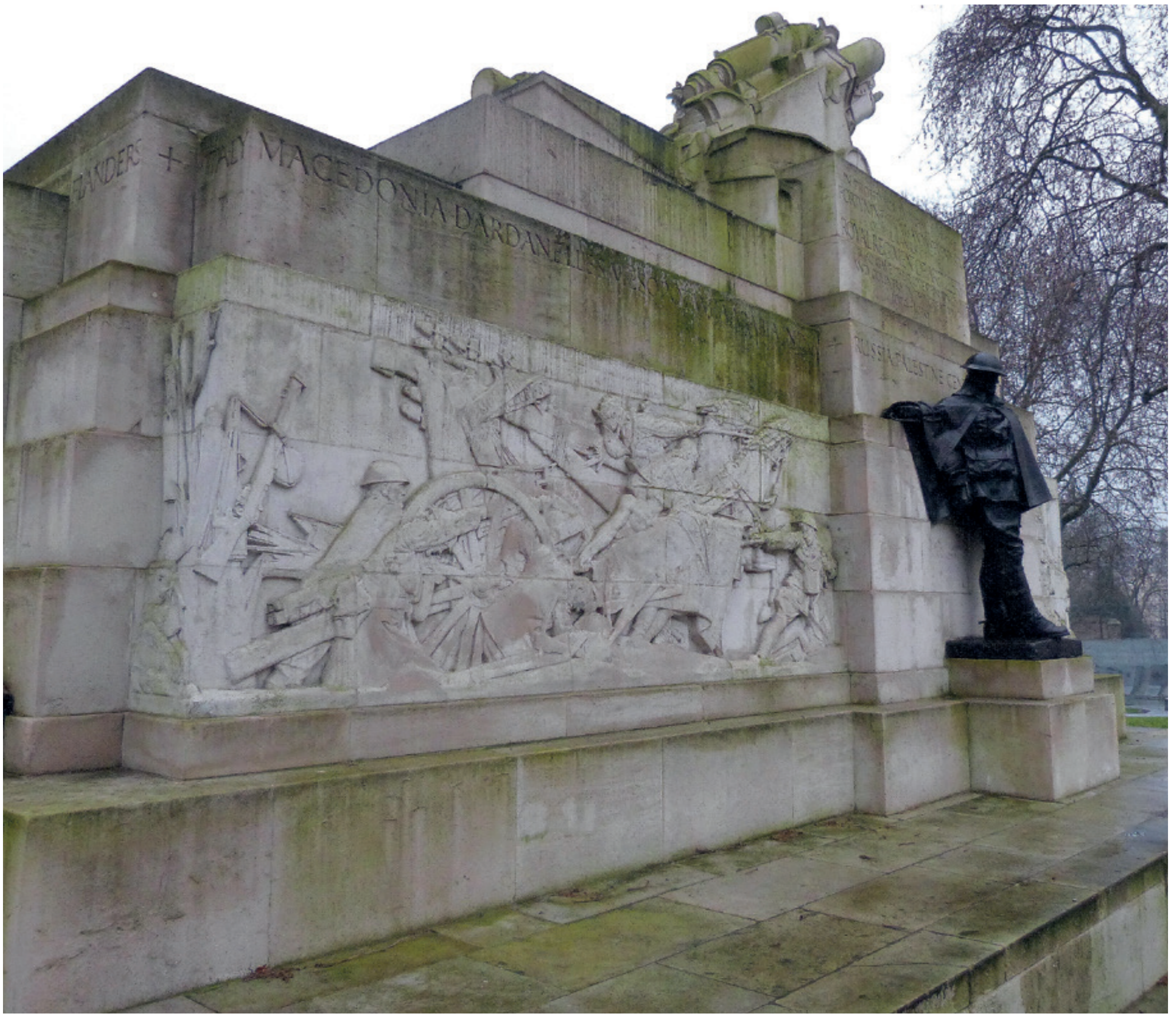
In the UK, development work at the Building Research Establishment resulted in the production of Brethane. This consisted of four components: a silane monomer, water, industrial methylated spirits and a lead-based catalyst. The polymerisation of the silane occurs within the stone in the presence of water. In the early 1980s trials of this were carried out on a wide range of buildings and substrates. These trials were monitored for a few years and the results were published in English Heritage Research Transactions Volume 2 (published January 2002). Unfortunately, the presence of lead within Brethane meant that, due to health and safety concerns, it never became commercially available.

