THE EFFECT OF INCREASED WINTER RAINFALL ON BIOLOGICAL CRUSTS AND THEIR IMPLICATIONS FOR SANDSTONE DECAY

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Abstract

Rainfall trends for the UK show that some areas, including the west of Scotland, are experiencing an increase in both the amount and intensity of winter rain. Future changes to the climate are predicted to exacerbate this effect, creating significant potential problems for the integrity of the sandstone architecture that is a major feature of Scotland's cultural heritage.

Here we describe initial results from a suite of field and laboratory based studies designed to determine the impact of winter rainfall on the growth and loss of crusts on Scottish sandstone buildings. Monitoring of biological and pollutant crusts on existing structures, and under experimental conditions will demonstrate how crusts develop in wet urban environments compared to those in drier, more rural regions. This approach should show whether elevated rainfall leads to an increase in biological activity and/or the development of complex biomineralic crusts. Conversely, increased rainfall may result in the preferential removal of these crusts, allowing the stonework to become 'self-cleaning', but potentially exacerbating degradation by exposing the stone beneath to other weathering agents.

The impact of rainfall on biological crusts has important implications for the mechanisms and rates of sandstone decay and for the type and cost of strategies used to limit damage. If crusts are removed by winter rain, fewer resources will be needed to clean stone for aesthetic reasons. However, enhanced biological activity or degradation will increase financial costs for statutory and voluntary bodies responsible for the care of historic buildings. If the effects of winter rainfall are geographically constrained, it may be possible to offset these costs by concentrating preventative and/or remedial work in particular areas.

Keywords: winter rainfall, biological crusts, sandstone decay

1. Introduction

Data analysis by the Climate Research Unit at the University of East Anglia (UK) and the UK Meteorological Office indicate that during the last 100 years, the intensity of winter precipitation has increased across the UK (Osborn and Hulme 2002) and that areas of Scotland, particularly western regions, also receive significantly higher amounts of rainfall (Alexander and Jones 2001). Ongoing climate change is likely to exacerbate these effects: work by UK climatologists as part of the UK Climate Impacts Programme (UKCIP) show that by the 2080s, under a high emission scenario, winter rainfall may increase in some areas by up to 30%. Extreme rainfall events will become more frequent, and intensity may be up to 20% heavier than current precipitation levels

(Hulme *et al*. 2002). This will have implications for the built environment, with increased stone wetting leading to deeper moisture penetration and potentially to saturation for long periods of time (Smith *et al*. 2004). This is likely to increase the weathering and degradation of dimension stone and to promote algal growth and the associated “greening” of facades. These processes create structural and aesthetic maintenance issues, especially for culturally important buildings.

2. Development of crusts on sandstone buildings

Once sandstone has been quarried, natural changes occur in the rock as water and salts move through pore spaces in response to surficial conditions and more direct contact with to the atmosphere. Dimension stone may be left to ‘season’ before it is incorporated into a built structure with potentially damaging salts being removed from the surface by dressing (McMillan *et al*. 1999). However, some salts may remain in the pore spaces to be liberated as the stone weathers, and superficial layers of crystallised salts and deposits create patinas on the weathered stone (Smith 1999). These patinas or crusts often incorporate biological material that may adhere to the surface or may penetrate deeper into the stone (Warscheid and Braams 2000). The composition and structure of these crusts and biological communities is still poorly understood, making it difficult to predict what effects environmental change may have on their development (Cutler and Viles 2011). Increased availability of water may promote greater biological activity but it is possible that surficial deposits will be removed during intense rainfall events.

Soiling of sandstones in the built environment has traditionally been through the development of black crusts composed of soot particles (sourced from polluted air) mixed with gypsum salts (crystallised from ions derived from pollutants and the underlying stone). Government legislation to reduce atmospheric pollution has resulted in the drastic decline of levels of soot in the air, thus limiting the formation of black crusts. From the 1970’s, cleaning of buildings was the main strategy to remove these crusts, often through the use of noxious chemicals. This approach persisted until the early 1990’s when it was recognised that the use of such cleaning methods was enhancing sandstone decay (Bluck and Porter 1991) and the replacement of damaged stonework became a more widely utilised strategy (Hyslop 2006).

Vehicle emissions supply nitrogen oxide to urban environments and it is possible that black crusts will be superseded by new complex patinas as biological activity is enhanced by increased nutrient levels (Smith *et al*. 2008) as well as warmer, wetter conditions (Hulme *et al*. 2002).

