TAN 25

MAINTENANCE AND REPAIR OF CLEANED STONE BUILDINGS

Technical Advice Note 25

Maintenance and Repair of Cleaned Stone Buildings

Technical Conservation, Research and Education Group

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TECHNICAL
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MAINTENANCE AND REPAIR OF CLEANED STONE BUILDINGS

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CONTENTS

ILLUSTRATIONS

LIST OF TABLES

FOREWORD

Natural stone was by far the most widely adopted building material used in the creation of the country's built heritage. It therefore merits the greatest understanding, and the highest application of skills and knowledge, in its care and conservation. However, over time Scotland's stone buildings have suffered from a variety of influences, not all of which have been fully understood when decisions aimed at promoting their well being have been taken.

From the 1960s the cleaning of masonry buildings for aesthetic, commercial and sociological reasons became commonplace. As a result, and due to a lack of awareness of the potentially damaging consequences of the different cleaning processes, much harm was unwittingly inflicted on the stone. Unfortunately, this approach continued for several decades. As the scale of damage became more evident, there was a developing call for research to be carried out to identify what was causing the resulting loss. Against this realisation the demand for stonecleaning continued, so there was also a need to try to steer building owners and managers away from aggressive techniques and materials towards those that were less damaging to the masonry.

Historic Scotland commissioned initial research into this complex arena in 1989. It investigated all of the stonecleaning techniques current at the time, and produced a 5-volume *"Stonecleaning in Scotland; Research Report"* published in 1992. This led to an international Stonecleaning Conference being held in Edinburgh in 1994 and the production of *"Stonecleaning: A Guide for Practitioners"* in the same year. Dealing predominantly with sandstone buildings, this preliminary research programme scientifically confirmed what had been long suspected by many practitioners: – that cleaning stone buildings had the potential to inflict different degrees of damage according to the method used and the skill, or lack of skill, of the operatives.

Further related research programmes followed and these resulted in additional pragmatic guidance being published. Published under TCRE's Technical Advice Note (TAN) series, *TAN 9 "Stonecleaning of Granite Buildings"* and *TAN 10 "Biological Growths on Sandstone Buildings"* were released in 1997, and *TAN 18 "The Treatment of Graffiti on Historic Structures"* in 1999.

Recognising that much had been put at risk over the years, it was acknowledged that the accumulated damage also required investigation. The aim was to try and quantify the severity of the damage and to offer an assessment of the long-term effects on the buildings. The challenge was to try to find some means of reducing the degree of inflicted loss that was being addressed in a currently emerging programme of stone repair projects on post-cleaned buildings. Consequently, a further research study was commissioned in 1998. Staff at the Robert Gordon University, Aberdeen, also carried out this 3-year programme of site investigation and laboratory research work. As this involved a number of the original participants in the 1988 study, a continuity of knowledge and expertise was therefore available for the new project.

The team carried out direct comparisons of cleaned and uncleaned facades of similar sandstones and granites, on similar buildings, of similar dates, in similar locations across Scotland. As a result they were able to quantify the depth and extent of decay, colour changes, and increased rate of weathering directly attributable to earlier stonecleaning procedures. Assessments were also made of performance and life-cycle costs in relation to future maintenance programmes, and some initial recommendations for future repair strategies were devised. The findings are now published, alongside this volume, as a Research Report, *"Consequences of Past Stonecleaning Interventions on Future Policy and Resources"*, in the TCRE series.

This Technical Advice Note (TAN 25) "translates" the Report findings into pragmatic advice. It sets out recommendations for appropriate repair philosophies and techniques that need to be considered when dealing with a post-cleaned damaged traditional building. Together, the two publications provide a comprehensive assessment of the effects of stonecleaning to guide practitioners, building owners and contractors in their future decision-making processes. The combined intention is to offer a deeper understanding of the practical implications for the aftercare of cleaned stone buildings where significant repair works are unavoidable.

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August 2003

SUMMARY

Stone cleaning of our sandstone and granite built heritage has a history stretching back over some 40 years, but peaking during the 1970s and 80s. In the early years especially, much of this cleaning was virtually uncontrolled and often inappropriately aggressive. Since 1992, stone cleaning of listed buildings and unlisted buildings within conservation areas has not been deemed to be permitted development, consequently planning permission and, where appropriate, listed building consent, for such cleaning has been required.

Over time, cleaning methods have evolved from relatively aggressive early forms into methods more finely tuned to the needs of particular stone types and the removal of harmful soiling. It has been recognised that some stone types cannot be cleaned using currently available methods due to their specific vulnerability. Nevertheless, there is an existing legacy of damage from previous uncontrolled cleaning that remains to be dealt with. Cleaning using aggressive or inappropriate methods, in addition to removing soiling, can have an immediately obvious deleterious effect on a building surface. However, there are also longer-term implications of cleaning that can have subtle, but no less damaging, effects on a building's external fabric, emphasising the need to seek expert advice and carry out adequate testing. There is also the issue of periodic re-cleaning with its implications for potentially harmful interaction with previous interventions and cumulative damage.

For effective maintenance of cleaned buildings, those concerned with their upkeep need to be aware of issues that may arise following cleaning, so that effective monitoring and intervention may be undertaken. This TAN does not therefore deal with stone cleaning methods in themselves, but with their long-term consequences and how the legacy of previous treatments affects maintenance issues for building façades and other stone structures.

The list of potential effects, both immediate and longer-term, that stone cleaning may have on building stone is wide ranging, from aesthetic effects such as colour change to large scale physical deterioration of stone. There is a wide range of stone types used in building, some of which (both sandstone and granite) are particularly vulnerable to natural weathering and ill-informed surface treatments. There is increasing awareness that where inappropriate cleaning methods have been used on vulnerable stone types, the rate of stone decay may be considerably increased. This is especially the case on some sandstone façades.

Purely aesthetic effects of stone cleaning may influence the value (in the widest sense) of a property, but they do not result in deterioration of the building fabric. Stone decay is a more serious consideration as it may result in loss of functional and, if appropriate intervention is not carried out, structural integrity. Stone decay is often particularly marked on functional features such as projecting string courses, mouldings and other features most exposed to climatic effects. Interventions that lead to increased moisture or soluble salt loading of stone are those most likely to result in accelerated rates of decay. It is important also to consider the influence of other components of the façade, such as joints and mortar. These provide an essential 'escape route' for moisture, but can act as reservoirs for damaging salts.

Accurate assessment of current façade condition is a necessary precursor to successful planning of repair and maintenance. There may have been treatments other than cleaning carried out on the façade - e.g. water repellents, biocides or chemical consolidants. The nature and scale of a problem should be established before carrying out any intervention. No remedial action should be undertaken on a stone building until the extent of decay is known, the cause of decay has been identified and a suitable method for treatment or repair has been established. Intervention must address the cause of decay, not merely the symptoms and the degree of intervention should be kept to a minimum.

Repairs should normally be dictated by good conservation practice, rather than by short-term expediency. Low cost methods, such as plastic repair (mortar patching) may, in themselves, be a cause of further deterioration. Cost is inevitably a factor in determining the methods used, but short-term savings can result in increased long-term costs. In common with many maintenance interventions, good practice may appear initially costly, but over the life span of a building the savings inherent in timely intervention can be considerable.

1 INTRODUCTION

1.1 Stone cleaning and the stone heritage of Scotland

This Technical Advice Note builds upon previous Historic Scotland research and related publications, which investigated and offered advice on the cleaning of sandstone and granite buildings in Scotland (Andrew et al., 1994; Urquhart et al., 1997). This publication is not concerned with advice on methods of stone cleaning; rather, it concentrates on providing information and guidance on identifying and dealing with the often-deleterious effects of ill-informed and uncontrolled stone cleaning, that have been a feature of our urban stone environment over the past thirty years.

In Scotland in the 1960s, we quickly followed the fashion set by Paris and London where black-soiled limestone buildings were transformed into clean, white or light-coloured structures, revealing the true magnificence of previously obscured architectural features. Unfortunately, there was a failure to appreciate that the way in which atmospheric pollutants attach to sandstone surfaces is fundamentally different to that of limestone and to remove the 'grime' from a sandstone required the use of much more aggressive cleaning systems; ranging from carborundum discs to strong acids and alkalis. There was an early realisation that some of these abrasive systems were excessively aggressive, were removing the surface of the stone as well as the soiling layer and, in the process, blurring the sharpness of architectural detail. In the 1970s and 1980s the use of chemical-based cleaning systems (acid and alkali washes, acid gels and alkali pastes and poultices) predominated, in an attempt to reduce the damage to the stone surface from abrasive systems.

Poorly trained operatives applied many of these chemical-based systems, with the result that porous sandstone façades were irreversibly altered in a variety of ways. The deleterious effect on sandstone may be aesthetic, as a result of colour changes through mobilisation and redistribution of iron or manganese minerals, or bleaching through the removal of coloured minerals. More seriously, chemical cleaning often resulted in residues being retained within the pores of the stone, forming salts that caused damage to the stone surface as they went through cycles of hydration and crystallisation.

While we have now a much better understanding of the issues and have developed considerably less damaging cleaning systems, the legacy of these past cleaning interventions on the stone heritage of Scotland remains with us. There is a growing awareness that past stone cleaning activities have resulted in an increase in the rate of decay of sandstone façades and that this has affected many historic and listed buildings. The stone heritage of urban Scotland is therefore at risk. The presence of stonecleaned façades, with the consequential damage to stone, is ubiquitous in our cities and towns, and clear advice on how best to address these emerging problems is contained in the following Advice Note.

1.2 Implications for the stone heritage

The action of natural weathering agencies and environmental pollution on our stone heritage has been compounded by the effects of stone cleaning. However, it is on sandstone buildings that the acceleration of decay has been most marked. On granite, the other common building stone in Scotland, the effects of stone cleaning are less significant. The accelerating rate of decay on some sandstone buildings is a cause for concern because there is a temptation to initiate repairs based on short-term expediency. Essentially, cost, rather than recognition of good conservation practice, dictates the quality of many repairs to damaged façades. This has led to the extensive use of plastic repairs in an attempt to cover up damaged surfaces. In turn, poorly executed repairs of this type have the potential to exacerbate the initial damage caused by stone cleaning. Deterioration appears to have been particularly marked on carved and functional features such as projecting string courses and mouldings. The loss, or partial loss, of function in a detail may detrimentally affect rain water run-off control on a façade and increase wetting and drying cycles in stonework at lower levels.

Good conservation practice is readily accepted on scheduled ancient monuments, whose preservation can be justified on cultural grounds alone. Its application to the repair of most other stone buildings is not so well recognised due to the economic pressures inherent in the need for a building to 'earn its keep'. Where a stone façade has suffered aesthetic damage as a result of stone decay, and ownership of the building is likely to

Illus 1. Cleaning at different times using a variety of methods results in a variety of colours and shades on a once unified facade. This is an example from Edinburgh.

be transient, there will be pressure to adopt the quickest and cheapest solution that will 'restore' the façade to a condition that is approximately similar in appearance to the original. Such an approach is unlikely to be the best long-term solution to the preservation of the stone heritage of our towns and cities.

1.3 Consequences of stone cleaning research

Stone cleaning has had a significant effect on the appearance of buildings and on their environmental context. The long-term outcome of stone cleaning is generally perceived positively by the public and building owners; however no stone cleaning method has yet been devised which can remove soiling without affecting the underlying stone, and the potential for immediate and longer-term damage to stone is seldom fully appreciated. Abrasive cleaning methods (e.g. grit blasting) inevitably result in some physical damage to the stone surface. Chemical cleaning may cause colour changes and can leave substantial chemical residues in porous stone. The soiling layer on building stone is often somewhat hydrophobic and its removal can change the behaviour of stone (and joints) with respect to movement of water and water vapour.

Appropriate stone cleaning methods, when used with care, can give good results. Where accumulated soiling is responsible for accelerated decay of the underlying stone then cleaning may be advantageous. Stone cleaning is however often carried out for purely aesthetic reasons with little understanding of the potential damage that may be done by improper or uncontrolled cleaning. Previous studies (Andrew et al., 1994; Webster et al., 1992; Urquhart et al., 1997) have established that inappropriate stone cleaning can damage building stone. The degree of damage caused at the time of cleaning depends on the technique and the stone characteristics, but stone cleaning also has consequences for the longer-term behaviour of the stone. Some of the effects of stone cleaning may take a number of years to become apparent and it has recently become evident that large scale stone replacement and repair is being carried out on façades that have been cleaned in the past.

