TECHNICAL ADVICE NOTE 10

BIOLOGICAL GROWTHS ON SANDSTONE BUILDINGS

Control & Treatment

TECHNICAL CONSERVATION, RESEARCH AND EDUCATION DIVISION

HISTORIC SCOTLAND

TAN 10

BIOLOGICAL GROWTHS ON SANDSTONE BUILDINGS

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Biological Growths on Sandstone Buildings

Control and Treatment

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HISTORIC SCOTLAND

PREFACE

As the Governments' agency responsible for safeguarding Scotland's built heritage, Historic Scotland maintains some 330 monuments in the care of the Secretary of State for Scotland. In the past, the control of biological activity and plant growths on the historic masonry of these sites was routinely carried out using a variety of "approved" treatments. However, there was some disquiet expressed that these applications may have been damaging the physical fabric to which they were applied. At the same time, there was a developing Health and Safety awareness in the general use of such chemicals. As a result, some 10 years ago, the treatments were stopped, pending a programme of detailed investigation into the need for them, and their effects.

In a related area, there was a growing concern over outbreaks of algal growths which were occurring on many of Scotland's stone buildings cleaned in the extensive "facelift" programme of environmental improvements carried out since the 1960s. This "clean to green" phenomenon inevitably provoked the use of other untested masonry biocides and chemical applications.

Responding to the emerging evidence of physical loss and damage to sandstone by some stonecleaning methods, Historic Scotland and Scottish Enterprise initiated research with the Masonry Conservation Research Group (MCRG) at The Robert Gordon University, Aberdeen, in 1989. The research findings were published in 1992 as *Stonecleaning in Scotland,* followed in 1994 by *Stonecleaning: A Guide for Practitioners.* This work led to a number of additional questions being raised, among them that of the "greening" of buildings by surface biological growths, and what could be done to effect control of this without creating the risk of further damage.

In August 1991, Historic Scotland commissioned the MCRG to undertake a programme of further research. The aim of this was to provide a better understanding of the mechanisms of biological growth on sandstone structures, their influence on stone decay, and the efficacy of various biocide treatments which might be applied. Building on earlier associated studies, the resulting research report, *Biological Growths, Biocide Treatment, Soiling and Decay of Sandstone Buildings and Monuments in Scotland,* was presented and published in 1995. The findings of that detailed study form the basis of this publication.

This Technical Advice Note has also been informed by RGU's related PhD research work by Maureen Young, and their Engineering and Physical Sciences Research Council funded project, carried out at Historic Scotland's Hermitage Castle, by Dr Melanie Jones and Dr Rachael Wakefield.

The 10th in the Historic Scotland TAN series, this publication is not intended to be a prescriptive document. Rather, it aims to better inform practitioners as to the range of technical issues which should be considered when faced with a building covered by surface growth, in order that individual specifications can be devised to respond more effectively to the particular factors involved.

It was written by Sonja Cameron, Dennis Urquhart, Rachael Wakefield and Maureen Young, all of The Robert Gordon University, MCRG, Aberdeen, with support from Robin Kent and Una Lee, Senior Conservation Architects, TCRE Division, Historic Scotland.

Particular thanks are due to the Macaulay Land Use Research Institute for producing and providing the scanning electron micrographs, and to all other associated individuals and organisations, who participated in, and contributed to, the research work.

Ingval Maxwell
Director
Technical Conservation, Research and Education Division
December 1997

ACKNOWLEDGEMENTS

The authors wish to recognise the support provided by the Faculty of Design, the School of Construction Property and Surveying and the School of Applied Sciences of the Robert Gordon University both in the preparation of this book and in the supporting research.

The helpful advice and support of the Technical Conservation, Research and Education Division of Historic Scotland in the preparation of the text for publication is gratefully acknowledged.

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INTRODUCTION

Biological growths such as algae, bacteria, fungi, lichens and mosses are common on the exterior of buildings especially in rural areas. They will colonise stonework wherever conditions of moisture, light, temperature and nutrition are suitable. Dark soiling on a surface is often equated with particulate soiling when closer inspection would reveal soiling of a biological nature. The issue of biological growth on buildings is to a large extent a matter of perception and aesthetics. It is important to bear in mind that their presence on stone is not necessarily harmful and, depending on circumstances, it may not be necessary to remove them. In the past, growths, in particular lichens, have sometimes been encouraged on buildings by a number of methods including applying a wash of cow dung and water, human urine or skimmed milk. A patchwork of differently coloured lichens over a stone surface may be considered aesthetically pleasing and indicate a relatively clean atmosphere. Due to modern air pollution, established lichens on older buildings may be increasingly rare examples of threatened species.

However, many people do not consider a covering of green algae or moss to be aesthetically pleasing, and occasionally the presence of biological growths may be thought undesirable. They can obscure and cause deterioration of inscriptions and carvings. Some organisms have sticky surfaces which can trap dust particles from the atmosphere, increasing the rate of soiling of the building surface and aiding the establishment of higher plants. These in their turn may increase water retention and block gutters and downpipes, leading to further defects.

In some cases, damage to stone may be caused or initiated by the presence of biological growths. In other cases, a biological growth may act as a protective layer shielding the stone from other factors which cause decay, such as wind and rainwater. Biological growth is only one of many environmental factors that may contribute to the deterioration of stone, and its removal will not necessarily halt the process of erosion.

Where control of growths on the surface of stone is considered necessary for reasons of safety, decay or aesthetics, it can often be achieved simply though the control of surface wetness by repairing or improving drainage, or encouraging quicker dry-out by reducing the sheltering effects of closely situated vegetation or other structures.

In recent times, biological growths on stone have been controlled by the application of biocide washes. These are generally effective for a short period of time only, and, as a result of recent health and safety legislation, some of the more effective products have been withdrawn from the market. This has reinforced the need for new research in the field which may lead to new products and methodologies.

This Technical Advice Note aims to provide guidance to practitioners regarding the colonisation of stone by biological growths, the effect of growths on the stone, and the feasibility as well as the means of removing the growth. It also addresses the problem of the reappearance of growth after treatment with biocides. A body of opinion exists which contends that the cleaning of sandstone buildings and monuments helps to promote the development of biological growths on masonry, especially algae, with the consequent aesthetic deterioration of the stone surface. It has been observed that algae can colonise cleaned stone within a few months of cleaning.

The focus of this advice note is on sandstone, because it is the predominant building stone in Scotland. However, since growths are found on other stone types as well, many of the observations made here are to some extent applicable to a whole range of stone types.

2
TYPES OF BIOLOGICAL GROWTHS AND THEIR RECOGNITION

2.1 Algae and Cyanobacteria

Algae are very simple plant forms. Unlike 'true' plants, they have no leaves, stems or roots, but exist as individual cells, clumps or colonies or as long strands or 'filaments'. They exist in many forms, from microscopic cells to seaweed and giant kelps. Algae are photosynthetic (that is, they use light to convert carbon dioxide into nutrients), and they are present in almost any environment that contains moisture and light. The various pigments within the cells, contained in specialised 'chloroplasts', can make them appear green, red, orange or yellow.

Algae

Most algae found on stone are predominantly green in colour (green algae or *Chlorophyta*). Occasionally algae may change colour as the environment changes, and as different life cycles of the cells are reached. Algae will grow across a range of pH, light intensity, moisture contents and temperature. They appear at the stone surface concentrated in indents, on protrusions or following the pattern of water runoff. In some cases they create an almost uniform coverage over large areas of entire surfaces. Algae grow in communities of many cells clumped toegether; their growth patterns rarely exhibit distinct boundaries or edges. Plate 1 illustrates a typical example of algal colonisation of sandstone ruins.

The communities are often enclosed in mucilage which protects them against drying out and helps them adhere to the substrate. They can reproduce in processes ranging from fragmentation at its simplest, to the complex production of spores. Algal spores are very resistant to drying out and may remain viable for many years.

Cyanobacteria (Blue-green algae)

Cyanobacteria or Blue-green algae are different from other algal groups in that the internal structure of the cells resembles that of bacteria and does not contain a distinct photosynthetic organelle. They are usually smaller, and some have photosynthetic pigments not found in other algal groups and which can give some species a distinct blue-green colouration. They can exist as filaments or as single cells. Most are encased in mucilage which, in some species, enables them to move.

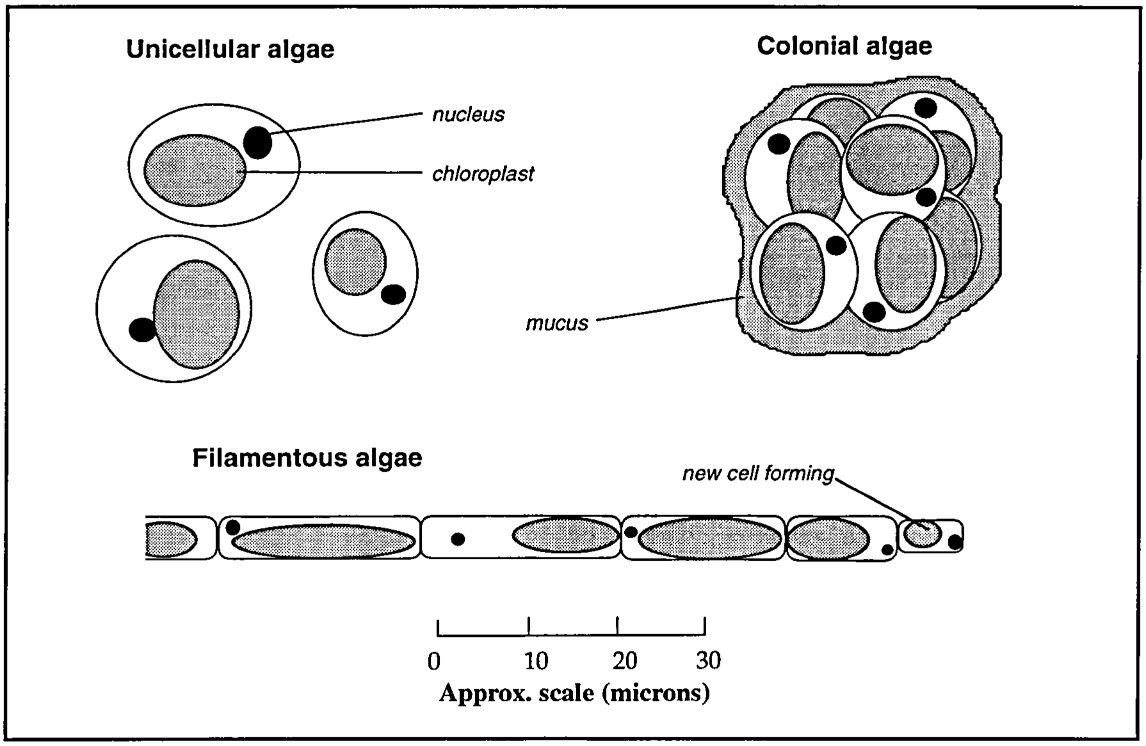


Figure 1: Diagrammatic illustration of basic forms of algae typically found on stone

Cyanobacteria reproduce by cell division and fragmentation. Most Cyanobacteria favour neutral to alkaline pH.

Nutrition

Algae are photosynthetic organisms; they absorb carbon dioxide from the atmosphere and use sunlight to convert this to energy for growth. They obtain other mineral nutrients from debris deposited by wind and rain, or from the substrate. Some species of Cyanobacteria can fix atmospheric nitrogen, which enables them to colonise areas free of vegetation and devoid of all but the most basic mineral salts. Cyanobacteria also tolerate lower light levels than other algal groups.

Effect on stone

The main body of opinion is that algae contribute to stone deterioration because they encourage water retention at the stone surface, and because they represent an early stage in the successive colonisation of the surface by mosses and higher plants. However, there is also growing evidence to suggest that algae do in certain circumstances play a significant role in stone biodeterioration - such as dissolution of mineral elements through acidic secretions, chemical and physical effect of mucilage and pressure of growth of cells situated in cracks, crevices and pores. Plate 2 shows an example of sandstone decay by the alga *Trentepohlia*.

2.2 Bacteria

Bacteria are single-celled organisms invisible to the naked eye. Many thousands of species exist. Cells can be rod-shaped, spherical, dumbbell shaped, spiral or even cuboid. They can appear singly, in pairs, or in groups. Bacteria are ubiquitous in nature, occurring almost anywhere that water is present. In favourable environments they grow in colonies of many millions.

Bacterial cells are protected by thick walls which consist largely of protein. In addition, they may be surrounded by slime capsules or be covered in

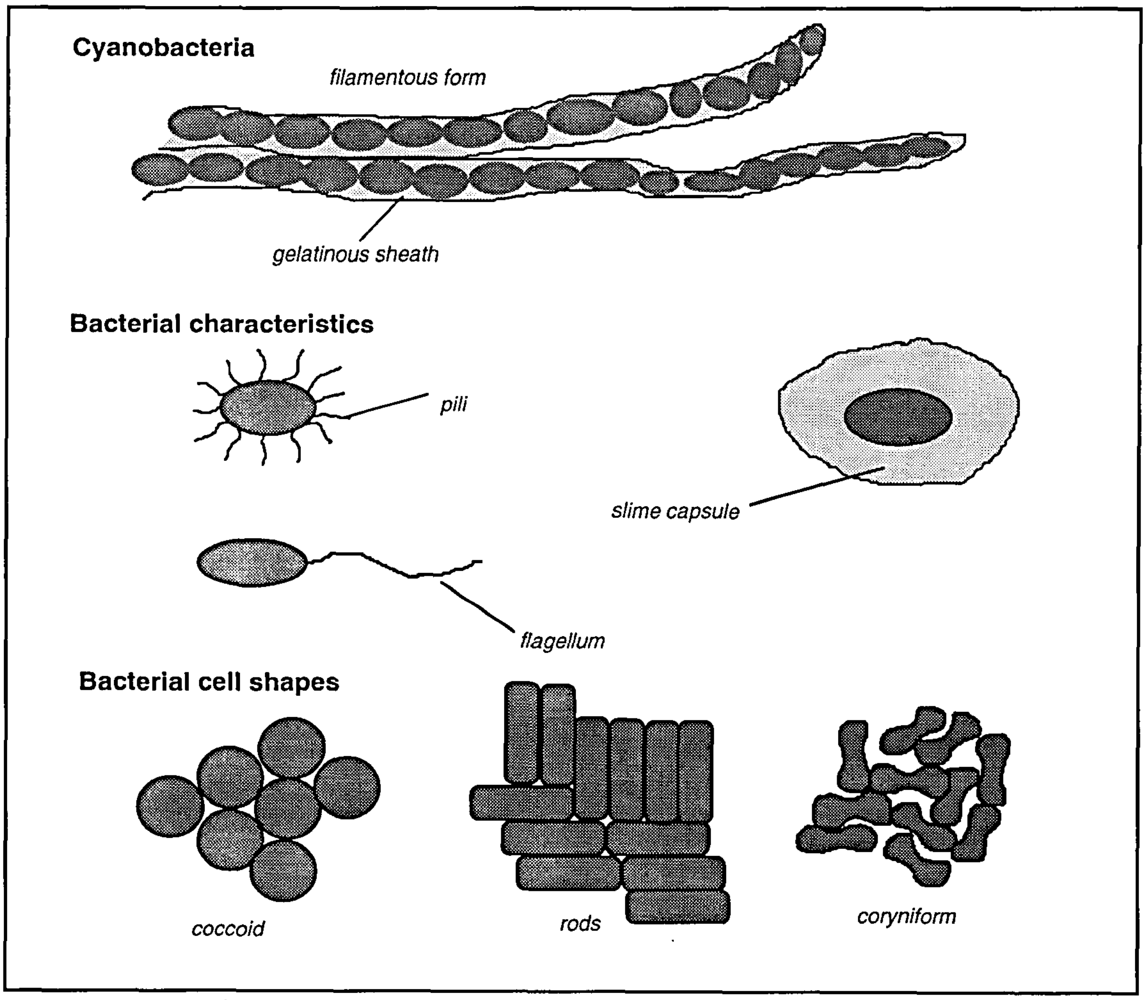


Figure 2: Diagrammatic illustration of some bacterial characteristics

protein filaments or *pili* which help them adhere to the substrate. Some species can move around in a watery environment, propelled by long protein filaments called *flagella.*

Bacteria reproduce by cell division. When nutrients are scarce, some are also capable of producing spores; others become dormant or fragmented. The spores of bacteria can stay viable over decades.