2.1 Characterisation of biological crusts

This study uses Raman microspectroscopy and scanning electron microscopy to characterise crusts and biological growths on sandstones from a number of historically important buildings in Scotland. Samples include a suite of six sandstones that have formed the basis of earlier weathering and greening experiments undertaken in Aberdeen (north-east Scotland) (Young 1997; Young and Urquhart 1998) and stone recovered during conservation work at the University of Glasgow (south-west Scotland). Additional material for environmental experiments has been obtained from a sandstone quarry in north-east Scotland, which provides durable dimension stone for new buildings and for heritage repair. These samples will be used in conjunction with observation of historic buildings to allow the development of crusts in the wet urban environment of Glasgow to be compared with those in the drier and rural setting of north-east Scotland.

2.2 Experimental Work

Blocks of 2 different types of Scottish sandstone, which were treated with biocide in 2006 and left exposed on a test-rig at Robert Gordon University, Aberdeen, will be used in initial experiments to determine if crusts can be removed by very heavy rainfall (>5 mm/hour, (Svensson and Jakob 2002)) over a period of time. Experiments will also try to determine if a wet-dry cycle is important to further crust development (or its subsequent removal), whether removing biological growth increases the effects of water wetting, and whether continuous wetting increases sandstone decay rates when compared to external control samples.

3. Initial results

Examination of biological growth on the suite of 6 sandstone samples shows that the number of species present on the stones is highly variable. In the original experiment, set up in 1993, 12 blocks of each sandstone type were arrayed on a north-facing test-rig and a further 12 blocks on a south-facing rig. Some were physically cleaned and others had biocide applied (Young 1999) but, nearly 20 years on, there is no apparent difference between the untreated blocks and the stones that were treated. However, the difference in the amount and type of growth between the sandstone subsets is remarkable, given that adjacent, although isolated blocks (Young 1997) have been exposed in the same environment for a relatively long period of time. Four of the sandstone types (Blaxter, Catcastle, Clashach and Locharbriggs) are dominated by algal growth whereas the remaining samples of sandstone support a more diverse fauna, observed on both north- and south-facing rigs. Growth on Corsehill blocks include club-moss and lichen and blocks of Leoch sandstone are covered in lichen, with 14 different species recorded on one 5 cm x 5 cm x 2 cm block (Figure 1).

Raman microspectroscopy shows that the sandstone surfaces are dominated by carotene, a biomarker used to protect cells from photo-oxidation (Figure 2). This is present on all samples, regardless of the type of biological growth, showing the dominance of photosynthetic activity.

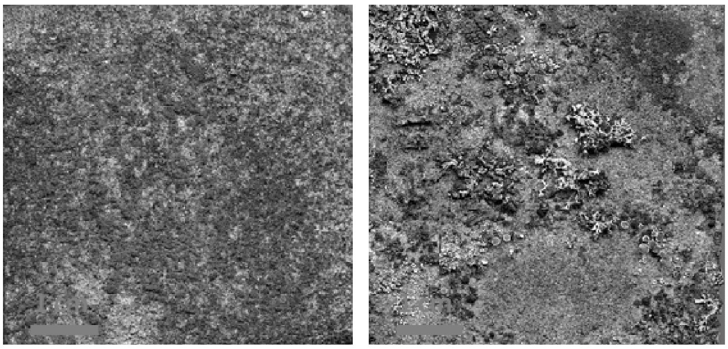


Figure 1. Photographs showing 2 of the 6 sandstones used in previous weathering experiments. The image on the left shows algae-dominated Blaxter sandstone and the right-hand image lichen-dominated Leoch sandstone.

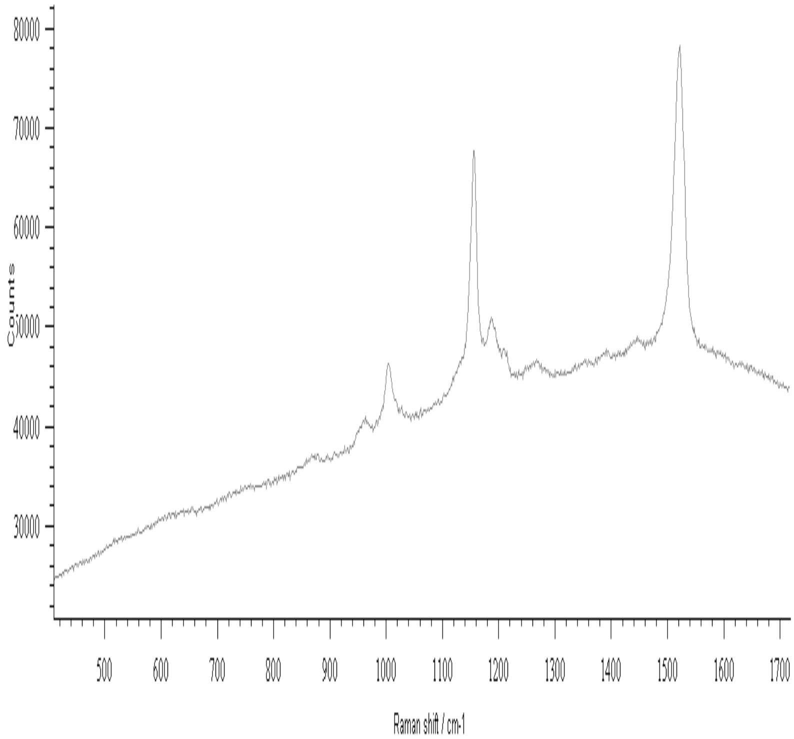
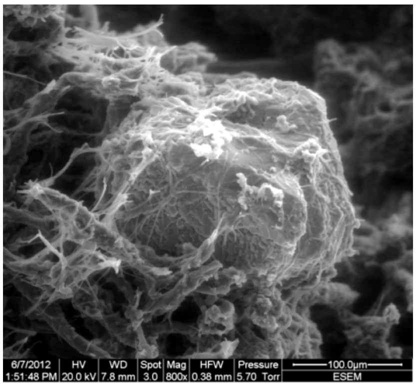