This Technical Advice Note is based on the results of research commissioned by Historic Scotland from the Masonry Conservation Research Group (MCRG) at The Robert Gordon University, Aberdeen (Young et al., 2000). The research objectives were to determine the extent and rate of stone decay on cleaned and

Illus 2. Loss of functional detail post stonecleaning. On this building a decayed string course has caused excessive erosion of the rock-faced sandstone below the string course. An unsatisfactory plastic repair to the string course has subsequently been carried out.

uncleaned building stone façades and to predict the effects of previous and on-going stone cleaning on the future costs of façade maintenance. The research programme included a number of surveys of practitioners involved in stone cleaning and other aspects of façade maintenance to determine their attitudes to stone cleaning, stone repair and replacement, maintenance programmes, life cycle cost issues and materials sourcing for repair purposes. Associated fieldwork involved the collation of information on the condition, amount and distribution of stone decay on sandstone and granite building façades in Edinburgh, Glasgow, Aberdeen, Dundee and Inverness. Data was collected over a two year period from 1997-1999 and includes façades cleaned up to 25 years prior to that period. The results therefore illustrate the ongoing effects of cleaning carried out over a long period. Stone cleaning methods vary in their effects on stone and, as a consequence of product developments, the methods themselves have undergone significant changes over this 25 year time period; however, the physical and visual effects of previous stone cleaning remain evident. The most aggressive methods of the past (e.g. high pressure grit blasting and highly concentrated chemical cleaning agents) are now seldom employed. Where the cleaning method is significantly different, the post-cleaning behaviour of a recently cleaned façade may therefore differ significantly from that of a previously cleaned, similar façade.

2 SOILING AND DECAY OF STONE FAÇADES

2.1 Soiling of sandstone and granite façades

The soiling of building façades is a complex phenomenon involving interactions between pollutants, biological growths and minerals in the stone (Table 1). Soiling consists of both particulates and biological material including:

- soot & particles from coal and oil combustion,
- hydrocarbons,
- sulphates, chlorides & other salts,
- iron oxides and hydroxides,
- lead compounds & other metals,
- silicate mineral dust,
- asphalt,
- rubber from car tyres,
- algae, bacteria, lichens, fungi & higher plants.

Soiling is not uniform across a façade; variations in stone type, architectural features and micro-climatic effects control its location and intensity. On most sandstone and granite, soiling is heaviest on and adjacent to frequently wetted areas, on horizontal surfaces, exposed detail or sloping areas of stonework (Illus 3). By contrast, the slight solubility of calcareous stone allows soiling to be washed off, so that on limestone, calcareous sandstone and concrete surfaces soiling is heavier in sheltered areas (Illus 4). The intensity and location of soiling are to a large extent controlled by the detailing on a building façade.

Colour

The natural colour of stone is determined by the component minerals, their grain size and their condition. Alteration of coloured minerals (e.g. those containing iron or manganese) by natural weathering or chemical treatments can cause localised bleaching or staining. When it is a natural process, the colour changes caused by weathering can lead to aesthetically pleasing intensification of pre-existing colour variations. By contrast, the abrupt colour changes that can result from inappropriate chemical applications may be inconsistent with the natural weathering patterns of individual stones or the façade (Illus 1 & 23). Such colour changes may be aesthetically disruptive where they do not conform to natural boundaries (e.g. if they are continuous across joints or stop abruptly at the limits of the treatment).

Soiling or colour change	Description	Natural or induced
Patina (Illus 15)	Colour changes on and below a stone surface caused by mineral movement as a result of many years of weathering and alteration.	Natural
Bird droppings (Illus 16)	Present on and below projecting ledges and other roosting positions.	Natural
Particulate soiling (Illus 17)	Includes soot, dust, hydrocarbons and other inorganic pollutants. Forms a dark discoloration on a stone surface.	Natural and induced
Biological growths (Illuss 18 & 19)	Algae, lichen, moss, fungi, bacteria and higher plants. Various morphologies and colours. Dead or dormant growths may be difficult to distinguish from inorganic soiling.	Natural and induced
Salt efflorescence (Illus 20)	Superficial, transient deposits of soluble salts, usually white or light coloured. Normally localised at the edges of zones of water run-off or moisture concentration.	Natural and induced
Black crust (Illus 21)	Hard, black encrustation normally composed mainly of gypsum. Distinct from the stone surface and up to several mm thick. Deposited in sheltered areas. May conceal underlying decay.	Induced
Metal stains (Illus 22)	Stains resulting from corrosion of metal fixings. Iron corrosion causes orange, brown or black stains. Decay products of copper leave green or blue stains.	Natural and induced
Stone treatments (Illuss 23 to 25)	Chemical stone cleaning can cause bleaching and/or staining. Water repellents or chemical consolidants may cause glossiness or darkening.	Induced

Table 1. Forms of natural and induced (man-made) soiling and colour change on building stone.

Illus 3. Typical soiling pattern on a sandstone building façade. Soiling is heaviest on areas exposed to rain and run-off.

Illus 4. Typical soiling pattern on a limestone building façade. Soiling is heaviest in sheltered areas, unwashed by rainwater or run-off.

Patina

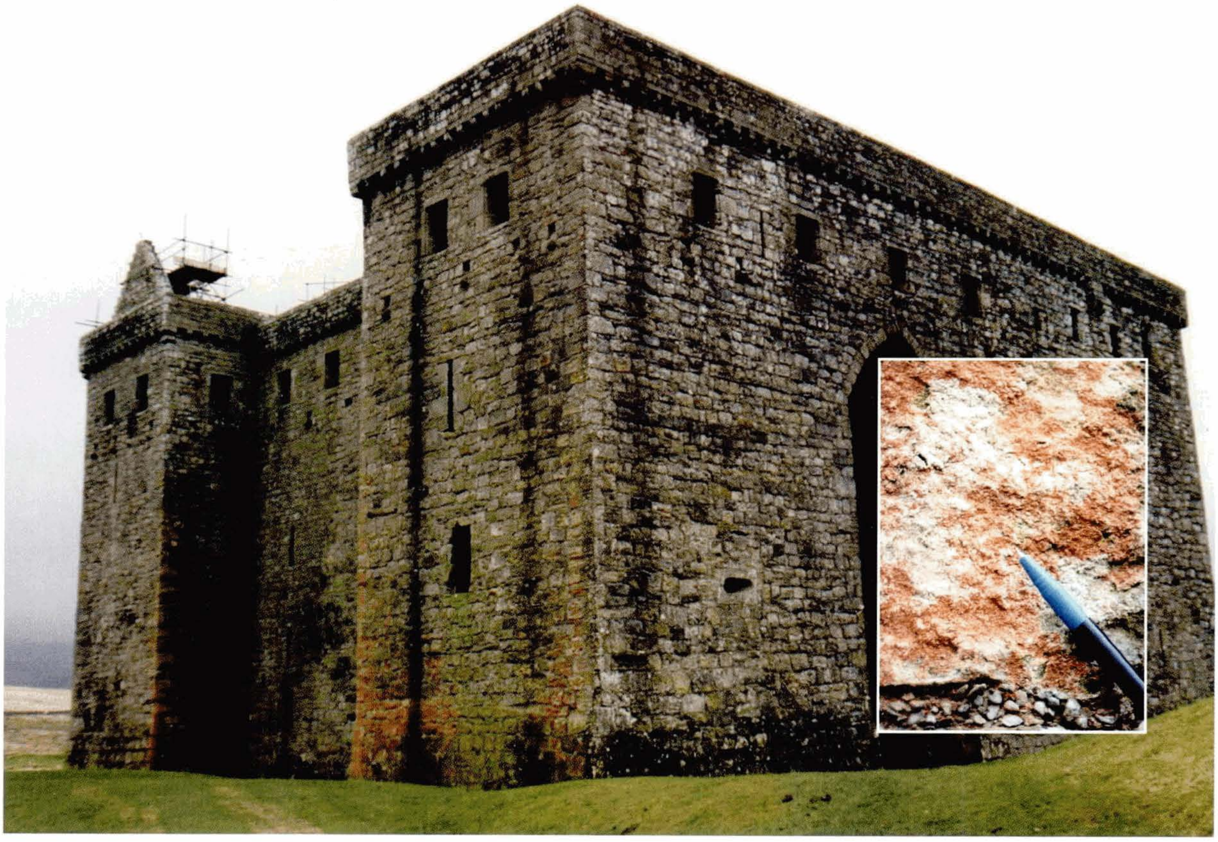
The patina that develops on stone surfaces is a result of complex interactions between the stone and its environment. It is distinct from soiling although components of soiling may be involved in its formation. Patination is largely a product of colour changes caused by alteration of the stone surface (Illus 15). Moisture movement, atmospheric pollutants and biological organisms contribute to its formation.

Black crusts

Black gypsum crusts are most commonly found on limestone, but they also occur on other stone types including granite and sandstone. Pure gypsum is white; the black coloration of crusts is caused by the incorporation of soiling particles. Black crusts occur in sheltered areas and adjacent to areas of rainwater run-off. They are commonly associated with pointing mortar, especially on non-porous surfaces (e.g. granite) where rainwater is channelled over the surface. Gypsum deposits form hard encrustations that may conceal underlying stone decay.

Biological growths

When actively growing, organisms such as algae, lichens or mosses are easily visible on stone surfaces due to their different colours and forms (Cameron et al., 1997); however, dark soiling on stone surfaces may also contain a substantial contribution from biological growths, which darken when they are dormant or dead. Not all organisms are green in colour. Lichens are especially variable in colour (including orange, yellow, red, green, white, grey and black varieties). Algae, bacteria, mosses and fungi also occur in diverse colours. Colour variations on stone that may initially appear to be a result of weathering or soiling can be caused by organisms (Illus 5).



Illus 5. Hermitage Castle, Scottish Borders. The orange colour is not the natural stone colour (which is buff), but is caused by the presence of an orange-coloured algae (Trentepohlia sp.).

Salt efflorescences

Efflorescences are soluble salts, usually white or off-white in colour (Illus 9-12 & 20). Causes of efflorescences include salts that have been:

- originally present in stone;
- derived from sea spray;
- derived from atmospheric pollution;
- derived from road salts;
- derived from pointing or bedding mortar.

On buildings that have undergone chemical cleaning or other treatments:

- residues from chemical treatments may form efflorescences (Illus 8).

Efflorescences are aesthetically disfiguring on a stone surface and often cause decay (Illus 20) when they crystallise below the surface (cryptoflorescence).

Metal stains

Stains can occurs around and below metal fixings as a result of corrosion or oxidation of the metal, with localised run-off of metal contaminated water below the projecting element. Coloration depends on the type of metal; orange, brown or black stains are common in association with iron fixings. Stains from copper and bronze are green or blue.

2.2 Decay of building stone

All building stone is subject to natural decay processes. The rate of stone deterioration is also affected by maintenance interventions. Ideally these should reduce the rate of decay, but neglected maintenance and ill-advised repair methods may increase decay. There is no fundamental difference between natural and induced forms of decay, the distinction lies in the rapidity and in the relative intensity of types of decay.

2.2.1 Natural decay

Some types of stone decay are self-limiting and will not progress beyond a certain stage; this includes pitting (Illus 30), loss of pebbles or inclusions and some forms of physical damage. Other types are progressive and the rate of decay may accelerate as the surface weathers, opening it up to further deterioration through increased influx of moisture. Weathering reduces the strength and durability of building stone by breaking down the bonding between mineral grains and increasing porosity through both micro-cracking and through dissolution or alteration of minerals. Slow accumulation of pollutants and gradual loss of strength over many years eventually result in substantial loss of surface within a relatively short period of time. The cycle of weathering then starts again from a new exposed surface.

Moisture is involved in many stone decay processes. Porous stones (e.g. sandstone, normal porosity range 10-25%) allow internal movement of fluids resulting in decay that potentially affects a relatively large stone volume. Where porosity is low, decay is relatively slow and mainly confined to the immediate surface; most granite for instance has a low porosity (often <1%). The forms of decay (Table 2) observed on sandstone and granite are similar - they differ in their relative proportions and in the rate of decay (Table 3). Decay is often localised in particular areas related to microclimatic effects.

Biological organisms are involved in some natural decay processes. Lichens, algae and mosses can cause localised damage although they often co-exist with stone with little ill effect. Higher plants with woody stems and roots cause physical damage by penetration and displacement of stones. Bacteria may be involved in many decay processes although their role and contribution to stone decay is at present unclear.

Limestone and marble

On limestone or marble structures the solubility of the stone makes measurements of rates of surface recession relatively straightforward. Measured dissolution rates are not 'natural' since they are controlled by acidic pollutants in the atmosphere. The rate of stone loss can be directly related to atmospheric pollution levels. 'Damage functions' can be calculated to quantify limestone weight loss based on deposition rates for sulphur dioxide and nitrous oxide pollution and rainfall on the stone. Rates of surface recession on limestone range from averages around 2-4 mm per century up to levels of greater than 100 mm per century.

Sandstone and granite

Non-calcareous stone types are subject to localised decay at non-linear rates. The minimum rate of decay can be close to zero. Maximum estimated surface recession rates are often less than 1 mm per century unless the stone is particularly vulnerable.

