Institution: Queen's University Belfast

Unit of Assessment: 17 – Geography, Environmental Studies and Archaeology

Title of case study: Stone Weathering and Conservation

1. Summary of the impact (indicative maximum 100 words)

Weathering causes deterioration and loss of historic and archaeological stone and is a major control on long-term landscape change. The impact of the Weathering Research Group (WRG) is three-fold: improved historic stone conservation practice; development of stone management protocols; provision of expert site evaluation for UNESCO World Heritage site and natural landscape proposals. Over the last 20 years, nationally and internationally, the WRG has unravelled the complexity of weathering processes, improved understanding of stone behaviour and contributed directly to better stone management and conservation practices for nationally and internationally important heritage structures and landscapes.

2. Underpinning research (indicative maximum 500 words)

The WRG [Smith 1979-2011; Warke 1995 to present; McCabe 2004 to present; Curran 1997-2003] has promoted an interdisciplinary approach to investigation of complex stone weathering issues whilst maintaining a geomorphological research focus. Its research expertise stems from a fundamental understanding of stone as a material and its work has relevance for those agencies responsible for the care of built and natural environments and their preservation for future generations.

From the mid-1990s the WRG sought better understanding of weathering processes, the complexity of interactions between these processes, their impact on stone and identification of legacies of damage (Refs 1 and 2). For example, identification of significant salt accumulation at depths greater than 60mm within sandstone demonstrated that removal of the outer 25mm of stone through 'dressing back' was not sufficient to stabilize weathered historic stone as this reservoir of deep salts would quickly become active when brought into contact with penetrating moisture (Ref 3). Application of findings to stone in the built environment underpinned a series of EPSRC funded projects [Grants 1, 2 and 3] that reinforced the WRGs research framework and its future focus. These projects identified the importance of weathering legacies i.e., how past weathering events and historic atmospheric pollution loads can significantly influence stone response to contemporary interventions and environmental exposure, creating conditions of nonlinearity in the stone-weathering response system. The scope of the WRGs funded research projects increased to reflect the a growing recognition of the complexity of historic and archaeological stone weathering behaviour and the difficulties associated with identifying the most appropriate and effective management options [Grant 4]. This is exemplified by the WRGs work on the long-term impact of historical fire events on masonry which demonstrated that fire may cause significant physical, chemical and mineralogical change that can be subsequently exploited by salt and freeze–thaw weathering cycles (Ref 4).

From the mid-2000s onwards research focus broadened to incorporate the potential impact of climate change on historic and new-build stone [Grant 5] through both its effect on weathering processes and the way in which such factors as increased depth and time of 'winter wetness' may contribute to 'deep' weathering of stone and increase surface colonization by algae and lichens. This work was instrumental in highlighting the importance of increased winter precipitation (rather than temperature changes) for future performance of stone structures in many areas of the UK and Northern Europe (Ref 5). This established the expert position of the WRG [Grant 6] in its work on ion diffusion and salt mobility within stone

exposed to prolonged periods of 'deep' wetting.

During the 2000s the WRG also recognized a need to make its research findings available in an accessible form to architects, conservators and those with a duty-of-care for historic stone structures. This was achieved through publication of a guide to 'best-practice' (Curran et al, 2010) and also by attracting further EPSRC funding for a KTP and a KTS [Grants 7 and 8] with the former instrumental in securing further funding from the EU [Grant 9] for development of a 'Natural Stone Database' (http://www.stonedatabase.com).

From small-scale process studies to large-scale landscape research, the WRGs work over the last 20 years on natural landscapes and the processes that shape them is best exemplified by its input into slope instability management at the Giant's Causeway World Heritage Site (Ref 6) where hazard identification and investigation has shaped management strategies and site development.