Nutrition

Bacteria are very flexible in the range of nutrients and carbon sources they can utilise for growth and reproduction. Some bacteria require organic nutrients. On stone, they obtain these from a wide range of sources such as mucilage and nutrients excreted by other cells (e.g. algae), debris deposited by wind and rain, or dead organisms. Some species are able to take up carbon dioxide from the atmosphere, like photosynthetic organisms.

Effect on stone

The activities of bacteria may cause stone to decay through the secretion of compounds which are capable of dissolving various components of the stone. Certain species of bacteria also secrete mineral acids, such as sulphuric acid, which can attack calcareous stones such as limestone and some sandstones.

2.3 Fungi

Fungal cells grow as long strands or *hyphae.* These strands have a diameter of about 5 to 9 μm and can be up to several metres long. Many thousands of species exist.

Reproduction usually occurs when nutrients are scarce, by the production of sporing structures. These range from the modification of hyphae tips to the development of highly complex multicellular fruiting bodies such as mushrooms and toadstools. Fungal spores are very resistant to dessication and may be viable after more than a year, in many cases after decades.

Nutrition

Fungi require organic nutrients, generally obtained from similar sources to those of bacteria. Both fungi and bacteria usually grow in close association with algae on stone surfaces and are frequently seen attached to algal cells. Some fungi can absorb organic nutrients from the atmosphere; others have been known to use carbon dioxide as a carbon source for growth.

Effect on stone

The hyphae of fungi can cause decay by physical penetration into and around grains in the stone. The hyphae of dry-rot fungus can penetrate soft mortar and brickwork. Stone mineralogical changes can also be brought about in the form of etching a generation of new minerals, through the biochemical activities of fungi. The secretion of organic acids, in particular oxalic acid, appears to be a major mechanism of mineral alteration.

2.4 Lichens

Lichens are organisms created through a symbiotic relationship between algae and fungi. They consist of a densely packed network of fungal hyphae, called a *thallus,* usually with distinct surface,

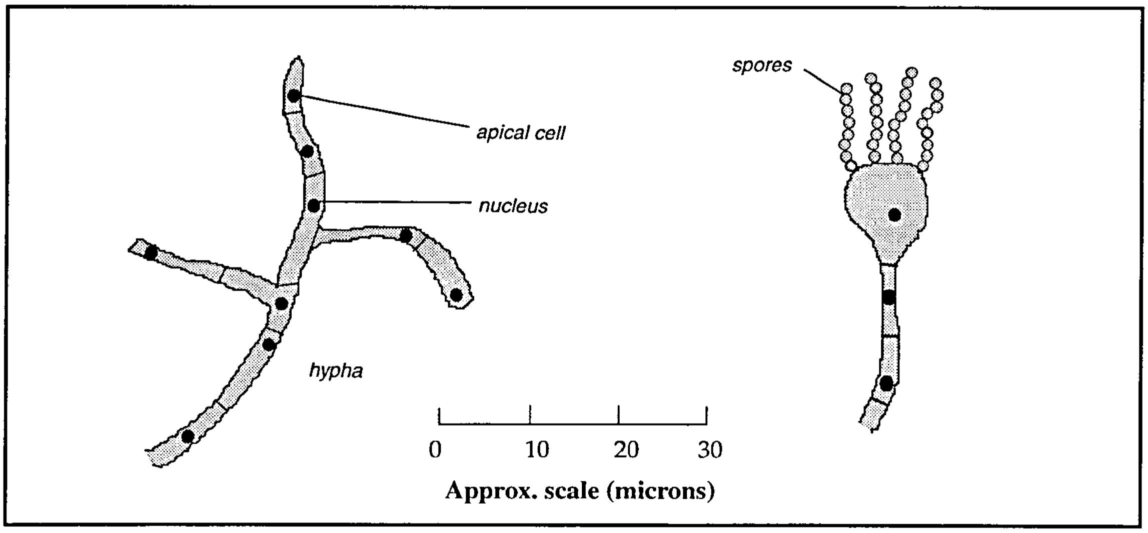


Figure 3: Diagrammatic illustration of components of fungi

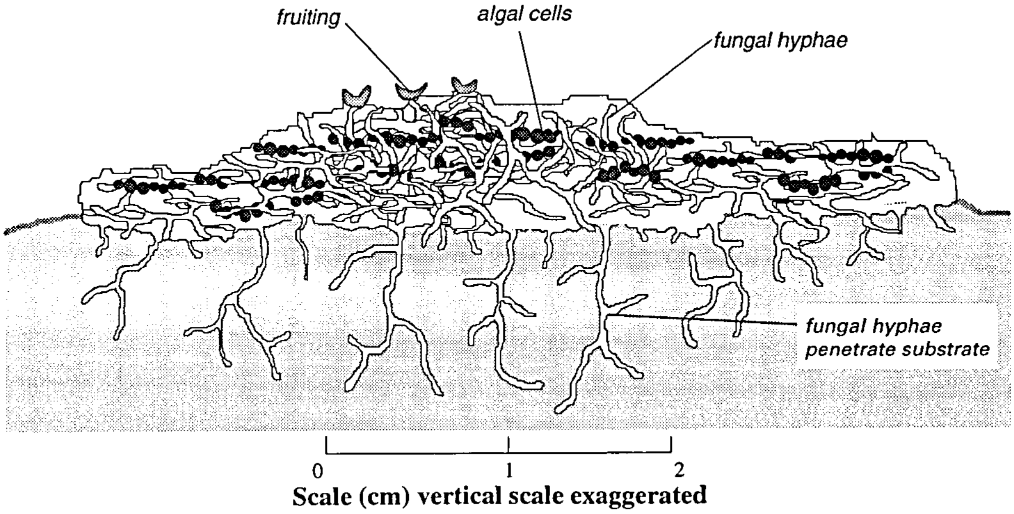


Figure 4: Diagrammatic cross section of typical crustose lichen

middle and basal regions. The middle region contains algal cells. Hyphae at the base of the thallus enable the lichen to attach very closely to the stone. The algal component provides nutrients for the fungi. Many hundreds of species exist.

Reproduction occurs through fragmentation of the thallus and by spores generated through the seasonal production of fruiting bodies. They typically appear at the stone surface as discrete patches, most usually with well-defined edges or borders. They differ in colour and physical appearance, depending upon species, and vary in size from a few millimetres to several centimetres long. Lichens are very slow-growing compared to other organisms, e.g. algae.

Nutrition

In lichens, algal and fungal cells exist in a symbiotic relationship. The algal cells photosynthesize and excrete nutrients which are absorbed by the fungal hyphae. The fungus provides an environment for the algae which protects them against extreme environmental conditions, and possibly provides them with basic mineral nutrients derived from the atmosphere and stone surface.

Lichens are extremely slow-growing organisms due to the limited availability of nutrients and water at the stone surface where they usually develop.

Effect on stone

Certain species of lichen can damage susceptible stone types, causing bleaching, blistering or sloughing of the surface through physical processes, and through the production of many and varied organic compounds. In severe cases of blistering, erosion pits which form at the centre of a lichen growth can reach several millimetres in depth (Plate 3).

2.5 Mosses

Mosses are small, simple plant structures consisting of a leaf region and a primitive root or *rhizome* growing together. The rhizome enables attachment to the substrate (wood, stone, soil).

Mosses reproduce through fragmentation or by means of a spore-producing structure called *sporangium*. They appear at the stone surface concentrated in cracks or crevices or on frequently wetted slopes such as roofs. Growths are usually in the form of discrete, often rounded clumps, dark green or reddish in colour.

Nutrition

Energy and complex organic nutrients are obtained through photosynthesis. Mosses usually require a certain amount of soil on which to attach and obtain mineral nutrients which are absorbed through the rhizomes. They require a much higher water availability for growth compared to algae and lichens, and are far more loosely attached to the substrate.

Effect on stone

Due to their high capacity to hold moisture, these plants lengthen the period of time over which the stone remains damp. Their presence is an indication of persistently damp conditions which are probably more damaging than the organism itself. In some cases, moss can cause some disruption to the stone surface or mortar joints.

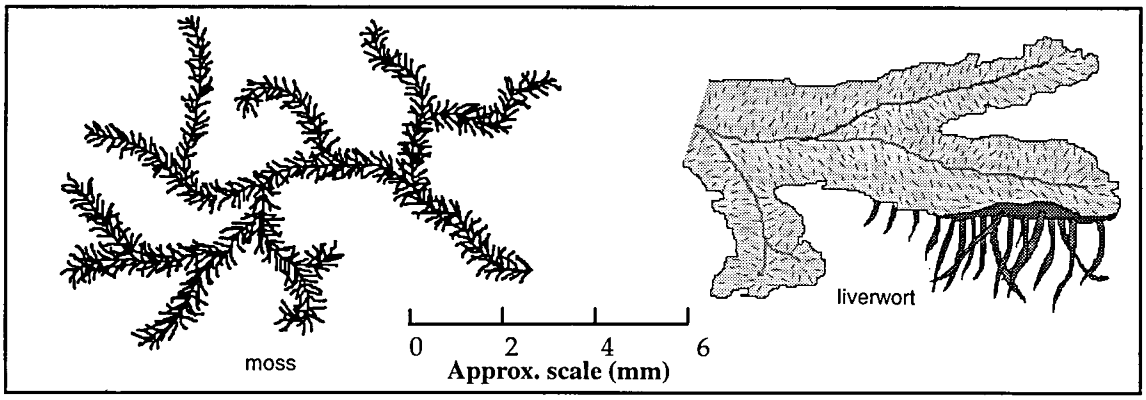


Figure 5: Diagram of moss and liverwort (after Caneva et al., 1991)

2.6 Liverworts

Liverworts are small, primitive plants (a few millimetres to a few centimetres long) consisting of a green, flat, lobed thallus. Small, primitive rhizomes aid attachment to the substrate (stone, wood, soil). Like mosses they reproduce through the production of a sporangium. They grow as individual plants usually on horizontal surfaces. In some instances, many plants may appear crowded together.

Nutrition

Liverworts require a lot of moisture and are found in areas which are wetted very regularly and frequently. Energy and complex organic nutrients are obtained through photosynthesis. Other mineral nutrients are absorbed through the rhizomes.

Effect on stone

The effect of liverworts on stone is unknown. No adverse effect has been observed to date.

2.7 Succession of colonisation

The types of growth that appear on masonry depend on many factors, with some growths being more demanding than others. Algae colonise areas which receive light and are frequently moistened, and tend to appear in very damp areas. Fungi and bacteria colonise most areas regardless of light, and are present in higher numbers when associated with photosynthetic organisms. Lichens prefer clean air, but they can tolerate extreme dehydration and nutrient limitation and tend to colonise stone surfaces which contain little moisture and where colonies of algae or moss are infrequent.

Succession on urban building stone may be quite different from that on stone in more rural locations, owing to the levels of air pollution. Many species, especially lichens, cannot now colonise habitats in which they would previously have been found. Instead, species which are pollution tolerant have vastly increased in number.

Establishment of organisms on a new substrate is normally quite a slow process (except in very damp conditions) as fresh stone has little in the way of available nutrients. On concrete surfaces colonisation will not occur until the pH of the surface has become less alkaline.

Colonisation begins by the deposition of airborne microbial cells and spores onto the stone surface. Whether or not the cells survive and the spores germinate depends upon the microclimate at the stone surface. If the stone surface is able to retain moisture for any length of time and traces of nutrients exist, it will be suitable for colonisation.

The colonisation of stone generally involves a progression or cycle of species which is principally controlled by the availability of nutrients and also by changes in the substrate and availability of moisture.

Many of the organisms that initially colonise stone, also called pioneer species, can derive nutrition by fixing carbon dioxide from the atmosphere. Such organisms (usually bacteria or algae) are able to colonise almost any stone surface if it remains wet for a suitable period. Cyanobacteria are common pioneer organisms. The ability of some to utilise atmospheric nitrogen for growth enables them to colonise areas free of vegetation and devoid of all but the most basic mineral salts.

After pioneering organisms have become established, other species can begin to colonise the surface and may displace and take over from the primary colonisers. These secondary colonisers can utilise products of metabolism and material trapped by the pre-existing biological growths as a nutrient source. They may include higher organisms such as moss or small plants, and the bacteria and fungi associated with them. Certain species of lichen may also take advantage of such pre-colonised areas.

Higher plants require a degree of accumulated organic and mineral material. Succession by them will generally occur on most surfaces which are allowed to accumulate debris. Since organic growth will probably affect the water retention properties of the stone, changes in water availability may also be a factor in the succession of biological growths.

The diversity of growths present at a stone surface depends upon social compatibility of the components and the micro-environment where growth occurs. It is common for mutualistic associations to be set up between different microbial species. The secretions of algae are readily available as nourishment for other microorganisms living in close proximity. Mutualism is common between algae and fungi growing in nutrient limited environments. It also appears that the colonisation of stone by fungi is strongly dependent on the prior development of bacteria. This may be due to a form of mutual relationship between the organisms. Plate 4 shows an example (highly magnified) of a microbial community found on sandstone.