Decay form	Description	Natural or induced
Honeycombing	Deep or cavernous pitting in a honeycomb pattern. More common in coastal locations	Natural
Case hardening	Hardened crust on top of soft, friable interior. Caused by mineral cement dissolution, with deposition and hardening near surface	Natural
Multiple scaling	Detachment of multiple planar elements parallel to a stone surface, unrelated to underlying texture in the stone	Natural
Crumbling	Loss of surface through detachment of clusters or clumps of grains	Mostly natural
Pitting	Small, irregularly distributed pits on a stone surface. In sandstone, often caused by variations in type or degree of cementation	Mostly natural
Differential decay	Differential weathering of individual stone components due to naturally occurring differences in their vulnerability to decay	Mostly natural
Decay of components	Zones of decay due to loss of clearly bounded elements or inclusions, e.g. clay nodules or pebbles	Mostly natural
Granulation (granular disintegration)	Loss of surface through detachment of individual grains. May be associated with salt efflorescences	Natural and induced
Flaking	Detachment of small, thin, planar elements parallel to a stone surface	Natural and induced
Blistering	Localised blistering of a stone surface	Natural and induced
Contour scaling	Detachment of large, planar elements parallel to a stone surface, unrelated to underlying texture in the stone	Natural and induced
Dissolution	Soluble minerals, especially carbonates, dissolved by rainwater	Natural and induced
Back weathering	Extreme decay, when a single block has weathered back to a significantly greater degree than surrounding stone	Natural and induced
Delamination	Detachment of single or multiple planar elements parallel to foliation or bedding plane. Often exacerbated by face or edge bedding	Natural and induced
Abrasion from cleaning	General loss surface or sharpness of detail as a result of aggressive stone cleaning	Induced
Mechanical damage	Loss of compact stone fragments by fracturing due to impact or other stresses acting on a stone	Induced
Fissures	Lines of fracture or open cracks wholly or substantially crossing a stone block. Often caused by settlement or impact damage	Induced

Table 2. Forms of natural and induced (man-made) decay on stone building façades.

Decay or soiling factor	Sandstone	Granite
Contour scaling	Common. Scaling varies from ~1mm up to several mm in thickness	Moderately common on localised areas. Seldom affects whole blocks. Thickness of scaling ~1-2mm
Multiple scaling	Common on clay-rich sandstone where the clay is vulnerable to expansion & contraction on wetting & drying	Not normally observed on granite except following fire damage
Flaking	Relatively common	Relatively common. Superficial
Granular disintegration (granulation)	Common, especially adjacent to joints	Moderately common, especially adjacent to joints. Often superficial
Differential decay	Dependent on sandstone type	Not observed, due to lack of bedding planes
Delamination	Dependent on sandstone type & orientation of individual stones	Not observed, due to the lack of bedding planes
Loss of mineral cements	Common on calcareous stone types where it may result in pitting	Not observed (mineral cements are not present in granite)
Honeycombing	Relatively common in coastal areas	Rare
Salt decay forms	Common. Forms of decay include scaling, granulation & honeycombing	Rare, except on highly weathered granite where granulation may be observed
Weathering colour changes	Common. Highly variable. Relatively large volume of stone may be affected	Slight. Less intense & more superficial than on sandstone
Bleaching or staining from stone cleaning	Depends on stone type & method. Colour changes may be intense	Less common. Colour changes less intense than on sandstone
Back weathering	Rare, except on sandstone of poor durability	Very rare
Case hardening	Mainly on calcareous sandstone where mineral cements become depleted internally & deposited near surface. Rapid loss when crust is broken	Very rare

Table 3. Comparison of decay and soiling behaviour of sandstone and granite.

Building sandstones, especially those used on older buildings, vary widely in their durability (Illus 6). The most common forms of decay on sandstone façades are granular disintegration (Illus 29) and contour scaling (Illus 26), which occur to varying degrees of severity on siliceous, ferruginous and calcareous sandstone. Multiple scaling layers are most common on argillaceous sandstone. The characteristics of sandstone affect how the stone responds to cleaning as well as to natural weathering. Those sandstones most prone to natural weathering also tend to be most vulnerable to damage during and after stone cleaning.

In comparison to sandstone, the rate of decay of most granite is significantly slower. On many granite façades decay is confined to the outer 1-2 mm. Exceptions to this do occur; for instance, older, weathered granite may be relatively porous and behave more like sandstone with respect to its rate and morphology of decay. Although contour scaling and granular disintegration do occur, the decay form most commonly observed on granite façades is superficial flaking (Illus 27).

2.2.2 Induced decay

Interventions that result in increased moisture loading of stone are likely to induce an increase in the rate of decay (Table 4). Permeability may be increased by dissolution of vulnerable minerals by acidic chemicals or by physical impacts on the stone surface (e.g. some surface finishing methods). Increased surface roughness caused by surface finishing or abrasive cleaning can slow rainwater run-off and increase the amount of water that penetrates porous stone. Increased moisture content also encourages biological colonisation. Interventions that result in increased biological growth may accelerate stone decay processes caused by organisms. Some of the more aggressive lichen and bacterial species thrive on high levels of air pollution.

The introduction of soluble salts into stone is likely to result in induced decay through sub-surface salt crystallisation. Soluble salts may enter the stone from applied chemicals, atmospheric pollution and road salts, as well as from 'natural' sources such as sea spray.

Stone cleaning has been shown to have a significant effect on long-term rates of decay of building sandstones (Section 3). Accelerated decay consequent to cleaning is a form of induced stone decay.

Stone	Sub-type	Examples	Characteristics
Sandstone	Siliceous	Stainton, Locharbriggs, Clashach, Craigleith	Generally durable and slow to decay
Sandstone	Calcareous	Spynie (Moray)	Vulnerable to decay, some types vulnerable to pitting
Sandstone	Ferruginous	Locharbriggs, Corsehill, Binny	Often durable and resistant to decay if stone also has siliceous cement
Sandstone	Argillaceous	Leoch, Kingoodie	Soft, vulnerable to decay, especially multiple spalling layers
Granite	Grey	Rubislaw, Kemnay	Hard, strong, low porosity, slow to decay
Granite	Pink/red	Peterhead, Corrennie, Ross of Mull	Hard, strong, low porosity, slow to decay
Granite	Pale orange	Loanhead (Aberdeen)	Pale orange/yellow coloration caused by weathering. Moderate porosity, low strength, vulnerable to decay
Granite	Black	Bon Accord (Swedish)	Geologically defined as 'gabbro' rather than 'granite'. Hard, strong, low porosity, relatively slow to decay

Illus 6. Characteristics of some common sandstone and granite types (NB some stone types or variants may appear in more than one sub-type).

2.3 The role of joints and mortar

Joints and mortar make up a substantial proportion of the volume of most façades and their role in the weathering and decay of stone is not insignificant. Mortar should be the weakest component of a façade, having a higher permeability than the building stone so that moisture movement into and out from the façade takes place through joints rather than stone. Where moisture movement is concentrated in the stone, its decay will be accelerated. Permeable mortar allows rapid evaporation of moisture through the pointing and will effectively 'drain' moisture from surrounding porous stone (Illus 7).

Although permeable pointing is necessary to the well being of stone it can provide an access point for agents of decay, as can the cracks which develop between hard cement-based pointing and stone. Ingress of moisture carrying pollutants or chemicals into these vulnerable zones can cause localised decay.

Mortar can be a source of calcium salts. Chemical reaction between acidic atmospheric pollutants and mortar can produce gypsum (calcium sulphate). In porous stone types gypsum is a common constituent of the soluble components which are normally found at depths up to several centimetres below the stone surface (Illus 8). The concentration of gypsum is normally greatest close to the stone surface and gypsum deposits are also found as crusts on sheltered surfaces. On non-porous stone types, due to the inability of moisture to penetrate the stone, gypsum deposits are almost entirely confined to the surface. Black crusts and smaller patches of gypsum deposition are therefore relatively common adjacent to joints on granite façades.

2.4 Effects of detailing

Many of the traditional details on building façades were designed to help rainwater shedding and reduce the moisture loading of stone, thereby reducing the rate of stone decay. Decay often occurs in areas below projecting elements where moisture loading is higher. Concentrated zones of run-off may further increase fluid loading. Water will generally move downwards through stone until it is drawn to the surface by capillary forces and evaporation. A large volume of stone may contribute fluids to a relatively small zone of evaporation (Illus 9). Since fluids moving through stone dissolve soluble salts, this can result in concentration of salt deposits (cryptoflorescence and efflorescence) and associated salt decay in narrowly defined zones (Illus 10). Specific instances of this type of concentration of salts include:

- bottom loading of stones (Illus 9),
- salt drapes below windows (Illus 10),
- salt deposition at the wetting limits where run-off is channelled through open joints in string courses (Illus 11),
- concentration of salt residues from chemical cleaning around open joints (Illus 12).

Decay can also be accelerated where moisture is trapped by use of incompatible materials, for instance:

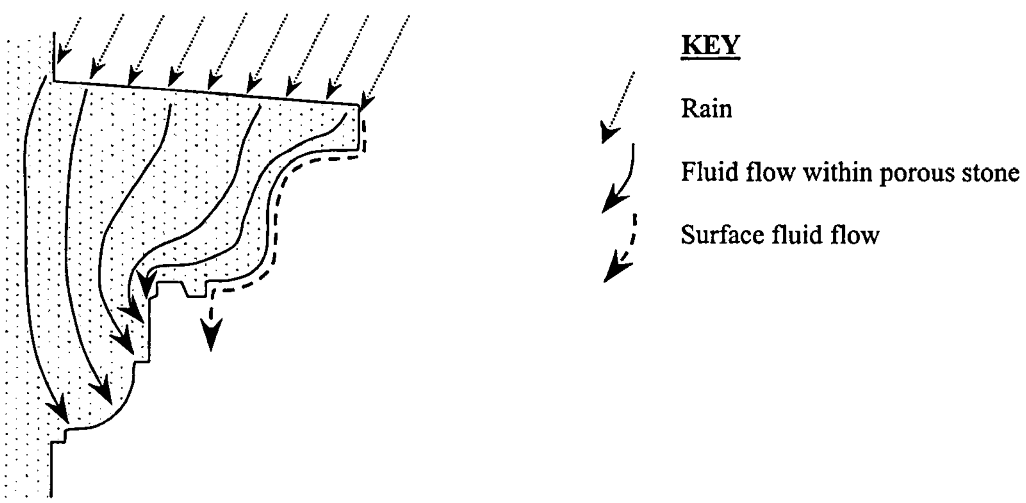
- porous sandstone above impermeable granite (Illus 13).
- porous stone with a hard, impermeable mortar (Illus 14).

Causes: Natural processes -------------------------------- Anthropogenically induced processes

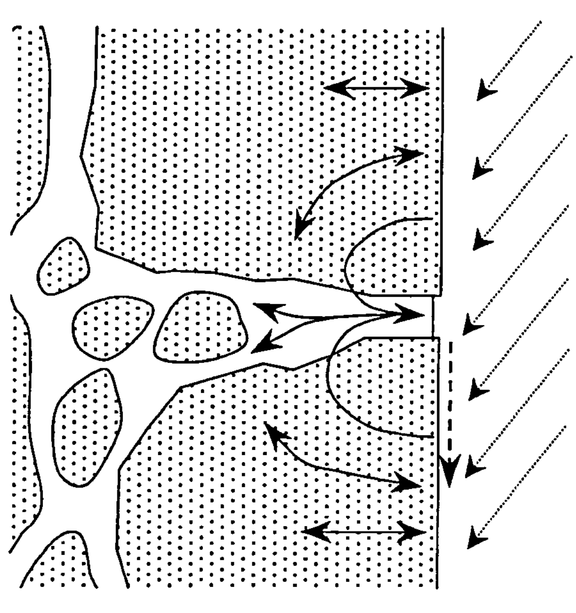
Effects: Form of decay or damage	Natural weathering: Decay of mineral grains	Natural weathering: Loss of natural mineral cements	Natural weathering: Formation of hard crust	Decay instigated by natural salts (e.g. sea spray)	Biological decay (e.g. lichens, algae, higher plants, etc.)	Decay instigated by air pollution (e.g. acid rain)	Incompatible adjacent materials or stone types	Inadequate detailing to control water run-off	Inadequate maintenance of gutters, downpipes etc.	Face or edge bedding of layered stone	Inappropriately aggressive abrasive cleaning	Salt decay by residues of chemical cleaning or de-icing	Chemical attack on minerals by chemical cleaning	Porosity blockage (e.g. some water repellents or paints)	Oxidation and expansion of iron fixings	Impact during scaffolding erection or other impacts
Granular disintegration		M		M		M	C	C	M		M	M	M			
Crumbling	M	M		M		M	C	C	M			M	M			
Pitting	M	M		C	M	M		C			M	C	M			
Differential decay	M	M		C		C		C	C	C	M	M				
Delamination		C		C	C	C			C	M		C		M	C	
Blistering			M	M	M	M	M	C	M			M		M		
Flaking				M	M	M	C	C	C			M		C		
Contour scaling		C	M	M		M	C	C	M			M		M		
Multiple scaling		C	C	M		M			C	M		C		M		
Decay of components	M	M				C		C	C		M		M			
Dissolution	M	M				C		C	M				M			
Honeycombing		C	M	M								C	C			
Case hardening		C	M			C							C	M		
Back weathering	M	M	M	M		M	C	C	C	M	M	M	C	M		
Abraded surface	C	C		C	M	M	C	C	C		M	C	M			
Mechanical damage					M		M				M				M	M
Fissures					M		M			M					M	M
Loss of pointing				C	M	C		C	M		M	C	C		C	M
Soiling					M	M		M	M							
Colour changes	M		M		M	M	C	M	M				M	M	M	

Major cause (M) Contributory factor (C) No or little effect (blank)

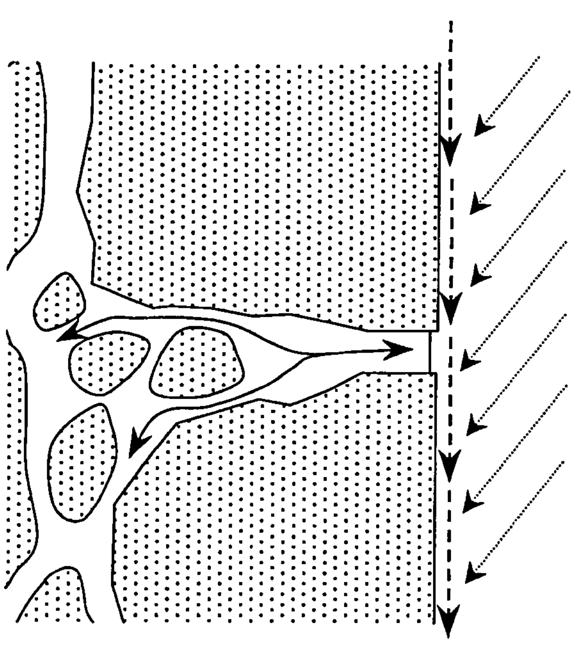
Table 4. Major causes of natural and induced forms of decay and damage to building stone.