3. References to the research (indicative maximum of six references)

1. Warke PA, Smith BJ, Magee RW. 1996. Thermal response characteristics of stone: implications for weathering of soiled surfaces in urban environments. *Earth Surface Processes and Landforms* 21: 295–306.
2. Smith BJ, Turkington AV, Warke PA, Basheer PAM, McAlister JJ, Meneely J, Curran J. 2002. Modelling the rapid retreat of building sandstones. A case study from a polluted maritime environment. *Geological Society of London Spec. Pub*. 205: 339–354.
3. Warke PA, Smith BJ. 2000. Salt distribution in clay-rich weathered sandstone. *Earth Surface Processes and Landforms* 25: 1333–1342.
4. McCabe S, Smith BJ, Warke PA. 2007. Sandstone response to salt weathering following simulated fire damage: a comparison of the effects of furnace heating and fire. *Earth Surface Processes and Landforms* 32: 1874–1883.
5. Smith BJ, McCabe S, McAllister D, Adamson C, Viles HA, Curran J. 2011. A commentary on climate change, stone decay dynamics and the 'greening' of natural stone buildings: new perspectives on 'deep wetting'. *Environmental Earth Sciences* 63,1691–1700.
6. Smith BJ, Ferris C-L. 1997. Giant's Causeway: management of erosion. *Geography Review* 11: 30-37.

Grants

1. 1997–EPSRC (£152k: Smith): Surface modification of building stone: implications for cleaning and replacement
2. 1998–EPSRC (£110k: Smith): Feedback mechanisms in decay of building sandstones
3. 2002–EPSRC (£64k: Warke) Complex weathering effects on the durability of masonry materials
4. 2007–EPSRC (£126k: Smith) Understanding catastrophic decay of building limestone
5. 2009–EPSRC (£410k: Smith) Climate change and greening of masonry: implications for built heritage and new build
6. 2012–Historic Scotland (£40k: Warke with McCabe) Heritage Science Fellowship
7. 2001–TSB and Invest NI KTP (£81k: Smith with Consarc Design Group) Research into Natural Stone Weathering
8. 2012–EPSRC KTS (£51k: Warke & McCabe with S. McConnell & Sons Ltd (Stonemasons)): Testing stone surface treatments for masonry

2005–EU (£80k: Smith) Compilation of natural stone weathering database

4. Details of the impact (indicative maximum 750 words)

The WRG has impacted on both the practice of building and landscape conservation and in the development of policies underpinning such practices. The case studies below exemplify the local, national and international range and significance of this impact in the last 15 years.

Salt distribution in sandstone: implications for conservation strategies

Locally the impact is illustrated by work conducted in collaboration with Conservation Architects (Consarc Design Group Ltd, Belfast). During planning for extensive conservation of a Victorian sandstone church in Belfast part funded by the Heritage Lottery Fund in the late 1990s, the WRG provided advice regarding stone replacement and the extent of weathering-related damage to existing stone, which had a direct impact on the extent of stone replacement required and necessitated the use of water repellent treatment for retained original stonework [Item 1]. This case shows the value of knowledge transfer and the collaborative relationship with this firm which subsequently resulted in publication of a guide for practitioners, short-listed in 2010 for the Royal Institute of British Architects (RIBA) President's Award for outstanding professional practice- located research [Item 2; Item 3].

Post-automation management of lighthouses and associated structures

Following automation of lighthouses around the UK and Ireland, reports of accelerated deterioration of interior stonework in these historically important structures increased with a rise in related maintenance costs. The WRG demonstrated that typically, a decay gradient exists within towers whereby the condition of stone in the lower levels is much worse than elsewhere reflecting higher humidity and greater salt concentrations [Item 4] Thus, accelerated post-automation decay was unintentionally triggered by reduced ventilation within towers and increased episodes of condensation on stone surfaces with deposition and accumulation of strongly hygroscopic salts. Work with the General Lighthouse Authorities (GLA) in the UK and Ireland, (i.e.; Trinity House; the Northern Lighthouse Board; the Commissioners of Irish Lights) culminated in publication of an advisory document in 2009 on approaches to building conditioning in marine environments [Item 5; Item 6].