2.8 Identification of common biological growths on stone

Organisms vary widely in their susceptibility to biocides. A treatment which can effectively kill one organism may leave another similar organism unaffected. Where the control of a biological growth by means of a biocide is considered desirable, it will be necessary to identify the type of biological growth to ensure that the appropriate and most effective biocide is used. It is often difficult to distinguish algae, lichen and moss on stone. Table 1 identifies some typical features.

Table 1: Common biological growths on stone

Growth	Colour	Appearance	Habitat
Algae	green or sometimes black, red, orange or yellow	• Can appear as uniform mats, patches, or streaks on stone surface, lacking defined borders • Sometimes slimy to touch if the surface is wet	• Substrate: wood, stone, soil, glass, plastic, etc • Favour areas that retain/receive frequent moisture, and light
Blue-green algae (Cyanophyta)	green, blue-green, grey, black	• Can appear as dark mats, patches or streaks on surface of stone, as above • Sometimes slimy to touch	• Substrate: wood, stone, soil, glass, plastic, etc • Favour humid environment; require less light than algae
Bacteria	not visible to the naked eye	• Microscopic examination required to distinguish against algae • Contribute to the slimy touch of growths	• Substrate: anything from living organisms to stone • Grow almost anywhere that water is present • No sunlight required • On stone surfaces often associated with algae
Fungi	depends on species	• Long strands or filaments massed together, sometimes large fruiting body on very decayed stone	• Substrate: anything from living organisms to stone • Require moisture, but no sunlight • On stone surfaces often associated with algae
Lichens	many colours (white, grey, orange, red, black, yellow, green)	• Vary between flat crusts close to surface or clusters of leaf-like structures growing away from surface • Defined borders, few mm to several cm across	• Substrate: stone, wood, soil • Often found in conditions too dry for other organisms; can absorb moisture from the air • Most species favour low levels of atmospheric pollution
Mosses	mainly green or reddish	• Leaf region of cells and primitive root growing together, often as small, discrete clumps, loosely attached to the surface	• Substrate: wood, stone, soil • Require very damp environment, sunlight and some soil
Liverworts	green	• Flat lobed thallus, a few mm to a few cm long, and small, primitive roots, loosely attached to the surface	• Substrate: wood, rock, soil • Require very damp environment, sunlight and some soil

3
THE NATURE OF SANDSTONE

Sandstones are sedimentary rocks formed from accumulated detrital, solid material. Their characteristics depend on a number of factors including the nature of the detrital material and the environment of deposition. Quartz is the principal constituent of most sandstones. It is frequently accompanied by significant amounts of feldspar and mica. Other mineral grains or rock fragments may also be present.

The fabric of a sandstone has three main components – the detrital grains, authigenic minerals (minerals which have formed since deposition) and pore space. As the sediment becomes buried, it is lithified and turned into sedimentary rock. The weight of overlying material causes compaction, so that pore space is reduced.

The lithification of sandstone occurs by two processes: pressure solution and cementation.

- Pressure solution is a process whereby adjoining quartz grains can become welded together by pressure from the overlying sediments, going into solution at their contact points leading to interpenetration. If this process is extensive it can result in an extremely strong and resistant sandstone.

- Cementation means that sediments are lithified through the deposition of a cementing mineral from an external source. These cements are deposited from fluids circulating through the pores, or by solution and redeposition of mineral grains within the sediment. Many different minerals can occur as cements in sandstones. The most common types are quartz (silica), clays, calcite, dolomite and iron-oxides. Any one sandstone can contain a number of different cements deposited at different times as the chemistry of the pore waters changed.

It is rare for the pore space in a sandstone to be completely filled. Porosities in sandstones range from virtually zero up to about 30-35%. Values are commonly in the range 15-25%. Pore space is one of several factors influencing biological growth on stone.

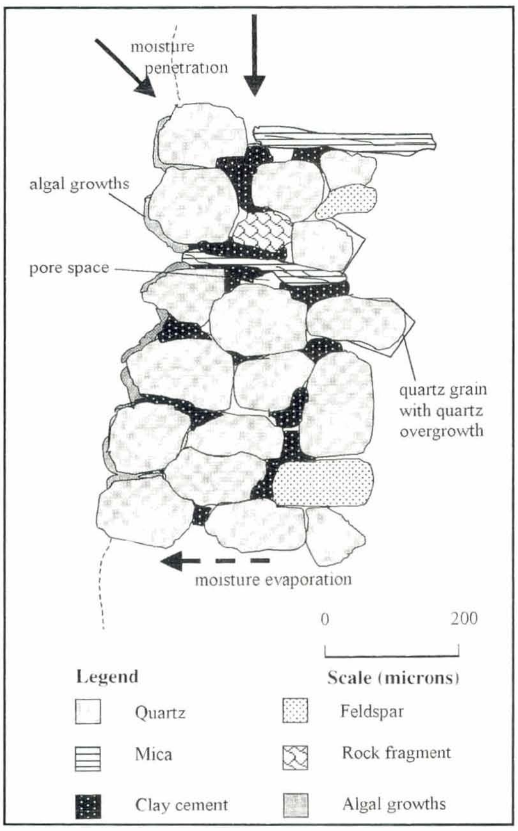


Figure 6(a):
Diagrammatic representation of structure of sandstone showing algal growths on exposed surface

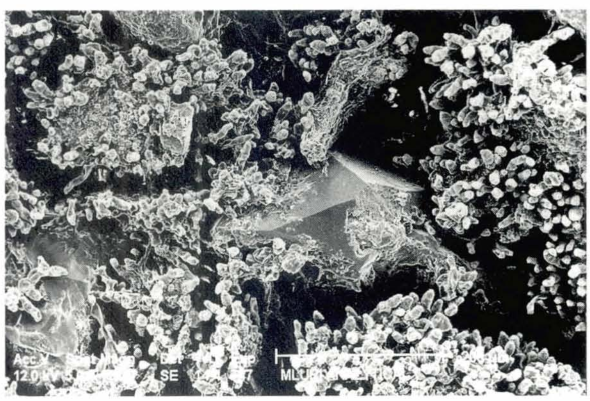


Figure 6(b):
Scanning electron micrograph of surface of sandstone showing algal filaments growing between grains

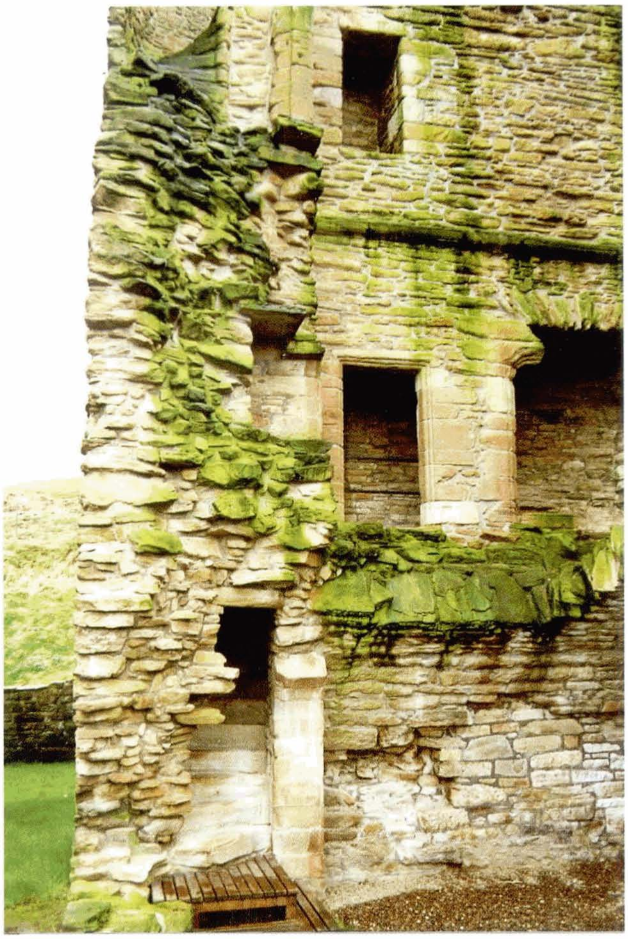


Plate 1
Typical example of algal colonisation of sandstone wallheads, ledges and splash zones at Crossraguel Abbey.

Plate 2
Example of decay of sandstone by the alga Trentepohlia. *Note the orange coloration of the growths.*

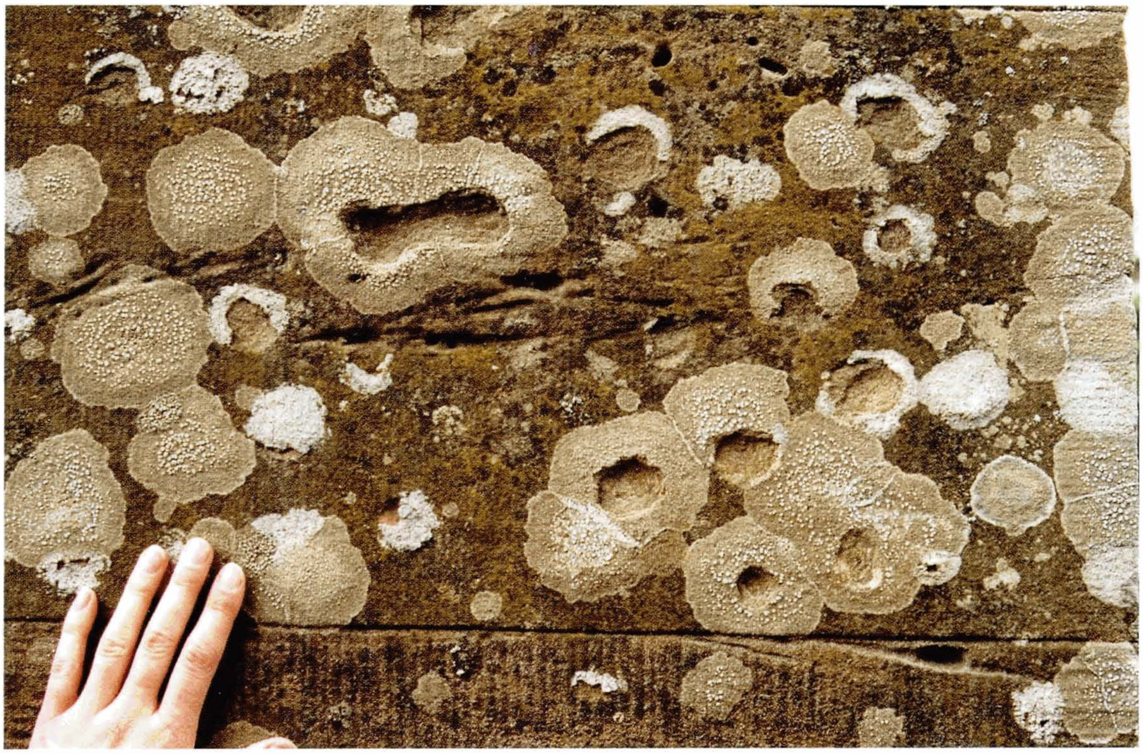


Plate 3
Example of lichen damage to sandstone. Note the formation of erosion pits at the centre of the growths.

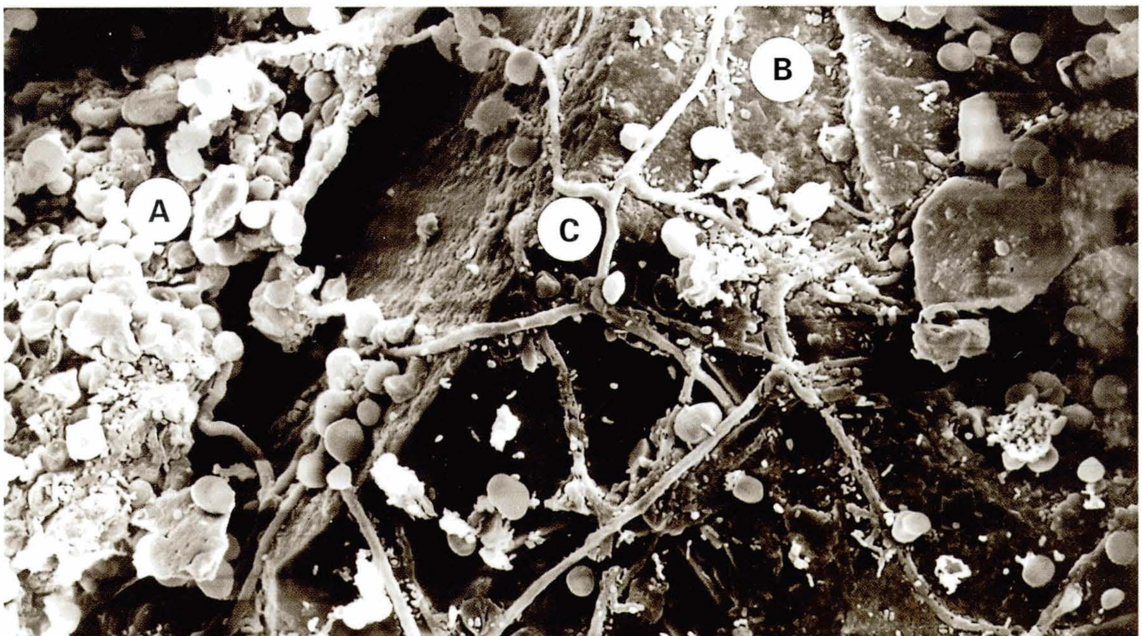
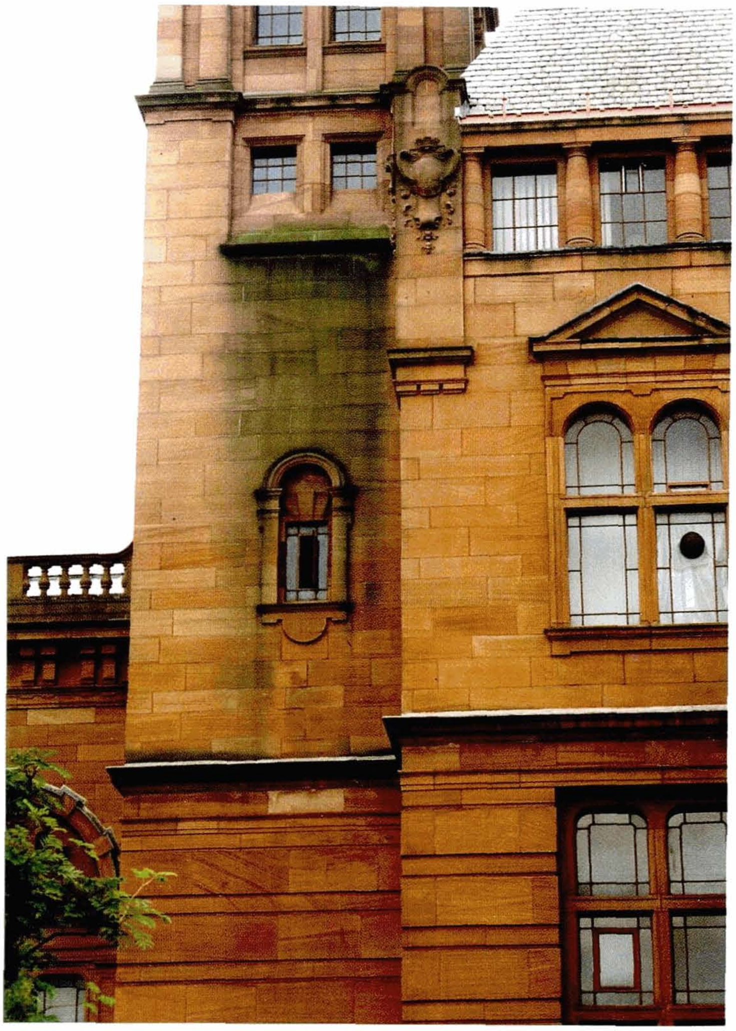


Plate 4
Scanning electron micrograph of a microbial community found on sandstone.
A = algal cells, B = bacterial clumps, C = fungal hyphae/algal filaments.