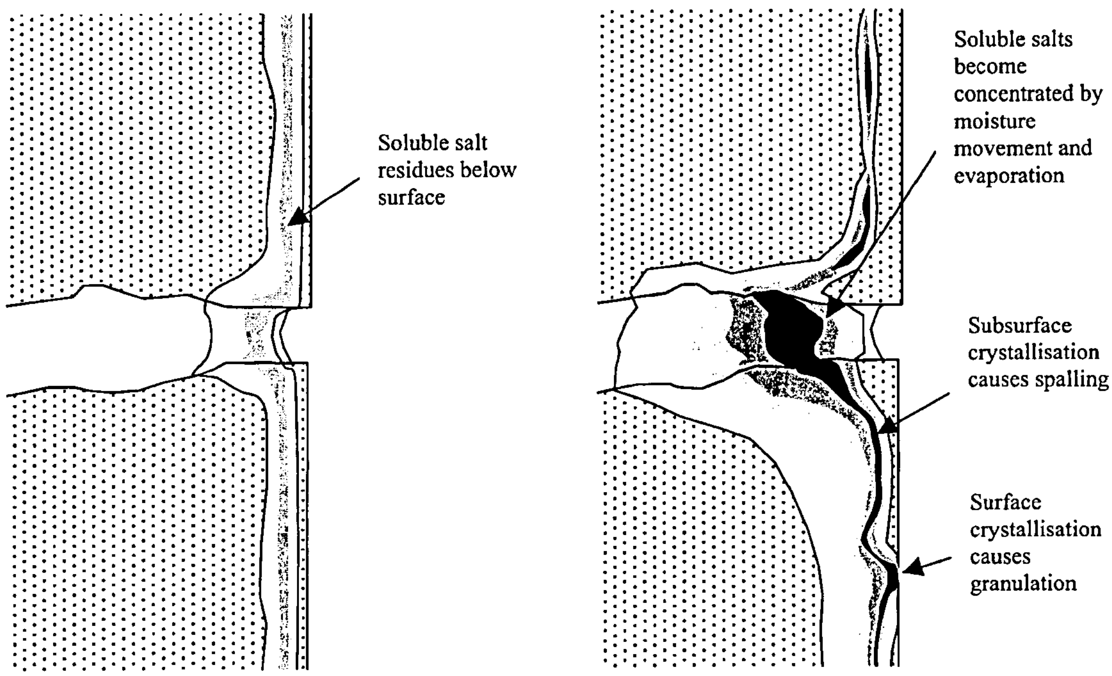
Illus 7a. Exposed detail can concentrate fluids from a large volume of stone into a relatively small zone of evaporation.



Illus 7b. Porous stone (e.g. sandstone). Fluids can flow through stone and mortar. Where correctly specified, most fluid movement and evaporation should take place through the mortar. Rain water run-off over the surface is minimal

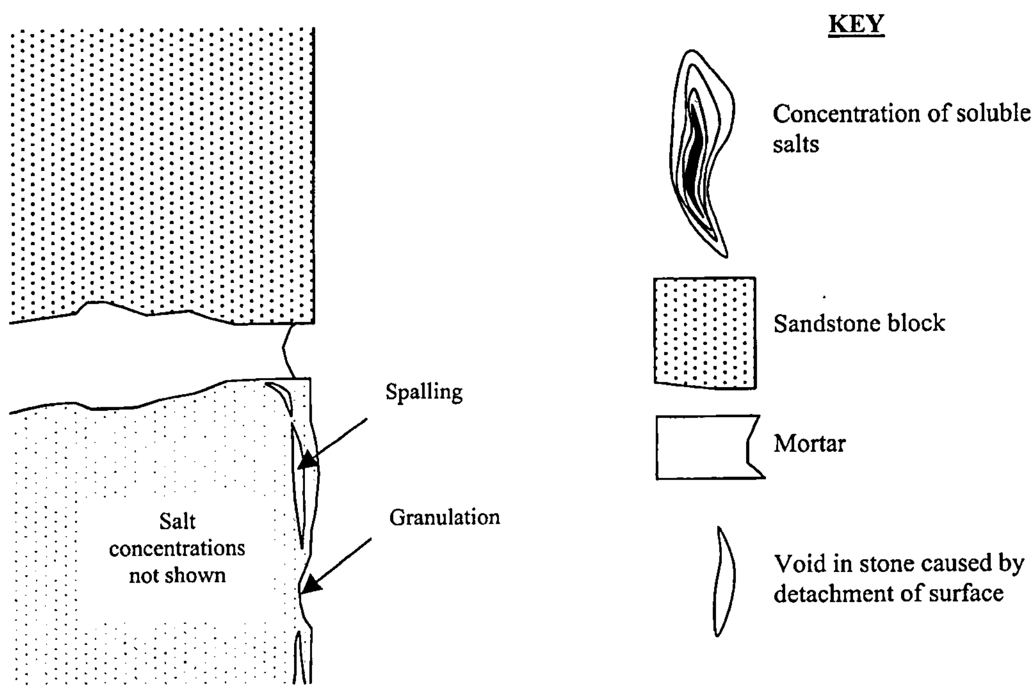


Illus 7c. Impermeable stone (e.g. granite). Fluid flow is confined to the stone surface and mortar Rain water run-off over the surface is substantial.



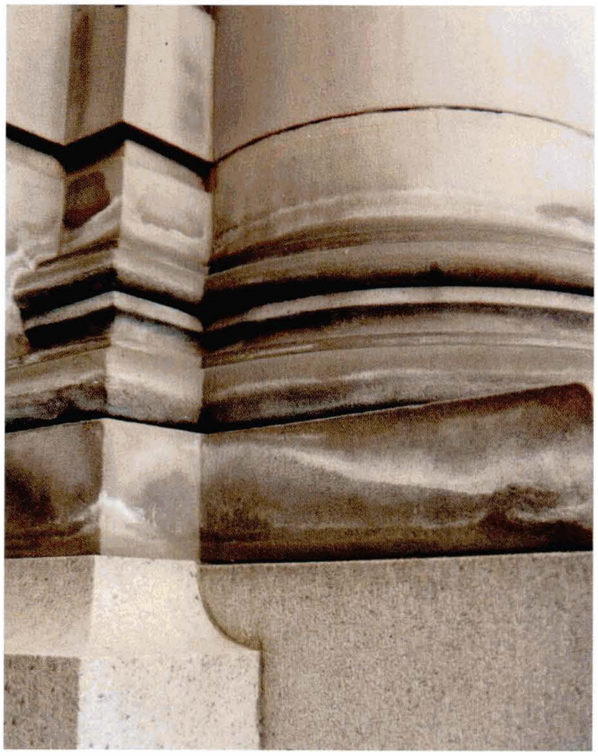
a) Following chemical cleaning, there will be soluble salt residues below the surface. Substantial concentration can lead to salt decay problems

c) Wetting and dry cycles concentrate soluble salts in particular areas as salt laden fluids are drawn to areas where evaporation rates are highest

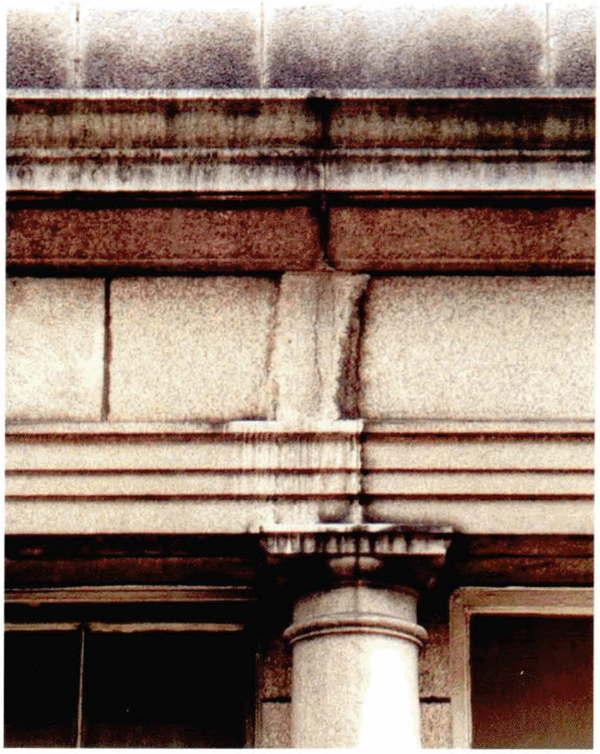


b) Salt growth and/or size changes of salt crystals on hydration-dehydration cause stone decay - e.g. granulation, spalling, flaking, etc.

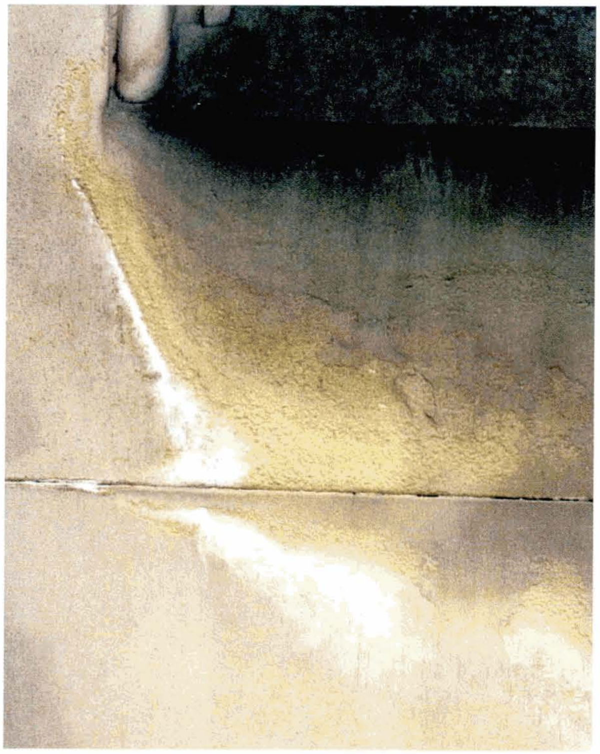
Illus 8. Model for redistribution of soluble salt residues from chemical treatment in porous stonework and development of salt related decay (not to scale).



Illus 9. Bottom loading of stones with salt caused by concentration of residues of stone cleaning chemicals. In this case a permeable stone (sandstone) sits above an impermeable stone (granite).