Recently there has been the opportunity to revisit some of the sites treated with Brethane. At Woburn Abbey in 1985 John Ashurst carried out significant trials with a variety of treatments to decayed clunch stone. Assessment carried out by Cliveden Conservation in 2010 showed that the area treated with Brethane had fared best and was still in good condition with consolidation at depth. Similarly, in 2017 assessment (on behalf of Historic England) of the clunch columns at the Temple of Concord at Audley End House showed that areas treated with Brethane in 1984 showed no deterioration, whereas adjacent untreated stone had continued to decay. These results suggest that Brethane fulfilled the criteria for a consolidant, but both examples were on clunch, which is a stone with particular characteristics and a mechanism of decay unlike most other limestones.

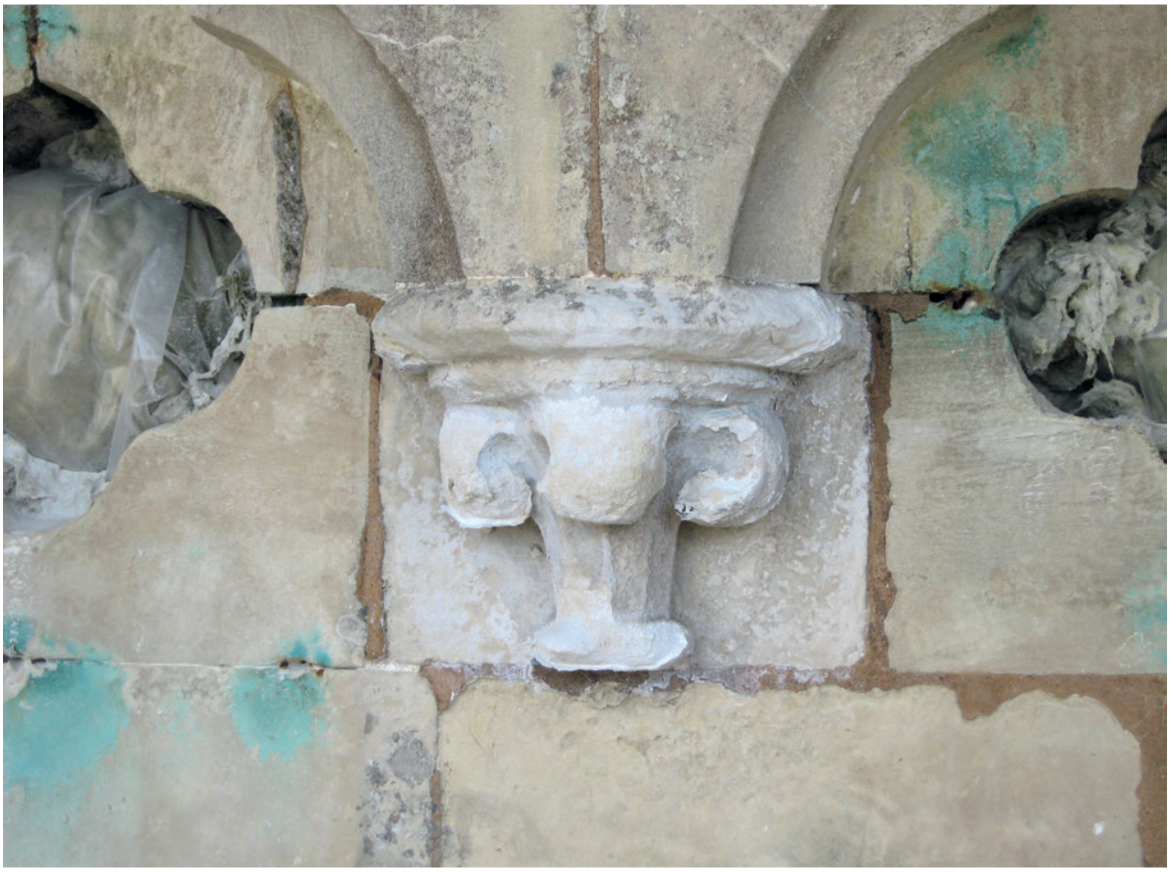
The magnificent relief carving (by Charles Sargeant Jagger) on the Royal Artillery war memorial at London's Hyde Park Corner was also treated with Brethane. Interestingly, the presence of lead in the treatment has meant that the carvings do not suffer from the accumulations of algae present on the rest of the memorial, but there has been continued loss of detail from the Portland stone and some areas are losing a surface crust 2-3 mm deep. This may be a result of the detachment of the harder consolidated surface.