Plate 5
Corner between north west and south west elevations. Note increased incidence of algal growth on north west facing wall.

Plate 6
Preferential colonisation of roughened surface of sandstone.



Plates 7 & 8
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Plate 9
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Plate 10
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Plate 11
Heavy biological growth on run-off zone and on carved detail. Black soiling at edge of the zone is typical of gypsum crust formation on calcareous sandstone.

Plate 12
North entrance to Inverness Cathedral: preferential biological colonisation of exposed surfaces.

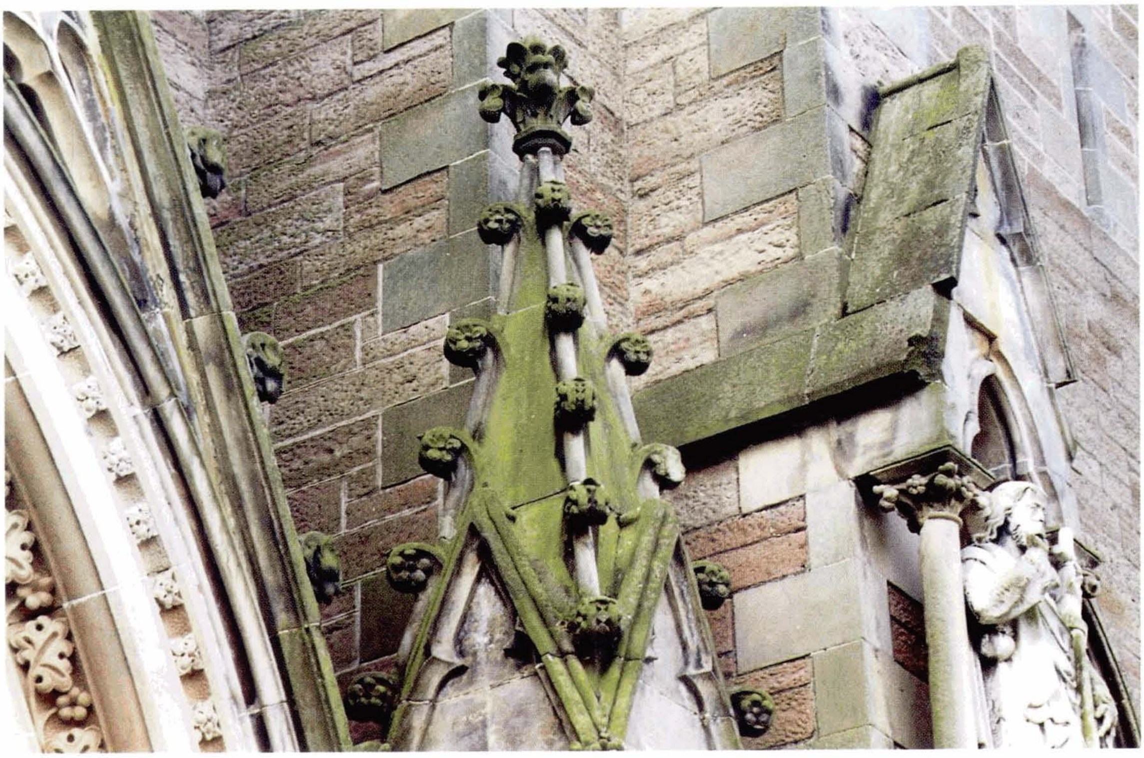

Plate 13
Inverness Cathedral: pattern of biological growths on carved detail.

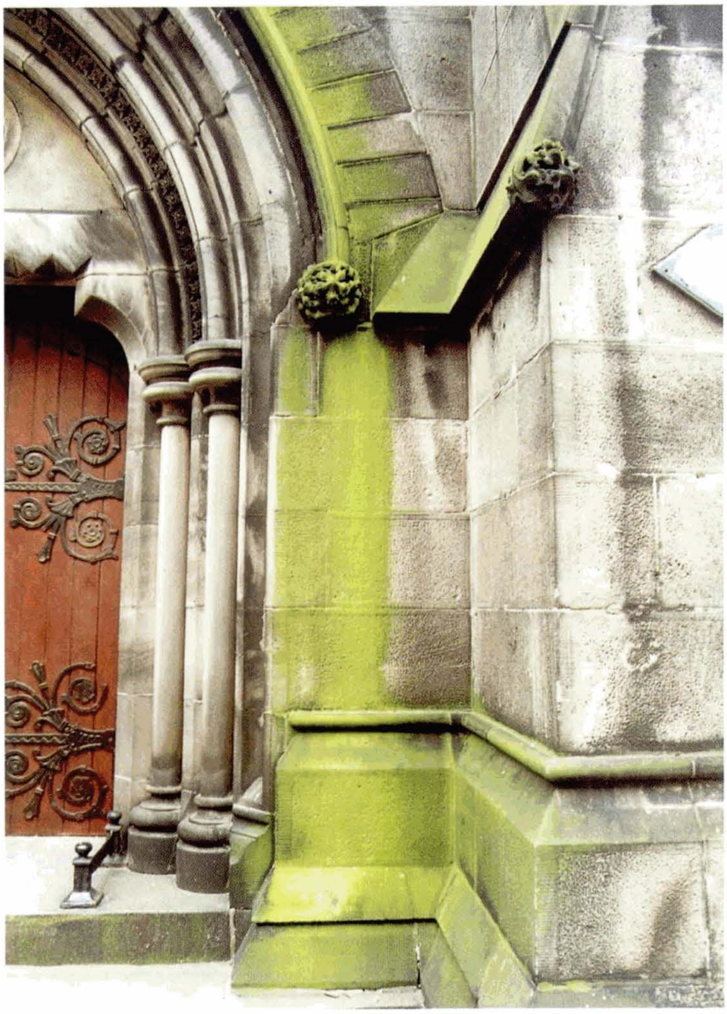

Plate 14
Door detail at base of church steeple showing channelling of run-off and algal growth on wetter zones.

Plate 15
Growth pattern on replacement stone. Note the inhibitory effect of alkaline run-off from new lime mortar.

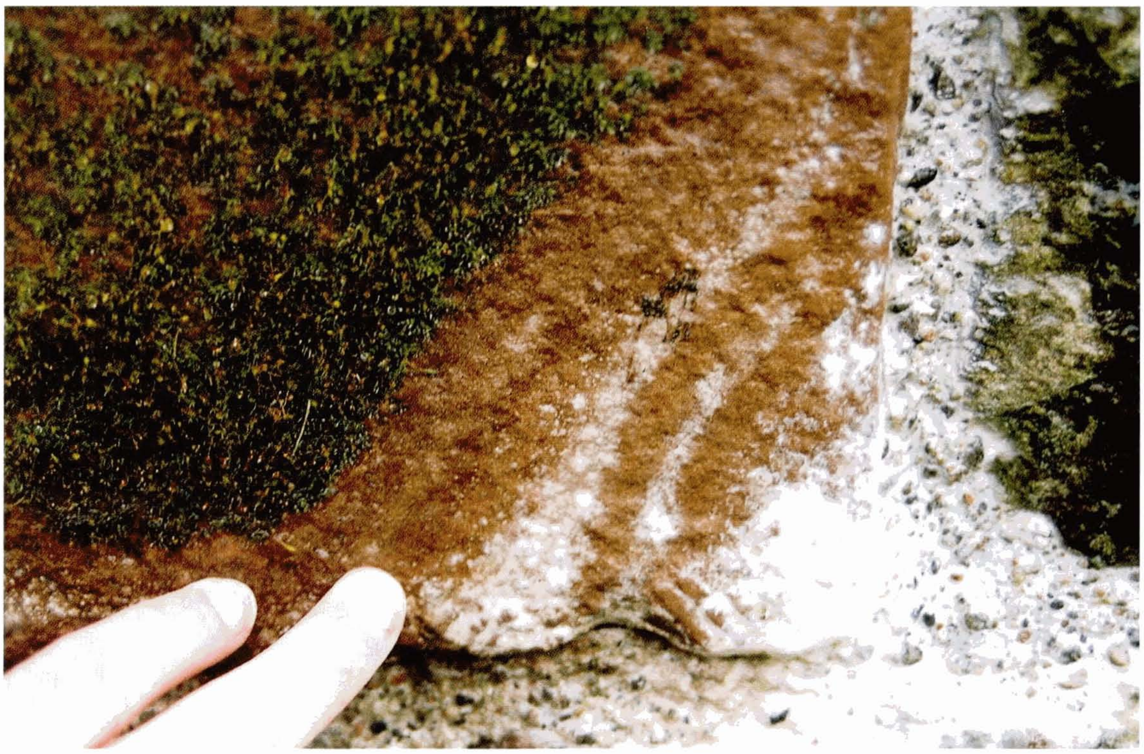

Plate 16
Inhibitory effect of new lime mortar. Note also salt efflorescence from the mortar.

4
FACTORS INFLUENCING BIOLOGICAL GROWTHS ON BUILDINGS AND MONUMENTS

The conditions required for biological growths to colonise an environment vary depending on the type of organism and the species. This means that the nature of the stone and the local microclimate are important factors in determining which organisms will colonise a building facade.

Photosynthetic organisms (such as algae), which utilise light to fix carbon dioxide from the atmosphere, require only moisture, mineral salts and light in the environment to grow. Other organisms (such as fungi and some bacteria) require moisture and nutrients but not light. Stone as an environment for growth favours organisms which do not require large amounts of nutrients in the form of carbon from the substrate. The growth of organisms which do, such as fungi and some bacteria, only becomes established in large numbers once photosynthetic organisms, providing carbon nutrients, have grown. Many organisms can withstand drying out for relatively long periods, but active growth usually requires relatively high moisture levels in the stone or high humidity in the surrounding atmosphere. In urban areas, the diversity and abundance of many biological growths has been greatly reduced by atmospheric pollution.

Most growths require primarily water, although not all to the same degree. The colonisation of a stone by algae is, to a great extent, associated with the availability of water at the stone surface. Some stones and surfaces are capable of greater absorption and retention of moisture than others, and thus provide a more hospitable environment for growth.

In the context of buildings and monuments, the important factors influencing water availability, and therefore biological growth, are:

- climate and geographical location
- orientation of the elevation
- characteristics of the stone
- availability of nutrients
- architectural form and detail of the building
- building maintenance

4.1 Climate and geographical location

Geographical location has an important influence on the type and intensity of biological growth on exposed facades. Amongst many other features, variation in growth depends to some extent on climatic differences and pollution levels.

In terms of climate, the important considerations in assessing the viability of a site to support biological growth are moisture availability (dependent on precipitation, sunshine, and wind exposure), temperature and light.

Moisture

The climate of Scotland is sufficiently variable to influence the amount of water available for growths to become established and to proliferate. Climatic data obtained from the Meteorological Office for seven meteorological stations distributed throughout Scotland show that there are significant variations in rainfall and other climatic factors (see Table 2). For instance, Dunbar has an average annual precipitation of just over 560 mm, while Eskdalemuir, only 50 miles away, is recorded with an average annual precipitation of over 1500 mm. It should be appreciated that even within a small area, across a city for example, there are local differences in precipitation and sunshine due to local features. In general terms, the east and north-east of Scotland (e.g. Dunbar, Kinloss and Arbroath) have significantly less precipitation and fewer days with nil sunshine than the west and south-west (e.g. Glasgow, Prestwick and Eskdalemuir); all of which contributes to the water availability for algal growth. Correspondingly, it appears that in general, buildings in the south-west support more growth than buildings in the north-east.

Temperature

Every organism has an optimum temperature at which maximum growth occurs, although the organism will also grow within a range of temperatures close to this ideal. Organisms occurring on stone are able to tolerate a wide temperature range. Generally, spores are more resistant to temperature extremes than the living organisms.

Table 2: Survey of climatic data for cities and towns throughout Scotland
(Data are long-term averages, supplied by the Met Office)

Station	Av. daily mean temp. (°C)	Av. total annual precipitation (mm)	Av. total annual sunshine hours	Av. annual no. days nil sunshine
Dyce	7.9	795	1356	71.9
Kinloss	8.4	622	1259	61.5
Arbroath	8.4	619	1502	71.7
Dunbar	8.9	561	1506	62.4
Abbotsinch	8.7	1005	1281	91.6
Prestwick	8.8	930	1440	69.5
Eskdalemuir	7.1	1531	1201	93.2

As far as Scotland is concerned, temperature conditions prevailing at stone surfaces are suitable for the development and growth of microorganisms.

Light

Light is required for growth by photosynthetic organisms such as algae and lichens. Some algae are capable of changing their colour in response to different light levels. Cyanophyta can tolerate lower light levels than other algal groups, and can consequently be found on the interior of buildings which receive some light and experience high levels of atmospheric humidity and/or damp walls.

On average, the wetter sites on the west coast tend to have less sunshine than the drier east coast sites, although the relationship is not consistent.

Pollution

Another factor which influences biological growth, in particular that of algae and lichens, is the extent of air pollution at the site.

In general, the diversity of biological growths, particularly lichens, is greater in rural than in urban areas. Places in rural areas tend to have a wide variety of lichen species, mosses and algae in relative abundance. By contrast, buildings in urban environments tend to be predominated by algal growths with few lichens.