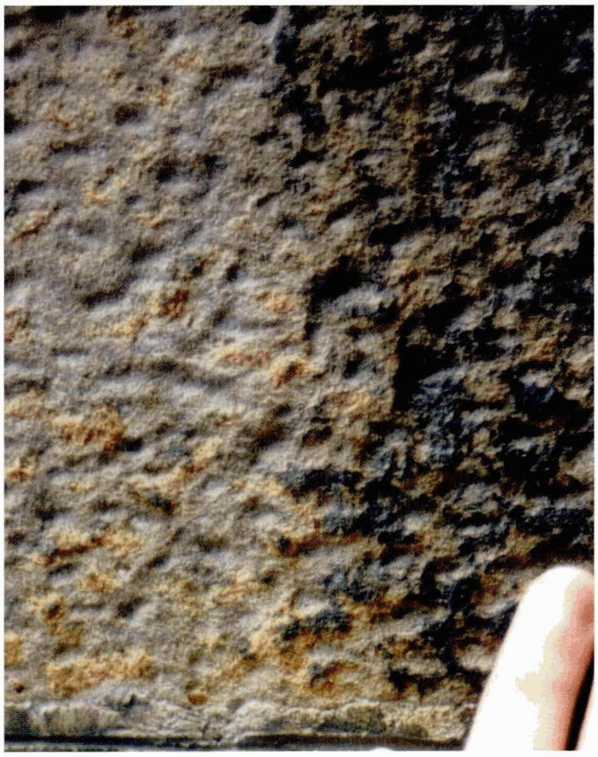
Illus 11. Salt deposition (gypsum) is commonly found at the wetting limits where run-off is channelled through open joints in a string course.



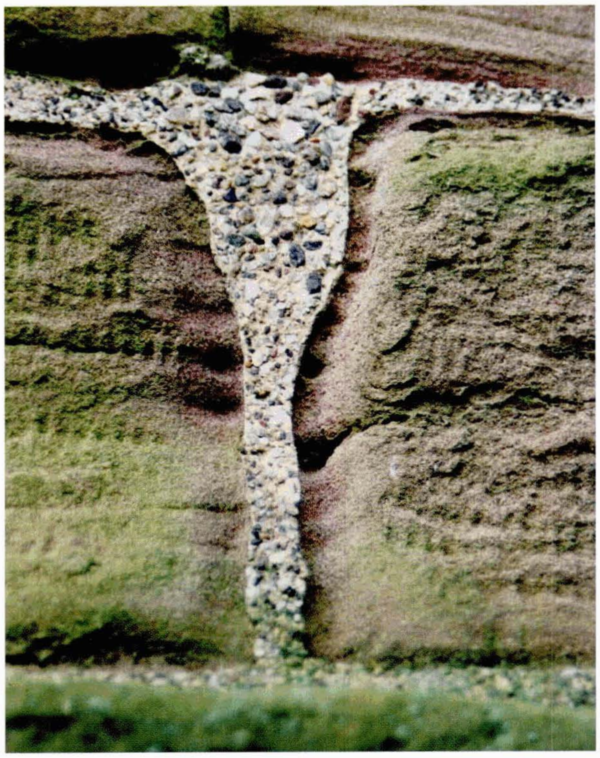
Illus 10. The 'drape' of salt efflorescence below this window is caused by run-off water concentrating salt residues from a large volume of stone within a small zone of evaporation.

Illus 12. Chemicals were retained in the open joints of this sandstone building following chemical cleaning. This resulted in the formation of salts around the joints in the weeks following cleaning.

Illus 13. Blistering of this sandstone is caused by moisture trapped against the underlying, impermeable granite.



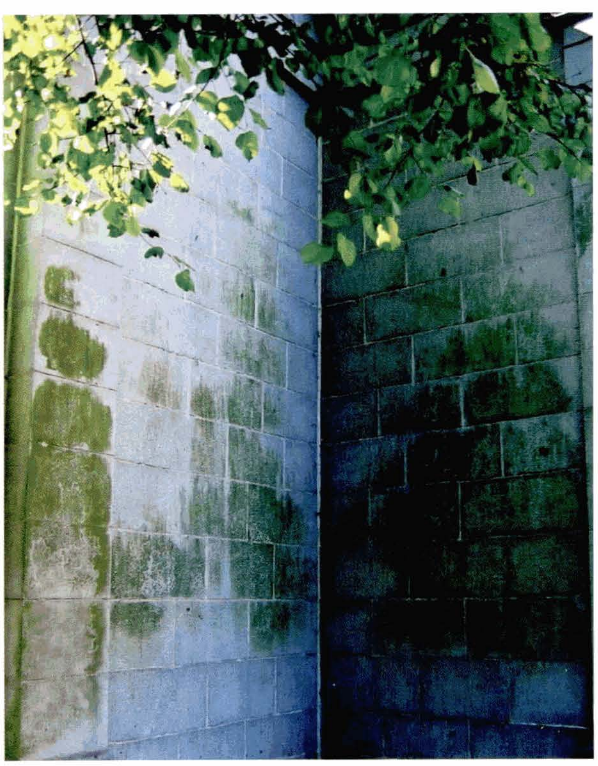
Illus 15. Patina. Patination is a natural colour change caused by surface and near-surface weathering of stone. The left side shows the orange and grey patina, the right side is soiled (black).



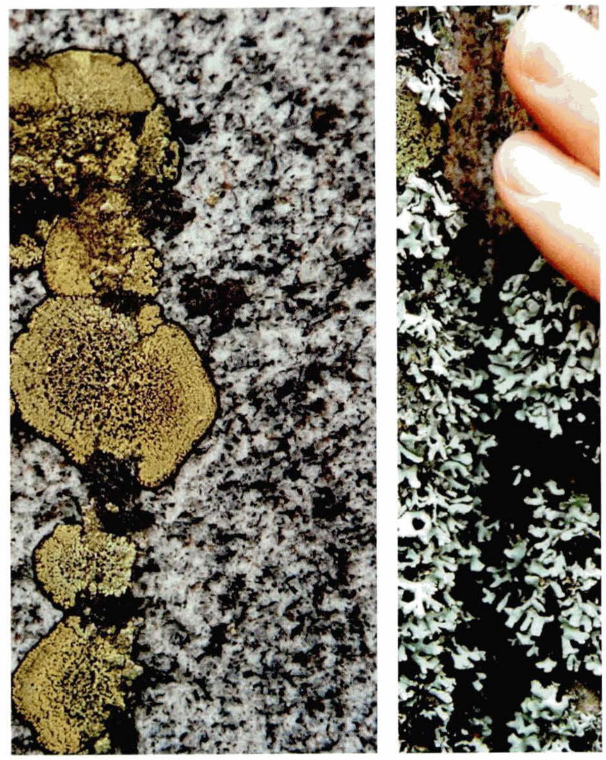
Illus 14. Decay of this sandstone around the joint is caused by the use of a mortar that is too hard and impermeable. Moisture movement is concentrated in the sandstone rather than the mortar.

Illus 16. Bird droppings are normally present on and below projecting ledges and other roosting positions. They provide nutrients for algae, lichens and other biological growths as can be seen below the alcove in the centre of the picture.

Illus 17. Particulate soiling. Thin, black or dark yellow/orange surface deposit tightly bound to the stone surface. Consisting of soot, dust, hydrocarbons, organic debris, salts, etc.



Illus 18. Algal growth. Green organic growth on a persistently damp stone surface. Some species are orange in colour and cyanobacteria (blue-green algae) are blue-green in colour. Algal growths appear black when dead.



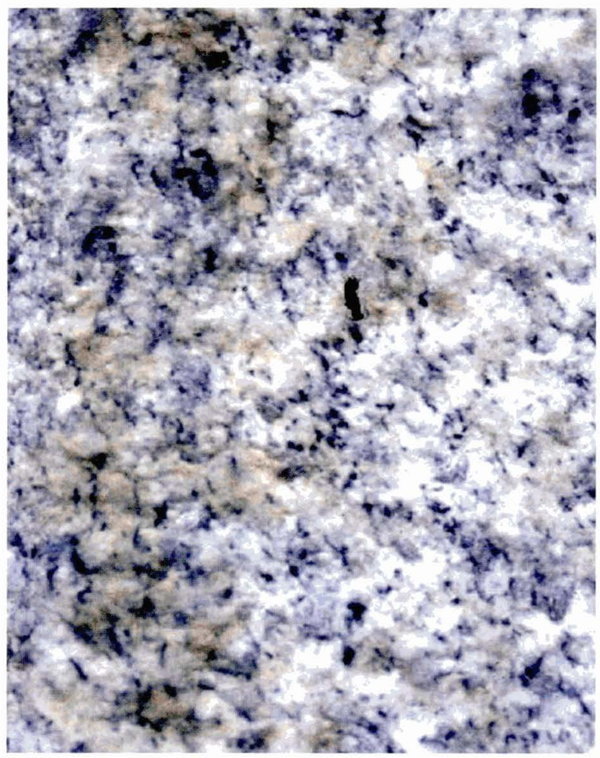
Illus 19. Lichens. Discrete crustose patches (left), coloured white, grey, orange, yellow, green or black. Many are pollution sensitive and foliose (right) or fruiticose forms occur only where pollution levels are low.

Illus 20. Salt efflorescence. Transient, superficial deposits of soluble salts, usually white or off-white in colour. Most often found at the edges of zones of water run-off or moisture retention. Salt efflorescences are often associated with stone decay.

Illus 21. Black gypsum crusts. Thick, black soiling deposits mainly composed of gypsum often occurring in a sheltered area and/or adjacent to pointing. On this granite, gypsum deposits are associated with pointing on a sheltered area wetted by an adjacent run-off zone.

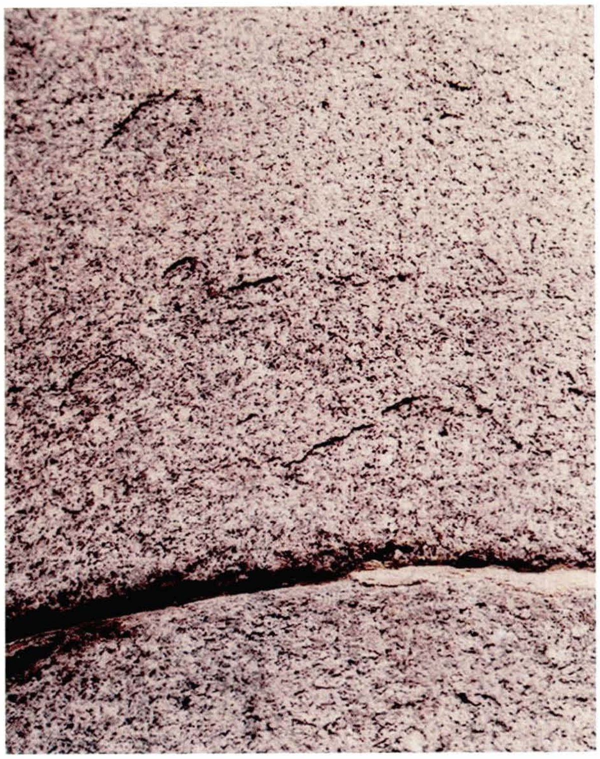
Illus 23. Staining. The façade on the right has been stained as a result of iron mobilisation caused by stone cleaning chemicals. The façade on the left has been bleached as coloured minerals have been dissolved and washed out of the surface.

Illus 22. Staining. Black and orange staining on this limestone occurs in the rainwater run-off zone below a decaying iron fixing.



Illus 24. Staining. Iron-staining of this granite has been caused by alkaline cleaning chemicals left in contact with the surface for too long.

Illus 25. Bleaching. The surface of this sandstone has been bleached by chemical cleaning. Coloured iron-bearing minerals have been dissolved and re-deposited under the surface - now visible due to superficial granulation.



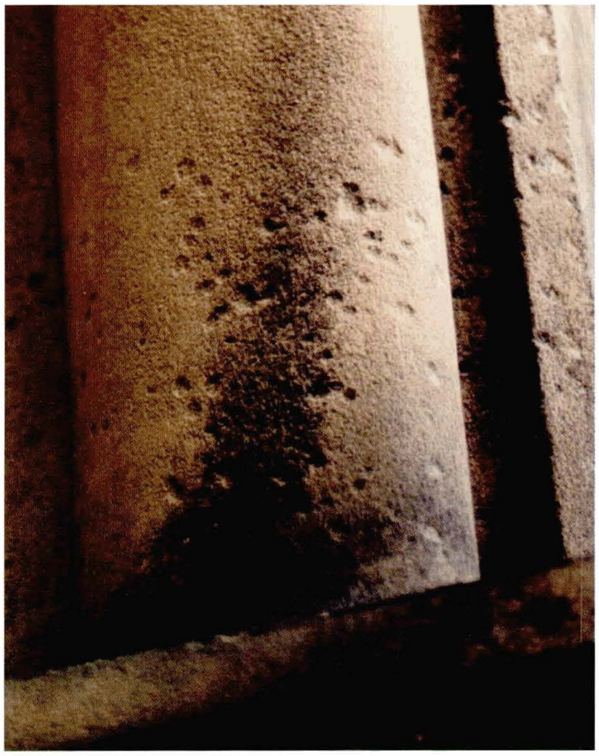
Illus 27. Flaking. Detachment of small, thin, planar elements parallel to the stone surface. This example shows flaking of a granite surface.

Illus 26. Contour scaling. The surface parallel detachment of large sheets of stone up to several millimetres in thickness as seen on the surface of this sandstone. Scaling is unrelated to bedding or other structures in the stone.