Although there seemed to be some potential for the use of silanes (and Brethane in particular) for stone consolidation, the lack of any proven long-term benefit has meant that chemical consolidants have rarely been used on external weathered stone in the UK for the last 30 years. This is in marked contrast to mainland Europe.

Limewater, which during the 1980s had found some favour among conservators as a consolidant for limestone, was based on the theory that by introducing a solution of lime (calcium hydroxide) into decayed stone and allowing the water to evaporate, lime would be left



The Royal Artillery war memorial in London's Hyde Park, showing the carved area treated with Brethane being free of algae



Nanolime has been used in of trials of consolidation of decayed Chilmark stone corbel at Salisbury Cathedral.

in the stone where it could carbonate and strengthen the matrix. Unfortunately, the solubility of lime in water is so low (approximately 0.14 g/litre) that it took 40 or more applications of limewater to get sufficient lime into the stone. Not only could this amount of water be detrimental to decayed stone, but it also initiated further salt migration and crystallisation.

Researchers in Florence realised that these problems could be overcome if concentrations of calcium hydroxide were increased and a non-aqueous medium used to deliver the lime. As a result, in the 1990s nanolime was developed; this is formed from the suspension of nano-sized particles of (synthetic) calcium hydroxide in alcohol.

When nanolime began to be imported and used in the UK as a stone consolidant, there were some concerns that there had been little relevant laboratory or field testing. Historic England and the University of Bath set up a major research project into the use of nanolime in 2011–2016. This involved treatment of weathered building stones, and testing both on site and in the laboratory. The results are described in the Historic England's *Nanolime: a practical guide to its use for consolidating weathered limestone* (May 2017).

The results show that, like so many consolidants before it, nanolime has not been the panacea for stone deterioration that many people were hoping for. The delivery, penetration and carbonation of nanolime are complex issues, and have been found to be dependent on properties such as concentration of nanolime, pore size of the stone, environmental conditions and the degree of decay of the stone. Results, perhaps unsurprisingly, were mixed, but for some stones under certain conditions, nanolime is able to consolidate to the required depth. For most stones, however, the consolidating effect tends to be limited to the outer 1–3 mm. In some cases, this may be adequate if it provides sufficient stability for subsequent conservation interventions, especially mortar repair and shelter coat. Nanolime should therefore be considered (along with other consolidants) as a potentially useful part of the conservation tool bag.

Two materials are getting some use in the treatment of decayed limestone; both are a hybrid between surface protection and consolidant, and both processes dissolve the very outer surface of the stone to which they are applied. They are ammonium oxalate (used particularly for the treatment of sugaring marble) and ammonium tartrate (hydroxylating conversion treatment, HCT) which is currently undergoing trials on Reigate stone, both as a consolidant in its own right and as a precursor to silane treatment.

Although the current situation regarding consolidants may not, in many ways, seem much more advanced than that described in 1860, there have been, and continue to be, significant improvements and developments, and consolidants remain an important part of the conservation process. However, their use should always be governed by thorough assessment of factors such as porosity, composition, causes of decay, past treatments, environmental conditions, and significance of the object or building. In general, a consolidant should be thought of as a treatment of last resort, to be used only after all other options for slowing the rate of deterioration of the stone (including preventive measures) have been considered.

David Odgers, an accredited conservator and consultant on stone and plaster, was the editor for the Stone volume of English Heritage's Practical Building Conservation series.