The type of algae found in urban areas is restricted mainly to toxitolerant species, which create a uniform appearance on stone. More rural towns tend to show a greater diversity of species.

The growth of moss is generally discouraged by the accumulation of excessive dust and pollutants present in the water and air of towns and cities. However, as with some lichen and algal species, toxitolerant moss species exist.

4.2 Orientation of elevation

In combination with climatic data, the orientation of an elevation has a major influence on the degree of wetness a facade receives. For organisms to colonise stone, the period of wetness is more important than the frequency of wetting. A facade which is usually damp over long periods can support the growth of algae and higher plants.

Moisture will evaporate less quickly from surfaces which are not exposed to direct sunlight and which are permanently in shade. For this reason, north-facing areas, which the sun's rays will only reach peripherally, are usually more favourable sites for growth than walls facing other directions. They are particularly favourable sites for colonisation from algae and moss which require relatively damp conditions.

Although east elevations receive direct sunlight at the same angle of incidence as west-facing facades, they receive it after a period of lower general atmospheric temperature (e.g. cool or frosty nights), while west facades have had the opportunity to warm up and dry out during the day. East facades therefore tend to dry out less quickly than south- or west-facing facades. As a result, they generally support more biological growth than walls facing south or west. Plate 5 shows the effect of orientation on algal growth.

South-facing elevations which are dried out quickly by the sun may be virtually free of large, visible growths. Algal growths are not usually found on stone surfaces at frequently dry locations especially where the surface is subject to wide fluctuations in temperature. However, lichens, due to their greater tolerance to low moisture availability, can often be found on west and even south-facing facades if they are wetted occasionally.

The direction of incident sunlight and prevailing winds are important factors of building geometry. Both of these may affect the speed of drying of stonework. Massive stonework, if thoroughly wetted, will retain moisture longer than less massive stonework. Walls where condensation takes place are also commonly affected by biological growths. North-facing elevations which receive no direct sunlight and retain moisture for longer periods may support abundant growth.

4.3 Stone characteristics

The nature of building stone is a very important influence on the type and abundance of organisms found on its surface. Stone types vary greatly in their characteristics, both their physical structure and chemical composition. It is common to find differences in the abundance of biological growths on different stone types in the same location. The mineralogical nature of a stone affects such characteristics as surface roughness, porosity, pH and availability of nutrients, all of which are important factors for biological growth.

Surface texture and surface roughness

The degree of roughness of the stone surface will tend to have the effect of trapping moisture and reducing the rate of surface water run-off. Surface roughness also concentrates moisture in troughs where growths usually accumulate. Generally, it appears that organic growth tends to be most rapid on rough, porous surfaces. This may be the case because spores can settle more easily on rougher surfaces and because rougher surfaces can provide more sheltered niches where organisms can become established.

Plate 6 shows the preferential colonisation of the rough face of sandstone.

Porosity

The porosity of a building stone is one of the most important factors determining its colonisation by particular micro-organisms. Generally, stone with a high porosity tends to be colonised earlier and to a larger degree than less porous stone. The colonisation of porous stone tends to be more rapid primarily because of its capacity to retain more water for a longer period. Algae will be capable of active growth for longer periods on stones which retain moisture for a longer time. Porous stone may also entrap dust particles or wind-blown soil which provide nutrients for microbial colonies.

Fine-grained, less porous sandstones can also support abundant growth if they hold moisture for relatively long periods. But if the stone has a smooth surface, and thus retention of moisture and nutrients from wind-blown debris are minimal, only very small colonies are able to survive. Stones with low porosity are very resistant to algal growth.

Substrate pH

Biological growths vary in their pH sensitivity. Some are highly sensitive and can only tolerate a narrow pH range, others are more tolerant and may flourish over a wide range of pH. Substrate pH can thus influence the rate of growth and types of organism which colonise a stone surface. Many algal and fungal species, prefer slightly acidic environments (e.g. non-calcareous sandstone or granite). Some Cyanophyta species prefer alkaline conditions (e.g. limestone, dolomite, marble, calcareous sandstones and lime mortars). Lichens vary in their pH preferences depending on the species, some being common on calcareous stones such as limestone or marble, others being found on acidic stones such as some sandstones or granites.

Fresh concrete surfaces remain resistant to colonisation by biological growths while their pH is high (11-12) but become more vulnerable to colonisation when the pH drops below 9 with weathering. The growth of mosses on relatively new replacement sandstone in a historic wall at Fort George, for example, does not appear on areas where wash-off from the newly applied lime mortar has occurred. This is probably due to the high pH of the lime water washed from the mortar onto the stone (Plates 15 and 16).

4.4 Effects of stonecleaning

Stonecleaning is used to remove particulate soiling deposits from building facades. Many stonecleaning methods will also remove organic growths from stone although there is no long-lasting biocidal effect. Many chemical cleaning treatments, because of the aggressive chemicals used, are likely to kill all organisms on the stone surface, although some spores may survive. On porous stone however, organisms may survive physical cleaning methods in sheltered niches beneath the immediate surface. In the absence of any preventative treatment, re-establishment of organisms is likely to occur within 6 months to 2 years on both physically and chemically cleaned surfaces depending on stone characteristics and location.

Whether physical or chemical methods are used, stonecleaning affects the surface and near surface characteristics of stone and this may influence the regrowth of organisms on the stone surface. Roughness is known to affect biological growths on stone surfaces and increased roughness caused by physical cleaning could increase the susceptibility of a surface to colonisation. Rougher surfaces provide niches where spores can settle more easily than on smooth surfaces and where organisms can find sheltered locations to begin colonisation of the surface. Additionally, run-off is slower over rougher surfaces than smoother surfaces and this can increase moisture absorption by rougher stone. Chemical cleaning may, in some circumstances, also affect surface roughness. Some chemical cleaning methods use acids which can dissolve minerals from susceptible stone types. Calcareous sandstones, for instance, contain the mineral calcite which may be dissolved from the near surface during chemical cleaning. This may result in increased roughening of the surface of such sandstones. Chemical cleaning can also affect colonisation of building stone in other ways. Regrowth of green algae has been observed to occur more rapidly and to a greater extent on some chemically cleaned building stone than on similar uncleaned stone (Plates 7 and 8). However, this effect declines over a few years and appears to have no long lasting effect on colonisation of building facades beyond the first few years following cleaning. After exposure over a number of years the differences in the degree of biological growth on cleaned and uncleaned facades may be insignificant.

In the longer term, physical or chemical cleaning of sandstone may not have a major influence on re-colonisation of the stone by algae and other organisms, as all vulnerable surfaces will become colonised over a period of time.

4.5 Existing growths

Organic growths themselves affect the moisture retention properties of the surfaces they colonise. The presence of growths on the surface, whether active or decayed, will tend to trap moisture by clogging pores, reduce the rate of run-off and promote further growth. The level of humidity inside the stone may be greater than that of the external environment.

4.6 Nutrients

Inter-relationships between micro-organisms

Due to the nature of the environment and natural succession processes, colonies are formed by many different kinds of micro-organisms growing together. The diversity of microbes present at a stone surface depends upon social compatibility of the colonies and the micro-environment where growth occurs.

In a nutrient-limited stone environment, both fungi and bacteria grow in close association with algae on stone surfaces, and fungal hyphae are frequently seen attached to algal cells. Primary producers (e.g. photosynthetic organisms, algae and Cyanophyta) secrete amino acids and sugars which are available to other heterotrophic organisms (e.g bacteria and fungi). In addition, many algal species exhibit some form of nutrient deficiency when growing without the fungi and bacteria with which they are normally associated in nature. Since much of the bioweathering of minerals has been attributed to the actions of fungi and bacteria, the supportive role of algae is most important.

In lichens, the symbiotic relationship between algae and fungi is most explicit. The algal cells in the lichen thallus photosynthesise and secrete nutrients which are absorbed by the fungal hyphae. The fungus provides an environment for the algae which protects them against extreme environmental conditions, provides a niche on the substrate, and possibly provides them with basic mineral nutrients derived from the atmosphere and the stone. This arrangement allows lichens to colonise stone surfaces which would not readily support other biological growth.

Nutrients derived from the atmosphere

Air carries mineral and organic nutrients in the form of dust, soot and soil particles which settle on the stone and become available to micro-organisms. The air may also contain nutrients in gaseous form. Local emissions of ammonia from animal breeding, soil fertilisation or industrial activity may increase the availability of nitrogen compounds to organisms in stone. Volatile organic compounds emitted from whisky distillery bonds are a ready source of nutrients for the whisky fungus which colonises masonry and wood close by.

Bird droppings

Bird droppings can act both as a rich source of nutrients for established biological growths and as carriers of micro-organisms and spores. They can provide nutrients such as nitrogen and phosphate which are lacking in most stone (Plate 9). This affects primarily ledges and the horizontal surfaces of free-standing walls.

Splash-back

Masonry situated close to the ground is particularly vulnerable to colonisation by algae. Not only does such stonework rcccive run-off from the building above and capillary water from its base, it also receives splash-back of rain water from the ground. Splash-back tends to contain more nutrients than plain rain water, carrying soil particles with it onto the stone surface. In these zones, algal growth tends to be particularly heavy, and mosses and higher plants may also occur. Splash-back also occurs above projections from the facade producing the well-known 'moustache effect' (Plate 10).

Former growths

Some areas on a building may be nutrient-enriched by deposits remaining from previous growths killed by biocides. This may encourage a more rapid recolonisation by algae after the effects of the biocide have been reduced to a suitable level. The presence of decayed growths on a surface will also tend to trap moisture, reduce the rate of run-off, and thus promote further growth.

4.7 Architectural form and detail

On buildings, very wet areas tend to support the most prolific biological growths, including colonies of algae with associated bacteria and fungi and small plants and mosses.

The architecture and detail of a building can greatly influence the degree of surface wetness. Stonework exposed to surface run-off will collect water and will thus remain wetter for longer than a protected facade (Plate 11). Features such as projecting string courses, splash zones above projections, window sills receiving run-off from large glazed areas, stonework projecting above roof level and free standing monuments all tend to be locations favourable for algal colonisation.

Wall bases are generally the dampest locations on a vertical facade. The base is wetted from run-off, by capillary moisture from the surrounding soil or pavement, and by splash-back from the ground. It may also be in a more shaded position. Often, organisms requiring most moisture are found at wall bases. Due to the increased nutrient concentration in zones that are in contact with soil, a higher diversity of species is also likely to occur.

On free-standing walls and building facades, most rain impacts and is absorbed on and near the top of the wall; hence this is the dampest area above the wall base and is most commonly colonised.

Horizontal and sloping stone surfaces are commonly colonised (Plates 12 and 13). Such surfaces tend to be damper for longer periods than vertical surfaces since they intercept more rainwater and drain more slowly, allowing water more time to soak into the stone. Spores, cysts and seeds settle more readily on horizontal or sloping surfaces, especially if they are damp. Buildings and monuments which taper outwards towards ground level, for example church steeples (Plate 14), and historic ruins which tend to have free standing walls will encourage water run-off down the exposed faces and thus promote colonisation (Plate 1).

Vertical surfaces normally dry out within short periods of time since relatively little rainwater will impact over much of the vertical facade. Consequently, vertical facades seldom support much organic growth unless they are in regions of high humidity or are often wetted, in which case growth normally follows areas of run-off.

Moisture retention appears to be most influential in determining the presence and amount of growth and species diversity.

Parts of buildings which are permanently, or predominantly, in shadow from adjoining buildings, in recesses or niches or overhung by trees and the like, will tend to remain wetter for a longer time. As the duration of wetness is more important than frequency of wetting, shaded sites encourage more growths and greater species diversity.

The distribution of algae on a facade is often highly predictable. They occur on sloping areas of stone work, around the top and edges of walls, on sills below exposed windows and under areas where water is channelled.

Moss tends to be located in similar areas as algae, as well as in cracks, joints and crevices where soil can accumulate. The distribution of lichens is much less predictable. They can be found on facades facing any direction, even south, and on more exposed stonework which is generally a somewhat drier location.

4.8 Mortar joints

Lime mortars are soft, easily weathered and more porous, and therefore more vulnerable to organic growths than cement mortars. The distribution of organic growth on facades is often strongly influenced by the pattern of joints and they may support a large variety of organisms. Some organisms occur in mortar joints but not on the stone itself and vice versa. The mortar joints are generally a more alkaline environment than the stone (especially if it is non-calcareous), and certain species are very sensitive to the pH of their environment (Plates 15 and 16).

4.9 Building maintenance

The maintenance of a building or monument can make an important contribution to the incidence of algal growth. Overflowing eaves and gutters, continuously running water storage tank overflows and leaking down pipes will saturate walls and frequently provide the location for the most unsightly and heaviest algal growth. Poorly maintained stonework, and particularly open or cracked mortar joints, encourage the entrapment of water and local colonisation in the vicinity of the joint.

Pointing methods in which the horizontal joint pointing projects out from the building surface may accelerate algal growth by trapping water running over the facade and increasing the time of wetness of the stone around the joint. Vertical projecting pointing can also channel water into joints.

In many older properties the absence of a damp proof course results in a moisture gradient in the stone, extending from ground level upwards. Such stonework, and especially projecting base courses within the ground-level splash zone, will be prone to algal development.

Problems with soiling and biological growths on building facades could often be avoided or reduced if facades were designed to minimise water accumulation and facilitate rapid run-off.

5
DETERIORATION OF SANDSTONE

Although biological growths do promote the deterioration of stone, the general view is that their contribution is not the most significant. However, there are exceptions, for example the severe blistering and pit formation which can be caused by some lichens, or spalling associated with algal growth. Biological decay is often not readily recognised at the stone surface; its real contribution, in combination with other decay processes occurring simultaneously, has not yet been evaluated.

Physical weathering processes are those which cause disintegration of stone without any alteration of the chemical composition of the mineral constituents. They include frost decay, wind erosion and thermal expansion and contraction.

Chemical weathering is damage to a stone through the chemical alteration and dissolution of some of its elements and/or their loss from the stone itself. They may be washed off in rainwater, or they may be deposited on the stone in a changed form. Elements may be leached from stone by rainwater, or attacked by atmospheric pollutants or the by-products of biological growths.

5.1 Formation of patinas

The development of a patina on stone is part of the natural weathering process and should not necessarily be regarded as detrimental to the stone. It may be seen as part of the aesthetic character of a building stone.

The patina which develops on a stone surface is a result of a combination of different processes. Partly it is created by the accumulation of soiling derived from external sources which includes soot and dust particles, aerosols and atmospheric pollutants. In addition, the stone surface is affected by the dissolution, alteration and redistribution of minerals within the stone. Many minerals are unstable in the temperatures, pressures and oxidising environment of the earth's surface. Over time they are slowly altered to more stable forms. Calcite, which occurs in limestones and in calcareous sandstones, is one of the most soluble commonly occurring minerals. It is readily dissolved and redeposited by fluids.