Figure 2. Raman spectrum showing characteristic peaks of the biomarker carotene, which provides protection for algal cells during photosynthesis.

Raman analysis of stone recovered from the façade of Glasgow University shows that this biomarker is also dominant in black crusts, even where biological growth is not clearly evident. Unsurprisingly, carbonaceous peaks are also observed in Raman spectra from these samples, indicative of inorganic atmospheric particulates.

Isolated mineral grains occur in all the crusts observed to date. Raman spectroscopy shows that these are primary grains of quartz and occasionally rutile rather than secondary mineral precipitates. Scanning electron microscopy shows grains incorporated into a lichen thallus, indicative of mineral plucking from the underlying stone (Viles, 1995) (Figure 3).



4. Discussion

The development of biological crusts is a complex process, reflecting both environmental factors and petrological properties of the stone (Warscheid and Braams 2000). Earlier work by Young (1997) on the sandstone samples utilised in this study found that porosity was an important factor in the time taken for colonization with the data showing a fairly good correlation between total effective porosity and the amount of algal growth. At the end of the 3-year study period, the stone type that had the lowest porosity values also had the least growth; Leoch has a mean porosity of ~6% and has pore sizes typically < 1 µm in diameter. This small pore size greatly reduced the rate of moisture movement through the stone, allowing the surface to dry out while the interior of the stone remained wet (Young 1997). This may explain why, having been slow to colonise, this sandstone now supports the most diverse flora of the 6 types studied. Young (1997) noted that lichen from the genus *Xanthoria* colonised samples of both Corsehill and Leoch sandstone; current study shows that this lichen continues to grow on these sandstones but has not colonised the adjacent blocks in the intervening period. With total porosity of ~ 18% Corsehill sandstone should dry out more quickly than Leoch suggesting that wetting time is only one factor influencing lichen growth; another of the sandstones studied, Catcastle, has porosity values that fall between those of Corsehill and Leoch but blocks of this type lack any *Xanthoria* growth. This genus of lichen generally occurs in nutrient-rich environments (Dobson 2011), particularly where fertilisers have been added (Frati *et al*. 2011). As the test-rig samples have been exposed in the same environment, preferential nutrient-addition is not plausible here, indicating that the underlying stone is acting as the nutrient source. Metal uptake by parietin containing *Xanthoria* species is more difficult at low pH (Hauck *et al*. 2009) but it is not certain what may be driving species differentiation in these sandstone samples. Young (1997) highlighted differences in substrate roughness as a factor in initial colonization but these effects are no longer discernible now that growth is well-established.

5. Implications for sandstone decay

Wetter environments are likely to have an increase in sandstone decay rates but it is not certain whether biological crusts will contribute to this or whether they will provide a degree of protection to the underlying stone (Carter and Viles 2005), thus ameliorating the effects of predicted environmental change. This study, through observational and experimental data, hopes to improve understanding of biological crusts on sandstones and thus inform strategies designed to limit damage to historic and culturally important buildings. There is considerable regional variation in the climatic effects predicted by the UKCIP (Hulme *et al*. 2002), which means that it should be possible to identify the most vulnerable historic properties and hence target maintenance plans appropriately.

Acknowledgments

AJW gratefully acknowledges fellowship funding from Historic Scotland and thanks Dr. Craig Kennedy and Dr. Ewan Hyslop from the Technical Conservation Group at Historic Scotland for valuable advice and support. Peter Chung from the Imaging Spectroscopy and Analysis Centre (ISAAC) at the University of Glasgow is thanked for providing analytical assistance. Dr. Maureen Young (Historic Scotland), Prof. Richard Laing (Masonry Research Group at Robert Gordon University) and Gavin Tennant (Tennants (Elgin) Ltd) are thanked for providing stone samples for use in this study.

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