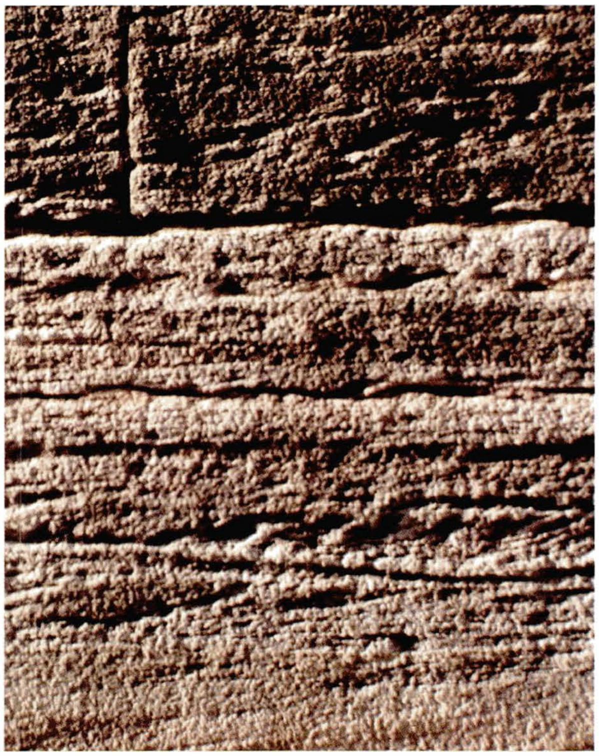
Illus 28. Blistering. Localised blistering of stone caused by expansion of a surface layer. This blistering on granite is caused by growth of gypsum crystals (black crust visible above the blister) which cause expansion and detachment of the surface layer.

Illus 29. Granular disintegration. Generalised loss of stone surface caused by detachment of individual mineral grains. Granular disintegration of this sandstone surface is caused by sub-surface crystallisation (cryptoflorescence) of salts. Crystallisation on the surface (efflorescence) can be seen below the area of decay.

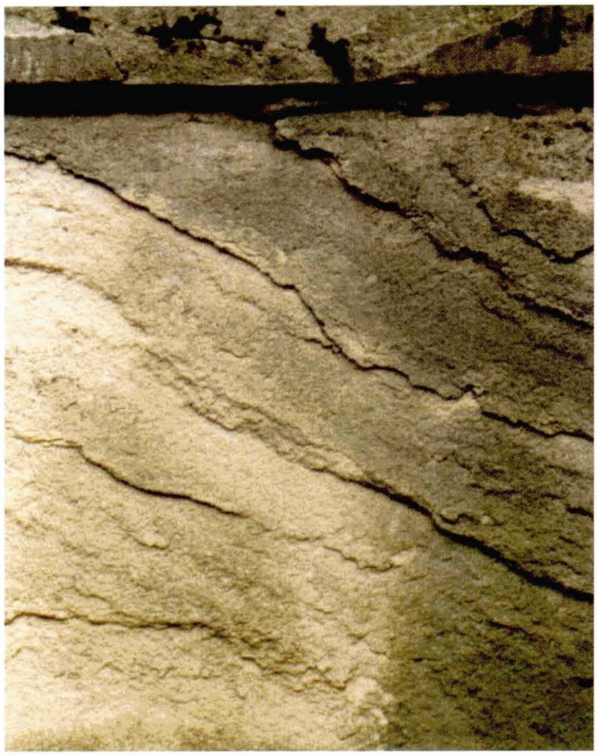
Illus 31. Decay of components. Clearly bounded zones of decay caused by the loss of elements or inclusions, e.g. clay nodules (as seen in this sandstone) or pebbles.



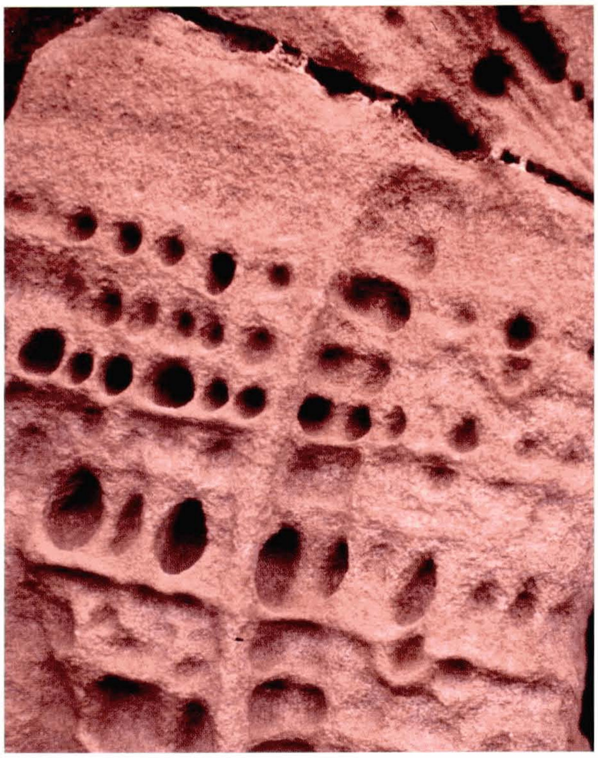
Illus 30. Pitting. Small, irregularly distributed pits on a stone surface. The pitting of this sandstone is caused by dissolution of calcite cemented patches. Being relatively weaker than the rest of the stone, such patches can also be eroded by abrasive or chemical cleaning.



Illus 32. Differential decay. Differential weathering of individual stone components due to naturally occurring variations in their vulnerability to decay. In this sandstone, some layers are weaker and more easily eroded than others.



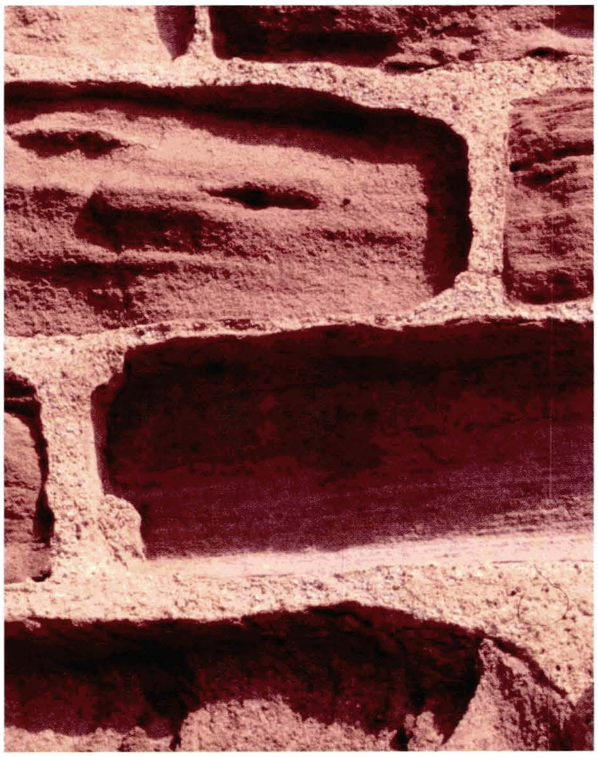
Illus 33. Delamination. Detachment of single or multiple planar sheets parallel to the natural layering or bedding of a stone. This sandstone has been face bedded and layers are now delaminating from the surface.



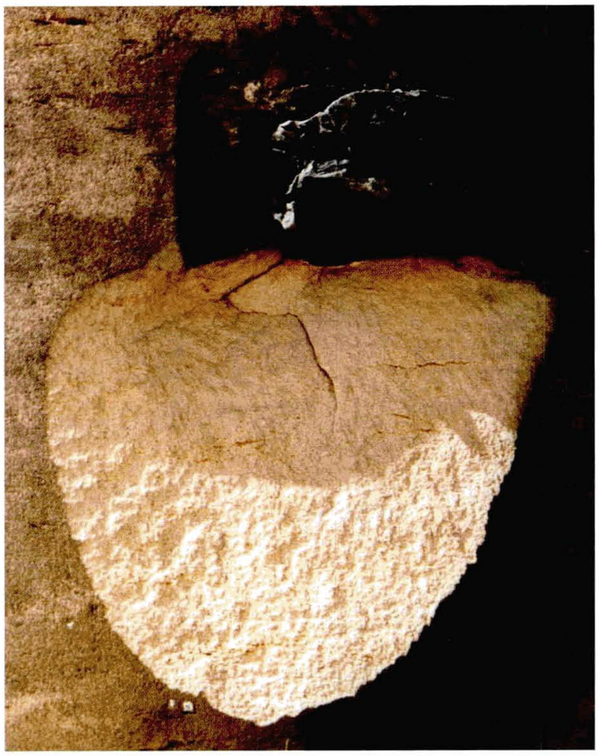
Illus 35. Honeycombing. Deep or cavernous pitting in a honeycomb pattern. Most common in coastal locations. This example shows honeycomb weathering of a sandstone.

Illus 34. Dissolution. Partial or selective dissolution of mineral grains, especially carbonates. On this marble plaque, set into sandstone, dissolution by rain water running over the upper edge has cut small gullies into the marble.

Illus 36. Case hardening. Mineral dissolution and redeposition near the stone surface results in development of a hard surface crust over a weakened stone interior. Breach of the crust often results in rapid loss of stone.

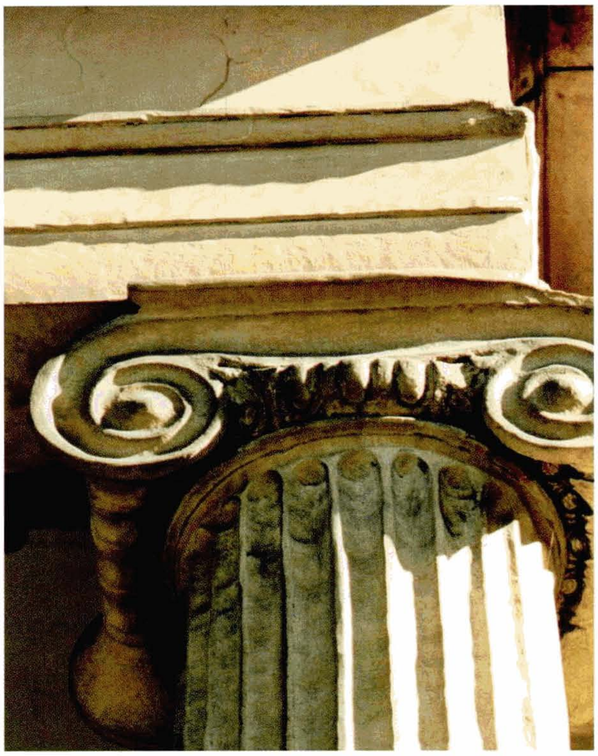


Illus 37. Back weathering. Rapid decay of single stones results in a surface where particular stones area much more deeply recessed than others.



Illus 38. Mechanical damage. Loss of compact stone fragments by fracturing. In this case oxidation and expansion of an iron fixing has caused fracturing and loss of a piece of adjacent sandstone.

Illus 39. Fissures. Lines of fracture or open cracks. Fissuring of this sandstone occurred because the stone was edge bedded and subject to relatively high stresses adjacent to a window opening.



Illus 40. Abrasion damage. General loss of surface or sharpness of detail known to have been caused by stone cleaning. On this sandstone, once smooth surfaces above the capital are visibly roughened. Originally sharp edges on the fluted column have been eroded.

3 EFFECTS OF STONE CLEANING ON THE BUILT HERITAGE

3.1 Stone cleaning methods

Development of stone cleaning

Since 1992, stone cleaning of listed buildings and unlisted buildings within conservation areas has not been deemed to be permitted development, and planning permission for such cleaning has been required from the relevant planning authority. In the case of listed structures, listed building consent is also required.

In Scotland, the amount of stone cleaning has declined from its peak during the 70s and 80s. Stone cleaning has evolved as people have become aware of deficiencies in older methods, and equipment and techniques have been refined. During the early years, methods tended to be overly aggressive. Formulations and techniques were developed for worst case scenarios resulting in over-treatment of less soiled stone. High grit blasting pressures and concentrated acids caused abrasive and chemical damage to many buildings. Problems created by past cleaning systems increasingly require to be addressed and are escalating with the passage of time. Re-cleaning of façades can compound the effects of previous over-treatment.

In recent years, with increased understanding, planning control and improved equipment, cleaning methods have become less damaging. Nevertheless, inappropriate cleaning continues to damage building façades, emphasising the need to seek expert advice and carry out adequate testing.

Avoidance of damage

This guide is not intended to provide advice on carrying out stone cleaning; nevertheless, practitioners should be aware of the basic rules of good practice for the avoidance of future damage.

Stone cleaning methods and their effects are summarised in Table 5. Inclusion in this table does not constitute a recommendation; some of these techniques can be highly damaging when used inappropriately. No cleaning method can remove soiling without some consequences for the underlying stone and the likely side effects must be taken into account when choosing an appropriate technique. Some façades may require more than one cleaning method for different stone types or conditions. Pre-testing of the chosen method (or methods) on an inconspicuous area of typically soiled stone is vital. The option not to proceed with cleaning should always be considered. Stone cleaning should always be carried out using the gentlest method that can achieve an adequate level of soiling removal. It is not necessary or advisable to attempt to remove all soiling from a façade. Some stone types and conditions are unsuitable for cleaning with any currently available techniques.