Organisms on and near to the stone surface can also play a part in the development of the patina. Many organisms secrete substances which can dissolve, deposit or cause the alteration of minerals. Some mineral elements can be leached out of the stone surface, others are deposited.

Interaction between all these factors results, over time, in the development of the patina which is distinct from, but may be in intimate contact with, the layer of dust, soil and growth. The formation of a patina on a stone surface often leaves an underlying, softer layer of stone which is depleted in some minerals. This can weaken the stone and spalling may later occur at this depth.

5.2 Biological growths and physical weathering

Biological growths can be responsible for physical weathering of a stone due to changes in size, physical penetration into and around grains, or changes to the porosity of the stone. Such changes to the physical nature of the stone will influence its response to other, non-biological decay processes. Biological growths can also enhance the moisture retention properties of stone surfaces by clogging pores and reducing the rate of drying of the surface.

The growth of organisms inside cracks and crevices and the growth of cells within pores of the stone may have two effects with regard to physical decay:

- cracks in the stone may be expanded due to (a) the pressure of cellular growth and (b) the expansion and contraction of growths and their mucilage during their wetting/drying cycles

- growths may trap water in the crevices, which contributes to freeze/thaw weathering, widening existing cracks and creating new ones.

The presence of algae on a stone can enhance freeze/thaw activities by increased water entrapment. The often copious mucilage of algae expands and contracts during wet/dry cycling and creates mechanisms similar to those of freezing and thawing. These mechanisms can cause physical damage to the stone surface. In addition, algal growth can promote the growth of other organisms such as fungi and bacteria, which can potentially contribute to chemical decay mechanisms.

Lichens are capable of very great expansion on wetting and contract considerably on drying, sometimes lifting grains of material off the stone surface in the process. Because lichen growths can penetrate several millimetres below the surface of stone, their contraction during drying may cause shear stresses in the surface layer of the stone, leading to its detachment.

Similarly to lichens, the hyphae of fungi and algal filaments can cause decay by physical penetration into and around grains in the stone.

Cell secretions may clog pores, and may trap moisture in stone by absorbing water from the atmosphere. This can enhance the damaging effects of non-biological decay processes such as freeze/thaw.

The presence of mosses is an indication of persistently damp conditions which are probably more damaging than the organism itself. However, due to their high capacity to hold moisture, these plants lengthen the period of time over which the stone remains damp. In some cases, moss can cause disruption to the stone surface or mortar joints. Damage can occur where mosses slough off a wall, either as a result of mass, death or the activity of animals. Where moss has been growing on mortar, areas of mortar can become removed with the sloughing process.

5.3 Biological growths and chemical weathering

Biological processes are intimately involved in the cycling of elements in the environment. Micro-organisms, algae, fungi and lichens are vitally important to geochemical processes and are involved, along with physical and chemical processes, in the degradation, dissolution and alteration of many minerals. In practice it is often difficult to separate stone decay caused by biological growths from that attributable to other causes. While it can be argued that biological growths are capable of causing damage to stone surfaces on which they grow, estimates of rates of decay are rarely made. It is important to note that although a decayed stone may have a large population of biological growths, it is not necessarily the case that these growths are responsible for any of the observed damage. Many other factors including salt efflorescence, thermal and moisture expansion and contraction, wind erosion and frost damage can be the causes of decay.

In the laboratory, lichens, fungi, algae and bacteria have been shown to be responsible for chemical alteration and dissolution of rock-forming minerals. However, it is not possible to extrapolate directly these data to biodeterioration rates in the field, since the relative contributions of chemical, physical and biological effects to weathering rates cannot easily be established.

Biological growths can be responsible for changes to the surface and near-surface texture of stone, which affect its weathering profile and may accelerate decay or soiling processes. Simply by being present on a surface, biological organisms alter its microclimate, affecting moisture content and surface temperature.

Many micro-organisms produce organic acids and other compounds which are capable of dissolving or altering minerals within stone. As a result, elements may become lost from the stone and either form insoluble crystals on its surface, become washed out with water, or become absorbed into the cells of the microbes.

Of the organic acids produced by biological growths, oxalic acid appears to be a common factor in altering calcium and other minerals, forming insoluble crystals of calcium oxalate. This is seen as a potential factor in stone decomposition, since the formation of calcium oxalate crystals is quite often associated with zones of calcium depletion and areas of stone decay where the stone surface has become loose and friable. However, it appears also that small amounts of iron tend to be leached out of sandstone by rainfall, and that the presence of organic material at the stone surface may reduce this loss in some way.

Lichens are organisms whose effects on the stone to which they are attached can sometimes be very evident. Lichen acids can lead to discolouration of the stone by bleaching, or the production of small holes at the stone surface. An extreme case of blistering and pit formation can be seen on Plate 3, where a combination of lichen acids, physical action and possibly salt accumulation directed in the centre of the lichen thallus have caused the stone to disintegrate.

6
BIOCIDES

There are a number of reasons why control of biological growths on stone surfaces may be considered necessary. Concern over such growths is largely centred on their aesthetic impact, with the view that buildings exhibiting streaks of algae in water run-off zones, for example, may lead to a perception of poor maintenance. However, if the organisms are responsible for physical damage to the surface, their removal and control may be desirable. Since algae are often among the first organisms to populate a stone surface, preventing their growth can reduce the potential for biodeterioration. Further, it may be desirable to control growths on horizontal paved stone surfaces for safety reasons when these are used by pedestrians.

Although control of growths usually depends simply on keeping the affected surface dry, in many cases encrustations of algae and lichens can withstand prolonged periods of drought and are capable of extracting moisture from the atmosphere. In some cases, this may result in a decision to destroy growths through the application of a biocide.

There are a number of factors which must be taken into account when using biocides.

- The treatment must be able to kill the problem organism whilst causing no harm to the operatives or others.
- It should have a reasonably long effective life.
- The treatment should not leave deposits in the stone, alter the natural stone colour or affect the structure of the stone in ways which could lead to, or exacerbate, long-term damage.

Although the following section gives advice on the selection, efficacy and application of biocides, it should be understood that it is not necessarily desirable to use these methods, and that other methods which may have less potential to cause damage to the stone should always be given consideration.

6.1 Generic types

In an earlier study, the most effective chemical biocides have been found to be quaternary ammonium compounds, borates and organo-tin compounds. Despite their effectiveness, organo-tin compounds are no longer approved in this country for terrestrial applications.

Of the currently approved substances, sodium hypochlorite was found to be more effective as a biocide than any other compound tested. However, concerns over the production of sodium salts in the treated stone samples (see below) restricts its use as a surface biocide for most building materials.

The wide variety of masonry biocides available at present and approved for use by the Health and Safety Executive can be categorised into five main generic types: quaternary ammonium compounds, amines, chlorophenols, phenoxides, and metals such as copper. Frequently, different generic types are mixed together, or mixed with another compound such as borate or zinc salts. Many of the chemicals appear in more than one formulation at different concentrations and proportions and are used against a wide range of biological growths.

A table detailing currently approved surface biocides used in the control of algae on stone surfaces is available in Appendix B.

6.2 Mode of action of biocides

The ability of biocides to prevent the growth of algae, mosses, lichens and other such growths can be generally attributed to one of two effects: growth inhibition or biostatic effect, and an irreversible, lethal or biocidal effect.

The mode of action of many biocide formulations on the microbe cell is still not fully clear. Biocide activity for any given chemical often varies with concentration, the type of target organism, and the media surrounding the cell. However, the main target areas of the cell which are affected by biocides are the cell proteins. Damage to cell proteins can cause a huge range of types of cellular dysfunction, which lead to biostatic or biocidal effects.

6.3 Selection of biocide

Organisms vary widely in their susceptibility to biocides. A treatment which can effectively kill one organism may leave another similar organism unaffected. Obviously, the treatment chosen should be appropriate for the problem organism, and in practice it may be necessary to identify the nature of biological growths and carry out field trials to test the efficacy of different biocidal treatments in particular situations. Many biocides are a mixture of different chemicals which act to exert a combined toxic effect on the target organism.

Spores produced by cells of algae, fungi and some bacteria are often resistant to most biocides and can remain dormant for long periods of time. Spores are thick-walled structures, usually in a highly dessicated state. They contain DNA and other elements required to enable germination and the restoration of full cell function when the environment becomes suitable for growth. Most spores are resistant to biocides containing quaternary ammonium compounds, disinfectants, alcohols, solvents, phenoxides and hypochlorides (phenoxides and quaternary ammonium compounds are common ingredients in formulations used against algae and fungi). Biocide compounds which are effective include ethylene oxide, gluteraldehyde, formaldehyde, halogens (chlorine, iodine and bromine), hydrochloric acid (as vapour) and hydrogen peroxide. Most of these latter ingredients are not common in surface biocides. Where they do occur, they are mostly formulated as fungicides.

Proprietary biocide products are constantly changing, both in their formulation and product name. It is often difficult to identify the important active ingredients from the information supplied by the manufacturer. The list of products given in Appendix B is not intended to be definitive but is indicative of the range of proprietary products available at the date of this Technical Advice Note.

No manufacturers' recommendations are given as to the type of stone any biocide could be suitable for. It appears that products are rarely designed specifically for the conservation of objects made of sensitive materials, and the compatibility of biocide and substrate is rarely considered. With these factors in mind, the large pH range of working biocide solutions could be a primary cause for concern in the selection of biocides for particular stone types. It is also recommended to test any biocide first on a small inconspicuous area of the building before general application.

6.4 Biocide efficacy and life span

Traditionally, biocide efficacy has been assessed in the laboratory on agar or liquid cultures of the target organisms. It is often the case that these substances perform differently when applied to a substrate such as stone. Biocide efficacy tests which take into account the interaction between biocide, micro-organism and stone have been recognised as being more relevant. Field studies and laboratory trials have to be correlated if results from laboratory methods are to be relevant in practice.

The effective lifetime of different biocides can vary widely, depending on the type of biocide, its concentration, the nature of the biological growths, the pH of the environment, temperature, microclimate, and the exposure of the treated area. Even with a single biocide type, effectiveness may be strongly influenced by the nature of the stone substrate.

In tests simulating natural conditions, the effective life spans of a representative range of algicides varied between between one and a half months and one year or more, depending upon the biocide and other circumstances. Invariably, whatever biocide is used, regular re-application to stonework will be required.

Concentration

Relatively minor changes in concentration may affect the efficacy of a biocide. Compounds such as phenols and alcohols are generally more biocidal at low concentration compared to quaternary ammonium compounds. Differences in concentration may partially account for the different life spans of the

Table 3: Biocides tested for this Technical Advice Note

Chemical content	Generic type	Referred to as
alkylaryl trimethyl ammonium chloride	quaternary ammonium	QAC1
benzylalkonium chloride	quaternary ammonium	QAC2
dodecylamine lactate, dodecylamine salicylate	amine	Amine
disodium octaborate, dodecyltrimethyl benzyl, ammonium chloride	borate & quaternary ammonium	Borate & QAC
dichlorophenol	phenol	Dichlorophenol
copper compound	toxic metal	Copper compound

three biocides containing quaternary ammonium compounds observed in experiments.

The size of a biological colony may also affect the concentration of a biocide. Generally, the larger the number of cells making up the growth, the higher the concentration of biocide required before it becomes effective.

Previous growths

The presence of dirt or other organic debris can reduce the effectiveness of some biocides through adsorption. The production of slime layers by some organisms or dense growth of the organisms themselves can lend considerable protection from the action of biocidal chemicals, the slime layers or outer cells forming a barrier between the biocide and the cells underneath. Additionally, biocides may be absorbed or adsorbed by the organisms and be lost from the surface as dead material sloughs off. In order to prevent loss of biocides in this way, all loose organic debris should be brushed from surfaces prior to biocide application.

Biocide loss
One factor which limits the efficacy of a biocide is its liability to be washed out of the stone with rainwater. Different biocides wash out to different degrees.

There is likely to be some amount of biocide dispersal from the stone surface after application due to influences other than rain. Compounds containing phenol in particular can be degraded by ultraviolet light and become chemically altered. Biocides can also be absorbed and broken down by micro-organisms present on the stone, or evaporate into the atmosphere.

Stone type
Stone type appears to have an effect on biocide efficacy. Identification of key components of the stone which determinine the efficacy of a biocide applied help to match biocide type with sandstone type.

The porosity of the stone influences the effective life span of the biocide. On a stone with low porosity and permeability much of the applied biocide may run off on application, and that which does remain on the stone is likely to be on the immediate surface and may be washed off quite rapidly by rain. On a more porous and permeable stone, liquids applied to the surface can soak in more deeply and they should not be so susceptible to wash-off. A biocide which penetrates below the surface may provide a reservoir in the stone.

Biocides which are so loosely held in stone as to be easily washed out in rain water are unlikely to have a very long effective life span, although this will depend on the amount of water which flows over the stone surface. To be effective for longer periods the biocide would need to be bound to minerals in the stone so as to resist immediate wash-off. To remain effective as a biocide, the active chemical must either be released slowly on wetting at a concentration high enough to be effective, or it must be bio-available while bound to the mineral surface.

Some biocides may become deactivated on adsorption to clay minerals or organic material. This occurs with phenols or free chlorine. Biocides such as quaternary ammonium compounds bind to siliceous surfaces in the stone, and retain their biocidal activity while bound. However, different efficacies for these biocides have been observed on different stone types. This has been attributed to the coating of the siliceous minerals with cements, as occurs in limestones, calcareous sandstones, and mortars. These coatings effectively form barriers between binding sites and the biocide.

6.5 Biocide effects on sandstones

General

It is fair to say that the majority of masonry biocides are not designed to be sympathetic to stone and many have been modified from existing compounds used in other areas of biological control such as agriculture, medicine and the food and offshore industries. The potential of masonry biocides to damage stone has only been addressed relatively recently, and it requires further investigation using the appropriate techniques.

If, previous to treatment with a biocide, the facade has been subjected to any other treatments such as water repellents or stonecleaning chemicals, care must be taken that the biocide will not react in any harmful manner with the previous treatment.

Colour changes

The most significant side-effect of biocides is their potential to alter the colour of the stone. A copper compound can give a visible blue-green tinge to light coloured stone which disappears slowly over several months. A combination of borate and quaternary ammonium can cause a measurable increase in yellow intensity which only lasts for a short while. A pink amine containing biocide can cause a reddening of the surface which lasts around 100 days. It has also been suggested that phenolic compounds applied to stone cause red spots at the surface, and it is recommended not to apply phenols to very light coloured surfaces. However, the colour disappears after some time.