Informing stone conservation protocols with Historic Scotland

The significance of viewing fire damage as part of a complex history of stresses experienced by stone was recognised by Historic Scotland with inclusion of this work in their technical publication advising conservators about the management of stone following fire damage [Item 7] and led indirectly to the appointment of McCabe to a Heritage Science Fellowship funded by Historic Scotland. The impact of this research is changing how conservation managers and practitioners think about stone as a material – with these findings integrated into Historic Scotland's good practice protocols on building conservation [Item 8].

Landscape management of World Heritage Sites

International impact of the WRG is demonstrated by Smith who, as a UNESCO World Heritage site evaluator was directly involved in development and implementation of management strategies for the Giant's Causeway World Heritage Site in Northern Ireland [Item 9]. The need for proactive visitor management was driven by visitor safety and an increase in the number and extent of slope failures at the site since 2000. Research on slope stability and identification of factors triggering instability with a long-term hazard mapping programme is used to inform the National Trust's accessibility plans for visitors to this site. This research led to Smith's appointment as a World Heritage Site assessor, and participation in UNESCO expert working groups undertaking technical evaluations for the International Union for the Conservation of Nature (IUCN) that inform UNESCO on inscription of sites for inclusion on the World Heritage Site list, including early hominid sites in Ethiopia, marine archaeology in Italy and Teide National Park, Spain in 2007 [Item 10].

The WRGs unique assemblage of expertise and experience places it at the centre of weathering research in the UK with a reputation for scientific innovation and application that forms a firm foundation for future research that focuses on the growing significance of climate change and its implications for long-term building and landscape conservation.

5. Sources to corroborate the impact (indicative maximum of 10 references)

1. Consarc Design Group Ltd. written testimony
2. Curran J, Warke PA, Stelfox D, Smith BJ, Savage J. 2010. *Stone by stone: a guide to building stone in the Northern Ireland environment*. Belfast: Appletree
3. http://www.architecture.com/NewsAndPress/News/RIBANews/Press/2010 / ShortlistsforthePresidentsAwardsforResearch2010announced.aspx
4. Warke PA, Smith BJ, Lehane E. 2011. Micro-environmental change as a trigger for granite decay in offshore Irish lighthouses: implications for the long-term preservation of operational historic buildings. *Environmental Earth Sciences* 63(7–8): 1415–1431.
5. Blakeley RJ, Warke PA. 2009. *Building Conditioning of Lighthouses, Accommodation, Outbuildings and Associated Structures. IGC5 Task Group Report*. Trinity House, London (ISBN 978 0853899549)
6. Commissioners of Irish Lights written testimony
7. Historic Scotland Guides for Practitioners 7: Fire Safety Management in Traditional Buildings: 'The identification and assessment of fire risk with advice on its management and appropriate technology consistent with accepted conservation principles, as well as an overview of legislation. A4 (PB) 9781849170 35, Part 1 pp 65, Part 2 pp 175'
8. Historic Scotland written testimony
9. Smith BJ, Orford J, Betts N. 2009. Management Challenges of a Dynamic Geomorphosite: Climate Change and the Giant's Causeway World Heritage Site. In: Reynard E, Coratza P, Regolini-Bissig G. (eds) *Geomorphosites Section III, Protection & Promotion*, p.145-162, O 2009 Pfeil, Munich – ISBN 978-3-89937-094-2
10. Smith BJ. 2007. World Heritage Nomination: IUCN Technical Evaluation of Teide National Park (Spain), ID No. 1258. In: *IUCN Evaluation of Nominations of Natural and Mixed Properties to the World Heritage List* (WHC-07/31 COM/INF.8B2), p.69–74. http://whc.unesco.org/archive/2007/whc07-31com-inf8B2e.pdf