Advice on stone cleaning methods can be obtained from the following sources: Andrew et al., 1994; Ashurst, 1994; BS 8221, 2000; Urquhart et al., 1997; Webster et al., 1992. Impartial, expert advice may be obtained from local planning authorities, universities with research experience in that area and from architects with appropriate experience. The key to avoiding damage is adequate pre-testing of potential cleaning methods. As much information as possible must be obtained on the previous history of the façade, as cleaning methods may react unpredictably with existing surface treatments (e.g. previous cleaning, water repellents or plastic repairs).

Adequate pre-testing can be a significant expense, especially where sampling and laboratory tests are required. However, the investment of money in choosing a non-damaging method of cleaning will more than outweigh the long-term repair costs of inappropriate cleaning.

3.2 Undesirable effects of cleaning on facades

Stone cleaning has effects beyond the removal of superficial soiling. When carried out using inappropriate methods, aggressive cleaning can damage stone. Many of the potential effects of inappropriate cleaning (Table 6) will be visible immediately or within a few weeks of cleaning; however, there may also be longer-term consequences with respect to the aesthetic, functional and structural integrity of stone.

Method	Brief description of use	Suitable substrates	Potential harmful consequences
	Abrasive methods		
Grit blasting	70-200kPa. Grits are aluminium-silicate or other non-silica types of various sizes used wet or dry. Siliceous grit banned.	Granite, harder sandstone	Abrasive damage to surfaces, increased water uptake, loss of detail. Technical improvements and reduced pressures have lessened damage
Low pressure abrasive	<35kPa, corundum or other non-silica grits in powder form (grain size <0.2mm)	Most types	Abrasive damage to fragile surfaces, increased water uptake, loss of detail. Lower abrasion makes this less damaging than 'traditional' grit blasting
Abrasive sponge	Sponge particles containing mineral grains of varying hardness at 100-200kPa. Developed to minimise abrasion of substrate and reduce noise and dust levels	Granite, some sandstone	Abrasive damage to fragile surfaces, increased water uptake, loss of detail
Frozen CO_2	Particles of frozen carbon dioxide used at pressures of 100-200kPa. Leaves no cleaning residue. Mainly used to remove chewing gum	Granite, harder sandstone	Abrasive damage to surfaces, increased water uptake, loss of detail.
Water jetting	High pressure water jets at up to 14000 kPa. Higher pressures do not significantly improve cleaning action or residue removal and are discouraged	Limestone and marble	Abrasive damage to fragile surfaces. Ineffective cleaning of granite or sandstone
Steam cleaning	High pressure jets of steam soften and remove soiling layer. Developments include better control of steam & temp. (150°C) and lower water volumes	Limestone and marble	Damage due to abrupt heating and cooling
Mechanical cleaning	Grinding disks, needle guns and other mechanical techniques. Banned or strongly discouraged due to extreme damage	None	Severe abrasive damage to surface, total loss of detail
	Chemical methods		
Acid	HF acid (conc. usually <5%). Some formulations contain phosphoric and other acid types. Often not permitted on porous stone. Where used, concentrations and dwell times should be minimised	Most granite	Chemical residues, salt formation, increased decay, bleaching, staining
Alkali and acid	Two stage process - alkali (e.g. NaOH) then acid (e.g. HF). Often not permitted on porous stone. Where used, concentrations and dwell times should be minimised	Most granite	Chemical residues, salt formation, increased decay, bleaching, staining
Acid gel	Ammonium bifluoride gel (releases hydrofluoric acid on contact with water). Often not permitted on porous stone. Where used, concentrations and dwell times should be minimised	Most granite	Chemical residues, salt formation, increased decay, bleaching, staining
Pastes & poultices	Variable composition. Some have no additives, others may contain surfactants, complexing agents or alkalis. Those containing no damaging chemicals are effective. Those containing acids, alkalis and salts should be treated as other chemicals shown above	Dependent on formulation	Chemical residues, salt formation, increased decay, bleaching, staining
Detergents	Non-ionic detergents can increase cleaning action during water washing	Most stone types	Damage may be caused by water jetting. Non-ionic detergents leave no damaging residues in stone
Chelating agents	Facilitate cleaning by binding with soiling. Used to break down sulphate crusts and in some stain removal (e.g. EDTA)	Limestone, marble	There is a risk of surface etching of calcareous stone and of deleterious colour changes. Some treatments may not be appropriate on porous stone
Stain removers	Includes solutions and poultices containing phosphoric and oxalic acids, EDTA, Na-citrate, Na-hydrosulphite & ammonia salts	Dependent on formulation	Surface etching may occur with some treatments. Chemical residues may occur. Some treatments may not be appropriate on porous stone
	Other methods		
Laser cleaning	High intensity lasers used to ablate dark soiling from lighter coloured surfaces. Developed for marble & limestone. Soiling removal problematic on coloured stone	Limestone, marble, other stone types with care	High risk to user & public. Bleaching and unintended colour changes may occur, especially on coloured stone
Peelable coatings	Latex coating applied to surface. Soiling adheres to coating and is removed when it is peeled off. Mainly for indoor surfaces. Avoids use of water and production of dust	Limestone and marble	Loss of fragile elements

Table 5. Summary of a variety of stone cleaning methods. Listing does not constitute a recommendation of the technique as some of these methods are highly damaging when used inappropriately.

Observation	Cause	Potential long-term effects	Treatment
Erosion, loss of detail or sharpness	Ab: Excessive pressure during cleaning or water jetting	Increased moisture penetration, biological growth and stone decay	None. Only stone replacement or re-dressing (not advised) will re-establish lost detail
Pitting	Ab/Ch: Erosion or dissolution of weaker spots in stone	Mainly aesthetic effect, severe cases similar to erosion effects	None. Only stone replacement or re-dressing (not advised) will re-establish lost detail
Crusts of rock dust or grit	Ab: Debris not washed off after abrasive cleaning	Aesthetic effect. Will increase rate of resoiling	Surface should be thoroughly washed and brushed down with water
Salt efflorescences	Ch: Residues of cleaning chemicals or mobilisation of pre-existing salts	Increased rate of stone decay due to sub-surface crystallisation	Dry brushing or poulticing may reduce salt loading
Orange or yellowish staining	Ch: Mobilisation and re-deposition of iron or manganese compounds	Aesthetic effect, though it may be very intense	Stain removing chemicals may be appropriate. These may not be suitable on porous stone
Excessive lightening or bleaching	Ch: Dissolution of coloured minerals	Aesthetic effect	None. Re-soiling will not re-establish natural patina. No artificial colour can re-establish a natural appearance
Variable coloration of terraced properties	Cleaning of properties at different times and/or using different methods	Substantial aesthetic effect	None. Once a difference is established, properties will not re-soil to a uniform colour
Excessive biological growth	Ab/Ch: Roughened surfaces, increased moisture retention or residues of chemicals that provide nutrients (e.g. phosphate) for organisms	Aesthetic effect. However, some organisms can cause stone decay. Algae increase the rate of re-soiling	Removal by water washing and brushing. Biocide treatments may be useful in some circumstances
Residual soiling or uneven cleaning	Ab/Ch: Lack of care in cleaning or inadequate method	Aesthetic effect	Residual soiling is often present and may be a deliberate consequence of avoiding over-cleaning. However, where it is due to poor technique, careful re-cleaning may be possible immediately after initial cleaning, where this will not damage the stone

Table 6. Potential side effects of stone cleaning observed immediately or within weeks of cleaning, their causes, potential longer-term effects and treatments. Ab: abrasive, Ch: chemical.

3.2.1 Short term effects

Heavier soiling is often located in the same area as stone decay due to the coincidence of pollutants and moisture. Consequently, the most intense applications of stone cleaning methods are often concentrated in areas where stone may already be weakened by decay. Undesirable consequences of inappropriate or overly aggressive cleaning may include:

- erosion of the original surface, with roughening and loss of detail or sharpness;
- pitting of the stone surface;
- residual debris from abrasive cleaning such as crusts of rock dust or grit;
- salt efflorescences - soluble residues of chemical cleaning;
- orange or yellowish iron staining caused by chemical effects on minerals;
- excessive lightening or bleaching due to chemical dissolution of coloured minerals;
- variable coloration of terraced properties caused by variation in cleaning method and date;
- excessive biological growth caused by residual chemicals or surface roughening;
- uneven cleaning as a result of inadequate technique.

3.2.2 Long-term effects

When carried out by competent practitioners stone cleaning may enhance the appearance of a façade and may even reduce the long-term rate of deterioration (where soiling was contributing to stone decay). However, ill-advised stone cleaning using an inappropriate technique, or cleaning that is carried out without due care poses a high risk of long-term damage to stone. Much of the damage to stone façades as a result of stone cleaning is historical, most aggressive cleaning having been carried out in the 1970s and 1980s.

Changes in the rate of stone decay

Recent research has shown that stone cleaning can affect rates of stone decay. The time lag (several years) between cleaning and subsequent decay may obscure the link from observers of a single building façade. Stone decay takes a number years to become apparent and the separation in time between cause and effect makes it difficult to perceive an earlier cleaning episode as the cause of current decay problems. Although the causal link between cleaning and stone decay may not be obvious, comparison of a large number of cleaned and uncleaned façades has demonstrated statistically significant increases in the rate of decay of stonecleaned façades for cleaning carried out up to 30 years ago. Depending on the stone type, cleaning method and competence of the practitioner, results can vary widely - some façades have experienced substantially accelerated decay, on others there has been little or no perceptible effect. Cleaning of some façades has reduced the subsequent rate of decay. This demonstrates the necessity of adequate pre-cleaning testing. The level of stone repair or replacement required in the decades following cleaning can, in some of the worst cases, represent over 25% of the building surface (Illus 43). This is a significantly greater cost than would be incurred by even the most thorough pre-cleaning tests.

Where the rate of stone decay is increased in the years following cleaning, there are clear implications in terms of planning for future costs of stone repair or replacement. The long-term costs associated with stone cleaning (Section 6) should be taken into consideration from the start, as they should influence the decision on whether cleaning should be undertaken and the choice of cleaning method. Short-term gains in value associated with a cleaner façade may be reversed if stone repair costs in the following decades are significantly increased.

Accelerated rates of decay

Decay resulting from inappropriate cleaning of sandstone is most active in the decade after cleaning. Beyond that period, stone condition gradually re-stabilises, however, excess decay during the initial period may have already affected a large volume of stone.

Stone cleaning has the potential to cause accelerated stone decay through a variety of mechanisms:

- chemical residues cause salt related decay (e.g. spalling, granular disintegration, etc.);
- abrasion opens up porosity at the surface, increasing the intensity of wetting and drying cycles and moisture loading;
- new or enlarged micro-cracking increases the vulnerability of stone to penetration by agents of decay;
- increased surface area caused by abrasion or chemical dissolution, and nutrients from chemical residues can increase susceptibility to biological growths;
- disruption of a stable patina on a stone surface results in chemical and micro-structural changes during its re-establishment;
- mobilisation of components of mortar by cleaning chemicals can cause deposition of calcium or other potentially damaging salts in adjacent stone.

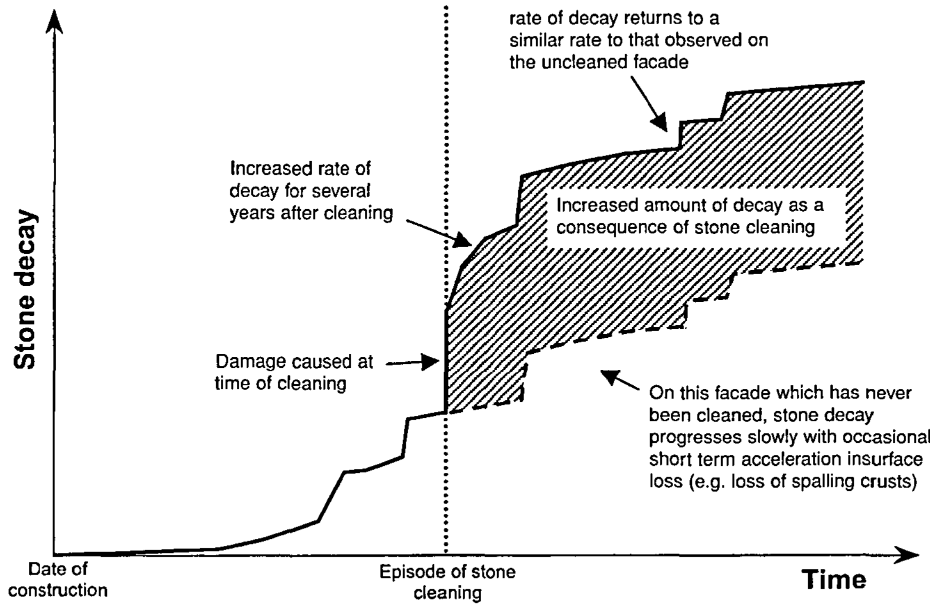
Reduced rates of decay

Stone cleaning can, in certain circumstances, be followed by a period when stone decay rates are reduced. However, façades displaying slower rates of decay following cleaning are in the minority. Mechanisms resulting in reduced decay may include the following:

- removal of damaging salts from the soiling layer at the stone surface (e.g. gypsum);
- dispersal of salts present below the stone surface and involved in salt instigated decay;
- removal of soiling that formed a hydrophobic barrier at the stone surface, thereby reducing levels of moisture within the stone;
- other interventions or maintenance carried out at the same time, including repointing or repairs to rainwater goods and functional detailing.