None of these colour changes last for more than a few months. However, it is possible that if biocides were regularly re-applied (as they would normally have to be), longer lasting or permanent colour change could occur. It is always advisable to test the biocide on a small, inconspicuous area of the building prior to overall application.

Salt crystallisation

There has been concern over salt crystallisation from some biocides which have the potential to form potentially harmful salts in stone and must therefore be completely washed out of the stone after treatment. Deposits in stone from salts which expand on crystallisation can lead to disintegration of the stone surface. Sodium may interact with sulphates in the stone to form gypsum, which can be particularly destructive to certain stone minerals.

Mineral dissolution and loss

Laboratory tests have shown that after the application of a biocide, some types of sandstone become considerably more susceptible to the loss of minerals from the stone structure. Sandstones contain certain mineral components which could be released by exchange mechanisms with the biocide, or by a pH effect of the applied biocide. In general, stone samples treated with amine or dichlorophenol-based biocides lost the greatest amount of mineral elements to solution in tests on sandstone.

The mobilisation of iron and iron-containing minerals from some stone types, and the resulting red staining of the stone surface, has already become an area of concern. Research has so far concentrated on colour changes or visual evidence from microscope studies of the dissolution of calcite in marble and calcareous sandstone and quartz in calcareous sandstone. There is also the possibility that some biocides may have the potential to disperse clays in sandstone. There is clearly scope for detailed further study to elucidate what mineral components become vulnerable to biocide attack, what long-term damages are possible and the mechanisms by which these occur.

The pH of biocides may affect the stones on which it is applied, since biocides with high (more than 8) or low (less than 4) pH may accelerate the dissolution of minerals in stone, such as silicates or carbonates respectively. **There is evidence that calcareous stones may be susceptible to damage from certain biocides and it may be safest to treat calcareous stones with biocides which do not have extreme pH values.**

Effect on water absorption

Some biocides can cause changes to the surface porosity of some stone types, which can alter the water absorption and evaporation properties of the stone. Such changes have been noted in the water absorption of stones treated with a range of biocides. Hydrogen peroxide (a component of some fungicides) appears to increase the absorption of water in marble. Other biocides such as quaternary ammonium compounds and amine-based biocides cause the stone to develop some hydrophobic properties which may help initially to repel water from the stone surfaces and discourage the growth of micro-organisms.

6.6 Recolonisation after treatment

Biocides lose their toxicity and effectiveness over time and, although some remain effective for longer than others, eventually any vulnerable stone is bound to be colonised. Biocides lose their effectiveness for a number of reasons. They may be washed out of the stone, they may be adsorbed and inactivated by materials in the stone, they may be subjected to chemical or photo-degradation or they may be lost along with the dead organisms as these slough off from the stone surface.

Due to the high impermeability of their cell walls, spores are normally very resistant to biocides. Biocides may therefore fail to kill the spores of some organisms and recolonisation can then occur when the biocide's toxicity has been reduced sufficiently. Surfaces with pre-existing growths are normally colonised more rapidly after biocide treatment than surfaces with no pre-existing growths, either because spores which were not killed by the biocides were left on such surfaces, or because the surfaces may be more exposed to run-off and the biocide is washed out more rapidly, or because organic debris from previous growths can provide nutrients for new growth after biocide toxicity has declined to a sufficient extent.

Recolonisation may not necessarily result in the re-establishment of the same organisms that were present prior to biocide treatment. In some cases biocide treatment may be followed by the establishment on the stone of a species tolerant to the biocide residue.

7
APPLICATION OF BIOCIDES

7.1 Planning the work

When planning the application of a biocide to an external surface, it is important to choose the right time. The most favourable point in the yearly cycle tends to be the summer, since in most cases it is advisable to apply the biocide after a dry spell of weather. Although growths are most susceptible to biocides in wet conditions, biocides also tend to be washed off more quickly during periods of rainfall. A biocide applied in dry weather will have time to be absorbed by the stone and will remain in the stone fabric to become effective in wet weather, when the growth absorbs it.

It is advisable to ascertain whether any other treatments, such as water repellents or stonecleaning chemicals, have been applied to the facade for which biocide treatment is being planned. Care should be taken that the biocide will not react in any harmful manner with the previous treatment.

7.2 Preparation of substrate

In general, it is important to ensure the dryness of the stone to prevent the premature loss of biocide due to washing off.

Power water washing is sometimes used to remove organic material prior to biocide application. Such treatment may cause damage to stonework and saturate the wall, and should therefore be used with great caution and on sound substrates only.

It is recommended in all cases, but particularly when the stone is heavily infested with growth, to remove some of the organic material by brushing prior to the application of the biocide. Growths which remain on the surfaces can absorb a proportion of the applied biocide which would then be ineffective, and any chance of this should obviously be reduced as much as possible.

Some organisms such as lichens resist wetting after a long dry spell. In such cases, it may be necessary to pre-wet the surface to assist absorption of the biocide by the organisms.

7.3 Application

The biocide should be well brushed in. After the initial application and brushing to get rid of dead matter, a reapplication of the biocide may be necessary since much of it may have been absorbed by the organisms.

It is normally advisable to treat areas of stone between distinct boundary edges to ensure uniformity of appearance on the treated stone.

8

ALTERNATIVE METHODS OF CONTROL OF BIOLOGICAL GROWTHS

Given that the potentially harmful effects of biocide on stone are still largely unknown, and that biocides lose efficacy over time and require constant re-application which is both costly and inconvenient, it is advisable to consider alternative methods of controlling biological growths on stone surfaces, if control is deemed necessary.

8.1 Building design and maintenance

Building design and maintenance affects both the likelihood of colonisation by biological growths and the effective life of preventative treatments. Control of growths can often be achieved simply through the control of surface wetness by repairing or improving drainage, or reducing the sheltering effects of closely situated vegetation or other structures. Surfaces which are sheltered from rain and those which remain wet for only a very short time are, due to their lower moisture content, less likely to be colonised by organisms. In addition, if a surface is not heavily washed by rain water, any biocidal treatment will remain in the stone for a longer period.

Biological growth can be limited by facade designs which utilise relatively non-absorbent materials, shed water quickly and reduce the possibility of established run-off patterns on the facade. Many classical decorative details, including string courses, cornices and pediments, control the flow of water over the facade. The use of drip moulds helps to throw water clear of the lower stonework. Good maintenance of drainage systems will prevent establishment of growths under leaking gutters or down-pipes and limit moisture retention on the building facade.

The presence of mosses on a building is an indication of persistently damp conditions which are probably more damaging than the organism itself. It may be wise to remove these growths as soon as possible and investigate the cause of dampness. Although biocides are available for the control of moss on masonry, they can generally be easily removed without the use of a biocide. Removal of accumulated soil and debris and prevention of excessive water retention are often adequate measures which discourage further growth.

8.2 Copper strips

A traditional aproach to inhibiting biological growths involves the use of narrow, thin-gauge copper flashing strips built into the length of horizontal mortar joints in the masonry at approximately one-metre centres. When surface water run-off takes place, this produces a mildly toxic biocidal wash. It is advisable to study the run-off patterns on facades prior to the installation of such strips so that they are placed in the most effective positions. These copper flashings will, however, tend to promote light green staining of pale-coloured sandstones which may be unsightly and difficult to remove.

8.3 Washing and brushing

In dry conditions it may be possible to remove some organisms, including algae, lichens and mosses, by scraping or bristle brushing followed by washing down with a minimum amount of de-ionised water. However, the stone will usually retain 'ring marks' from lichens. Algal growths will probably return within a few months of the treatment unless measures are taken to reduce the duration of dampness of the stone. Lichens, on the other hand, are fairly slow growing and may take many years to recolonise the stone surface.

8.4 Water repellents and consolidants

Water repellents have sometimes been used to prevent growth on porous stone. However, the use of water repellents is often inadvisable, in particular where the stone may be subject to wetting from internal sources, for instance by rising damp or water seepage through the wall interior or through joints. If this moisture is unable to evaporate normally, it will almost certainly cause accelerated decay of the treated surface either by frost damage or by salt deposition.

Prior to treatment with water repellents, any established growth should first be removed by application of a biocide. Water repellents inhibit growth by reducing the saturation of the stone and limiting the amount of water available to organisms. This may be effective at reducing some biological growths which require relatively damp conditions. However, none of these substances appears to have any long-term efficacy, and certain substances actually stimulate growth and are used as additional energy sources by the stone microflora.

When consolidants are used along with biocides that are supposed to be completely washed out, it is important to ensure that the biocide is indeed completely removed. Otherwise soluble salts may be trapped in the stonework by the consolidant, acting as a potential source of long-term decay.

8.5 Ultraviolet light

Ultraviolet light has been used as a control for the growth of algae and Cyanophyta, for example in the damp plaster interior of a church. Ultraviolet light can be used to kill photosynthetic organisms and carries none of the potential risks associated with the irreversible application of biocidal chemicals to a surface. The method appears to be efficient, easy to carry out and relatively inexpensive. Heterotrophic bacteria and fungi may not be removed by the UV treatment if located deep in the substrate. It is conceivable, however, that the numbers of heterotrophic organisms may decrease with time following the destruction of the phototrophic organisms. Application may be suitable for small areas, or in indoor situations where humidity is high. Whole building facades may be more difficult to treat. A 48-hour continuous treatment may be effective over 2 months or more. As with all treatments, tests should be conducted on unobtrusive areas before any full scale treatment is carried out.

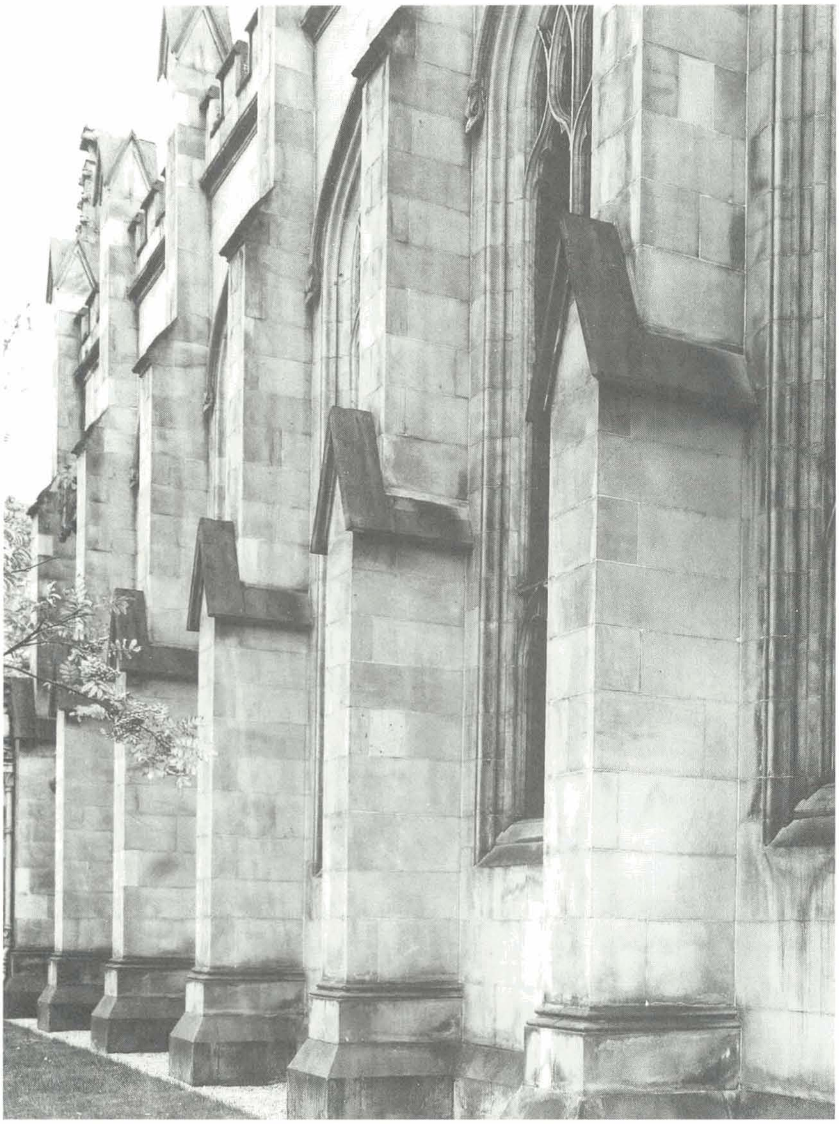

Figure 7:
A high level of biocide treatment will be required where the concentration of rainwater gives rise to heavy biological growth, seen here on sloping surfaces and mouldings

9
HEALTH AND SAFETY ISSUES

This information has been compiled from the comprehensive data supplied by the Health and Safety Commission publications of *Chemicals (Hazard Information and Packaging) Regulations 1993* (CHIP), *Control of Substances Hazardous to Health Regulations 1988. Approved Codes of Practice* (COSHH, revised 1993), and various HSC Construction sheets. The information included is of relevance to workers using biocides in the control of biological growths on stone work. For more detailed information, the references for these publications are cited at the end of this section.

Only biocide products with a Health and Safety Executive number should be used. Active chemicals used in surface biocides are subject to scrutiny for safety in use under the *Control of Pesticides Regulations 1986.*

9.1 Hazard information and risk assessment

The following guidelines and information refer to substances available on the market which are specifically designated as biocidal agents. The application of substances other than designated biocides in an attempt to control biological growths is strongly discouraged. Such attempts are highly unlikely to have the desired result, but may produce a variety of other effects which may be both undesired and unexpected.

Biocides are hazardous substances which can be irritant to the skin and eyes. They should not be ingested, and appropriate safety precautions need to be observed.

The supply label attached to the container of a substance deserves close attention. It provides a means by which the user of a substance gains information regarding the hazard a substance presents and the precautionary measures which must be carried out to prevent risk to the environment and the health and safety of the user. The supply label may also direct the user to more comprehensive information supplied on a safety data sheet by the manufacturer, but often the supply label itself is the only information a user will come across in practice. It is highly inadvisable to use a substance which is not in its original container.

A supply label should include all potential hazards which are likely to arise in the preparation and use of a harmful substance. It includes the following:

- symbols and indications of danger highlighting the most severe hazards
- standard risk phrases specifying hazards arising from the substance properties
- standard safety phrases giving advice of necessary precautions.

The classifications which may appear on supply labels of biocidal compounds are graded on the basis of health effects, both acute and long-term. They consist of very toxic (T+), toxic (T), harmful (Xn) and irritant (Xi).

In general, it should be understood that biocides can cause discomfort or ill health mainly through

- skin contact
- eye irritation
- inhalation of fumes or mist.

Work with biocides is subject to the *Control of Substances Hazardous to Health Regulations 1988* (COSHH), which requires the health risk to be assessed and then prevented or controlled. Users should get information on risks and precautions from the manufacturers/suppliers who have a legal duty to provide it.

Acids and alkalis will attack and corrode a variety of materials and a material resistant to one may not be resistant to another. Consult manufacturers or suppliers of the equipment on whether or not it is suitable for the acid or alkali to be used in it. With concentrated acids or alkalis, the manufacturers/ suppliers should be asked to respond in writing.

9.2 Precautionary measures

It is essential that the manufacturer's instructions on the lable of the biocide container be followed precisely. Further, operatives should familiarise themselves with the symbols and terminology used for guidance on the use of biocidal chemicals.

Preventing exposure

It is recommended to choose the most dilute solution which is effective. It is advisable to use proprietary brands of biocide which are diluted by the manufacturer/supplier rather than handle concentrated chemicals.

Controlling exposure

If concentrated biocides have to be handled and diluted, dilution should take place in a well-ventilated area off-site and concentrated biocide transferred using sealed equipment. Transfer the dilute material to site in properly labelled and sealed containers.

The biocide should be applied with a brush or roller with a splash guard. Spray application may be acceptable, but the use of atomiser sprays should be avoided since the fine mist created by atomisers is easily inhaled.

Personal protection

It is essential to wear protective clothing to protect skin, face, eyes etc from the toxic material. This includes eye protection, gauntlet gloves, protective overalls, and in some cases a protective apron and approved respiratory protective equipment. Professional application of biocides is recommended, and professional operators are required to follow the procedures stipulated in the *Control of Substances Hazardous to Health Regulations* (COSHH).

It is recommended to check with the manufacturer or supplier of protective equipment that it is suitable for the particular material being used and for the particular working conditions of the job in hand.

When removing existing surface growths and preparing surfaces, suitable respiratory equipment must be used to prevent the inhalation of mould spores or harmful dust, such as silica. Exposure to mould spores can cause reactions in persons with asthmatic or allergic conditions.

Always ensure that protective equipment is thoroughly cleaned with water after use and checked for any deterioration.

Protecting the public

Members of the public must be protected against exposure to the biocide. For the steps to be taken, refer to HSC Construction Sheet No. 24 *Chemical cleaners.*

Protecting the environment

Great care should be exercised to avoid contact of the biocide with the wider environment. Most biocides are toxic to plants, although larger plants may be resistant to damage. It is important to ensure that excess run-off from application of a biocide does not come in contact with other plant life.

Biocides or biocide run-off materials should not be discharged to rivers, ponds, surface waterways or drains or sewers. It is possible that some dilute solutions may be discharged into the local sewerage system in accordance with Water Authority Regulations, after consultation with the Water Authority.

Emergencies

Dilute spillages with water unless concentrated acids are involved, which have to be neutralised with slaked lime. Tools and equipment which may be contaminated should be treated similarly.

Anyone appearing to be affected by the biocides should be taken at once into the fresh air to be given first aid and referred to medical care. In most cases, first aid will involve drenching the affected parts with plenty of cool, clean water.

For further information consult HSE *Introducing COSHH: a brief guide for all employers to the new requirements 1988,* IND(G)65(L).

A number of commercially available biocides used in the control of algae on masonry in this country are listed in Appendix B together with the safety data provided by the distributor and the supply label where these have been obtained. The table was compiled from data taken from *Pesticides 1995* and updated from monthly information published in the Ministry of Agriculture and Fisheries Pesticide Register.

9.3 Legislation

For workers who expect to handle a variety of toxic substances for the control of biological agents around the work place, there are a number of guidelines laid out in the Health and Safety Executive COSHH publication of Approved Codes of Practice. The COSHH regulations apply to substances that have already been classified as very toxic, toxic, harmful, corrosive or irritant under CHIP and substances which have MELs (maximum exposure limits) or occupational exposure standards (e.g. carcinogens, mutagens or teratogens).

9.4 Work at heights

Most of the information in this section is based on the HSE sheets mentioned in the body of the text.

To apply biocide to a masonry elevation, it is normally necessary to work at some height, using ladders and/or scaffolding.

A ladder is primarily a means of gaining access to a workplace. However, it can also be used as a working place in its own right. There is a temptation to use a ladder for all sorts of work without considering whether the risk involved requires other equipment. It is often much safer to work from a properly erected mobile scaffold tower for instance.

If using a ladder, it is important to ensure that it is properly secured, that the correct grade of ladder for the work in hand is used, and that the ladder is in good condition. It is also important to avoid overloading. Never try to carry heavy items up a ladder.

Details and guidelines on the safe use of ladders can be found in HSE Information Sheet *Safe use of ladders,* Construction Sheet No. 2 (revised). References to legislation can be found in *Construction Working Places Regulations 1966* and *Health and Safety at Work etc Act 1974.* Additional advice and information can be obtained from local offices of the Health and Safety Executive.

When using scaffolding, it is of primary importance to ensure the stability of the construction. The stability of a scaffold will be affected by the way it is used, and it is important that the right sort of scaffold is erected for the intended work. There should be means of protecting the public from falling materials. A scaffold should never be overloaded, and any materials stored on it should be evenly distributed to spread the load.

The scaffold must be inspected before use, and inspections must be carried out by a 'competent person' and the results recorded in Register Form 91 available from HMSO. Only competent scaffolders should erect and dismantle scaffolds. Before erecting a scaffold on a public highway the appropriate highway authority must be contacted and permission obtained.

Details and guidelines on the safe use of scaffolds can be found in HSE Information Sheet *General Access scaffolds,* Construction Sheet No. 3 (revised) and HSE Information Sheet *Tower scaffolds Construction,* Sheet No. 10 (revised). References to legislation can be found in *Construction Working Places Regulations 1966* and *Health and Safety at Work etc Act 1974.*

9.5 Statutory consents

Anyone seeking to carry out any works to clean biological growths from scheduled monuments must seek scheduled monument consent in advance. The position is slightly more complicated on listed building consent in that, whilst it is not always expected that someone wishing to treat biological growths on sandstone would need to secure listed building consent, it is, strictly, a matter for the local planning authority in the first place to determine whether or not any particular action needs listed building consent.

Therefore, anyone considering treating biological growths on a listed building should first of all seek advice from the conservation staff of the planning authority, who, in some cases, may request an application for listed building consent if there is doubt about the efficacy or safety of the method selected. The same advice could apply to such works for an unlisted building in a conservation area.

Such consent is likely to be restricted to those proposals which, on the basis of recent research and current technical knowledge, reduce to an absolute minimum the risk and possible scale of damage. Proposals should include provision for pre-trials or tests on unobtrusive areas before the final specification is determined and before full scale treatment is carried out.

Should consent to apply a biocide be obtained, it is advised to employ contractors of proven ability who are known to be able to carry out the work exactly as specified and with good supervision.

The following guidelines present some of the issues to be taken into consideration by applicants and decision makers alike.

Concerns and considerations

Potential damage

In recent years, there has been growing professional concern about the scale and extent of irreversible damage to stonework which can be inflicted through the application of certain biocides. The application of chemicals will often interfere in a complex and unfavourable way with the manner in which the stone responds to natural weathering.

The removal of a natural coating from a sedimentary rock such as sandstone has the effect of opening up the surface and of permitting a greater degree of water penetration. This will accelerate natural decay. Where growths are removed by chemicals, the treatment may result in materials being taken into the stone structure which will promote further decay.

Aesthetic implications
Treatment with biocides can change the colour of a building. Such changes have an effect upon the appearance not only of the building but also of its immediate surroundings. Treatment should not take place where the surface to be treated forms part only of a single building or a group of buildings which form an architectural unit.

Additional considerations
When a biocide is applied to growing organisms, it often happens that, although they are destroyed, they leave a blackened residue that may take a long time to weather away.

It must be remembered that the effect of biocide treatment may be very short term. Within a few years, the extent of growth may be such that it totally negates the perceived benefits of treatment.

GLOSSARY

Bio-available	available to biological organisms
Biocidal effect	the effect of substances that destroy plant life
Biostatic effect	the effect of a substance which prevents cell growth and reproduction without killing the cell
Heterotrophic	(organism) dependent on an external source of organic compounds for energy and/or minerals
Hyphae	filaments of a fungal thallus
Mucilage	complex organic compound related to the polysaccharides, of vegetable origin, and having glue-like properties
Organelle	a specialised protoplasmic part of a cell having a particular function. Protoplasma is a jelly-like substance which makes up the largest part of each cell
Particulate	tiny solid particle of a pollutant
Photoprophic	(organism) which obtains energy from sunlight
Substrate	matter or surface on which an organism lives
Thallus	a simple vegetative plant body lacking in differentiation; may be unicellar, multicellular, branched or unbranched

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HSC *Chemical cleaners,* Construction Sheet No. 24

HSE *General Access scaffolds,* Construction Sheet No. 3 (revised)

HSE *Tower scaffolds,* Construction Sheet No. 10 (revised)

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APPENDIX A
HEALTH AND SAFETY LEGISLATION

The following summary of COSHH regulations aims to highlight that information, instruction, training and health surveillance should be made available to the user of hazardous substances such as biocides.

Assessment of health risks associated with the use of hazardous substances (Regulation 6)

Suitable and sufficient assessments of risks to the health of all employees created by work involving hazardous substances should be carried out by employers before the use of such substances (regulation 6(1)).

Risk assessments should involve:

- identification of substances (including micro-organisms) which employees may become exposed to (including through the possibility of failed control measures)
- the effects the substances can have on the body
- the form and location of the substances
- the ways in which and the extent to which any employee or other persons could become exposed to a hazardous substance, and any foreseeable deterioration in or failure of control measures for such substances (regulation 6(15)).

Suitable and sufficient assessments should include:

- an assessment of risks to health
- consideration of the practicability of preventing exposure to hazardous substances
- the steps which need to be taken to achieve adequate control of exposure where prevention is not reasonably practicable (regulation 6(14)).

COSHH information, instruction and training (Regulation 12)

Employers should ensure that exposure of employees to hazardous substances is either prevented or is, at least, adequately controlled where total prevention is not practicable (regulation 7(1)).

In the use of hazardous substances, employers should ensure that users, in connection with the employer's duties, receive information, adequate training and instruction to enable them to ascertain:

- the possible risks to health from exposure to a substance (regulation 12(1a))
- the precautions which should be taken to avoid risk (regulation 12(1b))
- the correct procedures for cleaning, storage and disposal of substances and equipment (regulation 12, §100(b))
- the emergency procedures following exposure to a hazardous substance (regulation 12, §100(c))

Information should be available to workers of exposure monitoring procedures, which should be carried out in the workplace by a suitable procedure (regulation 10(1a)). The employer should keep a record of any monitoring carried out (regulation 10(3)). The arrangements for access to results should be known. Where substances which have maximum exposure limits (MELs) are used, notification should be made if a MEL has been exceeded (regulation 12, §98(d)). In addition to this, users should have ready access to information of any relevant anonymous health surveillance (regulation 12(3)).

Health surveillance

Users of hazardous substances have a duty to attend for health surveillance where appropriate. In cases where effects on health may be anticipated after a latent period, this can include continuing surveillance after cessation of exposure (regulation 11).

Categories where health surveillance becomes appropriate and typical procedure (regulation 11, §91):

- using substances which cause recognised systemic toxicity – appropriate clinical or laboratory procedures carried out
- substances known to cause occupational asthma – evidence of work-related respiratory symptoms
- substances known to cause severe dermatitis – skin inspection by a responsible person.

APPENDIX B: SOME ALGICIDES/GENERAL BIOCIDES CURRENTLY APPROVED FOR USE AND SALE AS MASONRY BIOCIDES BY THE HEALTH AND SAFETY EXECUTIVE

NOTE Proprietary biocide products are constantly changing, both in their formulation and product name. It is often difficult to identify the important active ingredients from the information supplied by the manufacturer and the list of products given in Appendix B is not intended to be definitive, but is indicative of the range of proprietary products available at the date of this Technical Advice Note.

CHEMICAL CLASS	PRODUCT	HSE REFERENCE
alkyl trimethyl ammonium chloride	**Abicide '82** Langlow Products Ltd.	HSE 4470
alkylaryl trimethyl ammonium chloride & disodium octaborate	**Boracol 10 RH Surface Biocide** Channelwood Preservations Ltd.	HSE 4911
Remtox Boracol 10 RH	**Masonry Biocide** Remtox Chemicals Ltd.	HSE 4100
benzalkonium chloride	**Algae Remover** Sadolin (UK) Ltd.	HSE 4781
	BN Algae Remover Morgan Nehra Holdings Ltd.	HSE 5381
	BN Moss Killer Morgan Nehra Holdings Ltd.	HSE 5047
	Conc Quat Semitec Ltd.	HSE 4904
	Cuprinol Cuprotect Patio Cleaner Cuprinol Ltd.	HSE 5527
	Gloquat RP Rhone-Poulenc Chemicals	HSE 4815
	Howes Olympic Algaecide Killgerm Chemicals Ltd.	HSE 4845
	Moss Cure Cementone Beaver Ltd.	HSE 4478
	Paramos Chemsearch	HSE 4524
	Snowcem Algicide Snowcem PMC Ltd	HSE 4806
benzalkonium chloride & 2 phenylphenol	**Fungicidal Algaecidal Bacteriacidal Wash** Ultrabond Ltd.	HSE 4216

CHEMICAL CLASS	PRODUCT	HSE REFERENCE
benzalkonium chloride & carbendazim & dialkyldimethyl ammonium chloride	**Algotox** May and Baker Garden Care	HSE 4901
benzalkonium chloride & disodium octaborate	**Deepflow 11 inorganic Boron Masonry Biocide** Safeguard Chemicals Ltd.	HSE 5528
dialkyldimethyl ammonium chloride	**Lichenite** Mould Growth Consultants Ltd.	HSE 3930
	Mosscheck Biotech Environmental Services Ltd.	HSE 4870
dichlorophen	**SP 153 Sterilising Detergent Wash** Joseph Mason Plc.	HSE 3920
dodecylamine lactate & dodecylamine salicylate	**Green Range Murosol 20** Cementone-Beaver Ltd.	HSE 4456
	Larcen Concentrated Algicide Larcen Manufacturing Ltd.	HSE 4968
	Safeguard Mould and Moss Killer Safeguard Chemicals Ltd.	HSE 4607
dodecylamine lactate & dodecylamine salicylate & zinc octoate	**Algicide E** Nutec Chemicals Ltd.	HSE 4214
sodium pentachlorophenoxide	**Mosgo P** Agrichem Ltd.	HSE 4337

Source: Ministry of Agriculture Food and Fisheries & Health and Safety Executive. Reference Book 500, *Pesticides 1995,* HMSO.