Duration of stone cleaning effects

The decay rates of robust stone types, including granite and the more durable sandstones, are little affected by the less aggressive stone cleaning methods. However, for many sandstones and other less durable stone types the rate of stone decay following cleaning may initially be significantly accelerated. Induced decay is at a maximum for a few years following cleaning, thereafter, the effect normally declines. This does not imply that the results of stone cleaning become negligible over time. When decay is accelerated, a significant amount of damage may accumulate within a few years and even after many years have elapsed the total amount of decay on such a façade will always be significantly greater than that on an equivalent uncleaned façade. This situation is illustrated in Illus 41 where damage caused at the time of cleaning and in a few years after cleaning is shown to result in substantially more decay on the inappropriately cleaned façade.



Illus 41. Where stone decay is accelerated for a time following cleaning, this diagram illustrates the absolute amount of decay that might be expected on a cleaned compared to an uncleaned façade.

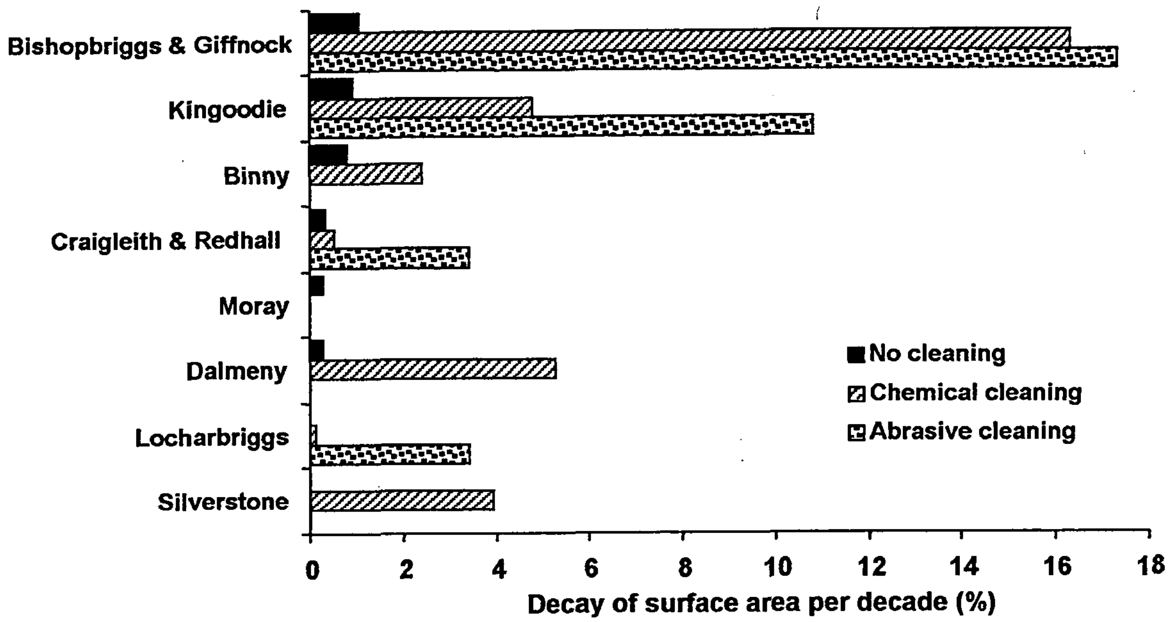
Although in some circumstances rates of stone decay may be reduced following cleaning, this should not be taken as a recommendation to clean particular stone types. The effects of stone cleaning are highly variable and it is possible to cause accelerated decay by the use of inappropriate cleaning methods on even the most resilient stone types. In addition, consideration of stone decay alone takes no account of other forms of damage that may be caused by cleaning (e.g. staining or abrasion).

The influence of stone characteristics

Under natural weathering conditions, the rate of decay of individual sandstone types can vary by at least an order of magnitude. In terms of surface coverage, the rate of spread of stone decay over uncleaned façades varies from close to zero up to about 2% decay of surface area per decade. These underlying 'natural' rates of decay can be a useful indicator of the likely response of a façade to stone cleaning as sandstones with a higher 'natural' rate of decay tended to be those most badly affected cleaning. Sandstone characteristics predisposing stone to accelerated decay included weak cements such as clays and calcite, and lower compressive strength.

Based on observations of façades cleaned over the previous thirty years, the rate of stone decay in the decade following cleaning may often be an order of magnitude greater than the rate on the equivalent uncleaned façade. Illus 42 shows some typical results from measurements of rates of decay before and after stone cleaning. On façades that were not cleaned, decay rates were variable but relatively low, however, accelerated decay was often observed on cleaned façades. The effects were more extreme on some sandstones (e.g. Bishopbriggs) than on others (e.g. Binny) and in a few instances decay rates were reduced following cleaning.

Although granite is not immune from decay there is little evidence to suggest that carefully controlled, appropriate cleaning methods cause damage or significantly accelerate decay. However, it should not be inferred that stone cleaning cannot damage granite; inappropriate cleaning has been observed to cause bleaching, staining and roughening. Poorer quality, more porous granites (e.g. weathered types) are especially vulnerable. Weathered, porous granite behaves similarly to sandstone with respect to its vulnerability to abrasion and ability to retain chemical residues.



Illus 42. Average rates of decay on sandstone façades in the decade following stone cleaning. Most sandstones decayed more rapidly after cleaning, some Binny and Moray sandstone decayed more slowly for several years following stone cleaning. Rates of decay are affected by stone type, cleaning method and the care taken during cleaning.

4 ASSESSMENT OF STONE FAÇADES

4.1 The need for assessment

Accurate assessment of the current façade condition is a necessary precursor to successful planning of repair and maintenance. It is important to establish the nature and scale of a problem before carrying out any intervention. No remedial action should be undertaken on a stone building until the extent of decay is known, the cause of decay has been identified and a suitable method for treatment or repair has been established. Intervention must address the cause of decay, not merely the symptoms and the degree of intervention should be kept to a minimum.

It can be useful to compare the condition of the building in question with other adjacent properties of the same age and design. This may help to narrow down the cause/s of deterioration.

4.2 The assessment process

The level of detail required in a condition assessment depends on the use to which the data will be put. An example pro-forma for collation of information on stone building façades is included in Appendix C. This pro-forma, which includes the facility for detailed surveys of façade condition prior to intervention (e.g. cleaning, or other treatments), may be adapted for use in particular circumstances. Some information can be collated prior to examination of a building and may require searches of historical information sources; other categories require measurement on site.

4.2.1 Previous history

Details of previous interventions (cleaning, maintenance and repair) on façades can be time consuming to locate, but may give vital clues to ongoing decay processes. Records of stone condition and details of previous interventions are an invaluable resource for assessing the outcome of alterations to a façade and in determining the long-term effectiveness of interventions. Recording the materials applied to a façade allows any potentially harmful interactions or vulnerable materials to be identified at an early stage. Previous treatments may have unforeseen interactions with subsequent treatments (Illus 43).

Illus 43. Rapid stone decay on this façade has been caused by a harmful interaction between cleaning and water repellent treatments applied to the stone.

Previous interventions may include:

- repointing,
- consolidation,
- stone replacement,
- demolitions, rebuild or extensions,
- plastic repair,
- stone cleaning,
- water washing,
- application of chemical water repellents,
- application of chemical consolidants,
- surface coatings,
- rising damp treatment.

Important information about previous interventions that should be recorded includes:

- dates of interventions,
- source of information about intervention,
- contact details for architects or contractors,
- composition of mortar mixes,
- materials used for plastic repair,
- sources of stone for repair,
- data on chemicals or abrasives used in cleaning,
- application methods of chemical treatments,
- pressures used for water or abrasive cleaning,
- any other relevant information including availability of reports, drawings or photographs.

Information on previous interventions can be difficult to obtain. Sources may include building residents, owners or agents, the local authority, architects, grant awarding bodies and library records. Listed buildings will have required planning consent for treatments considered to be an alteration of the building fabric and details will be available from the local planning authority. Many city centre façades have a cleaning history. Where contractors can be identified, they may have records of the methods used.

Where no records can be located, the façade itself and adjacent façades can provide useful clues. Abrasive cleaning methods, especially in the past, often resulted in abrasive damage to the surface finish. This damage may be observed by comparing a cleaned to an adjacent uncleaned façade. Chemically cleaned façades may exhibit bleaching or staining when compared to the natural colour of adjacent uncleaned buildings. Where a cleaned façade abuts against an uncleaned façade there can be clues at the junction. Abrasive cleaning usually leaves a diffuse border zone. Chemical cleaning leaves a sharper junction between cleaned and uncleaned, and chemical splash marks can often be observed on the uncleaned side.

4.2.2 Equipment for façade assessment

Recommended equipment for use on site includes:

- notebook,
- clipboard,
- elevation drawings or prints from photographs,
- graphite & coloured pencils,
- small ruler,
- binoculars,
- camera with a zoom and wide angle lens and the ability to take close-up photographs. Specialist lenses that allow for correction of perspective can also be useful,
- sample bags with a permanent marker pen for labelling,
- penknife (if samples of stone, soiling or efflorescences are taken for analysis),
- magnifying lens (x10),
- dropper bottle containing a solution of 10% hydrochloric acid (useful for identifying limestone or calcareous sandstone - the acid will produce bubbles of CO_2 when applied to calcareous substrates). NB. Take appropriate precautions when handling this acid.
- compass (required for measuring façade orientation),
- pocket spirit level,
- measuring tape,
- small tape recorder, Dictaphone or similar may be useful for taking notes,
- torch.

4.2.3 On-site assessment

The building survey must be undertaken by an appropriately qualified professional. A preliminary site visit may be useful to establish the general condition of a façade. Where façade elevation drawings are not available, photographs of the façade can be taken at this stage, if detailed mapping of the distribution of decay and/or soiling is required. A4 or A3 photocopied prints from photographs can be useful for recording details of façade condition. The pro-forma in Appendix C illustrates the type of information that may be usefully recorded to prioritise necessary interventions. This includes:

- general information including reference no., address, date, building age, type, use, etc.,
- stone type & condition,
- pointing type & condition,
- condition of rainwater goods,
- soiling types, intensity and distribution,
- other colour changes,
- previous interventions & their effects,
- drawings, photographs and other media used to record façade condition.

Comparisons may be usefully made with the condition of adjacent buildings, as this can reveal specific problems related to the maintenance of the property under investigation. While ground observation using binoculars can be adequate for many façades, larger or more complex buildings may require closer inspection from access points within the building, or from scaffolding or hoists. In addition to recording the occurrence of deterioration, the surveyor should attempt to determine its cause.

4.2.4 Reports and records

A report on façade condition must be prepared by an appropriately qualified professional. It should cover the following areas:

- history of the building façade including its materials and previous interventions,
- areas and materials inspected and methods used (e.g. inspection from street level or scaffolding, samples taken, methods of analysis),
- current condition of the façade (including stone decay, soiling, biological growth and defects),
- identify the causes of defects and deterioration, or suggest further investigations that may be necessary,
- recommend interventions that may be required, classifying them according to urgency:

i. immediate,

ii. urgent (within 1 year),

iii. essential (within 1-5 years),

iv. desirable (not structurally or functionally necessary at present),

(see also Davey et al., 1995)

- identify the likely outcome of interventions and make recommendations for future façade maintenance.

4.3 Assessing the evidence

4.3.1 Investigating causes and consequences of stone deterioration

The causes of stone deterioration are numerous. Problems may be related to factors intrinsic to the stone, the building design or its construction; others are caused by external factors, such as pollution, climate or inappropriate maintenance interventions interacting harmfully with the building fabric (Illus 44).

Causes of stone decay do not act in isolation. Synergistic interactions between factors can result in enhanced rates of decay. For instance, salts introduced into stone from an intervention such as chemical cleaning may become highly concentrated within a localised area of stone by water flowing through stone from a leaking gutter. Most stone deterioration is a result of interactions between a number of factors.

Stone decay is a natural process whose progress may be accelerated or retarded, but never completely halted. In some circumstances it may be possible to take preventative action to avoid deleterious future consequences for the stone. In other circumstances it may be sufficient to monitor the situation, taking action only when necessary.

On a façade that appears to be in sound or satisfactory condition there may still be factors which could cause for concern about its future condition (Table 7).

Current factors that could give rise to future problems include:

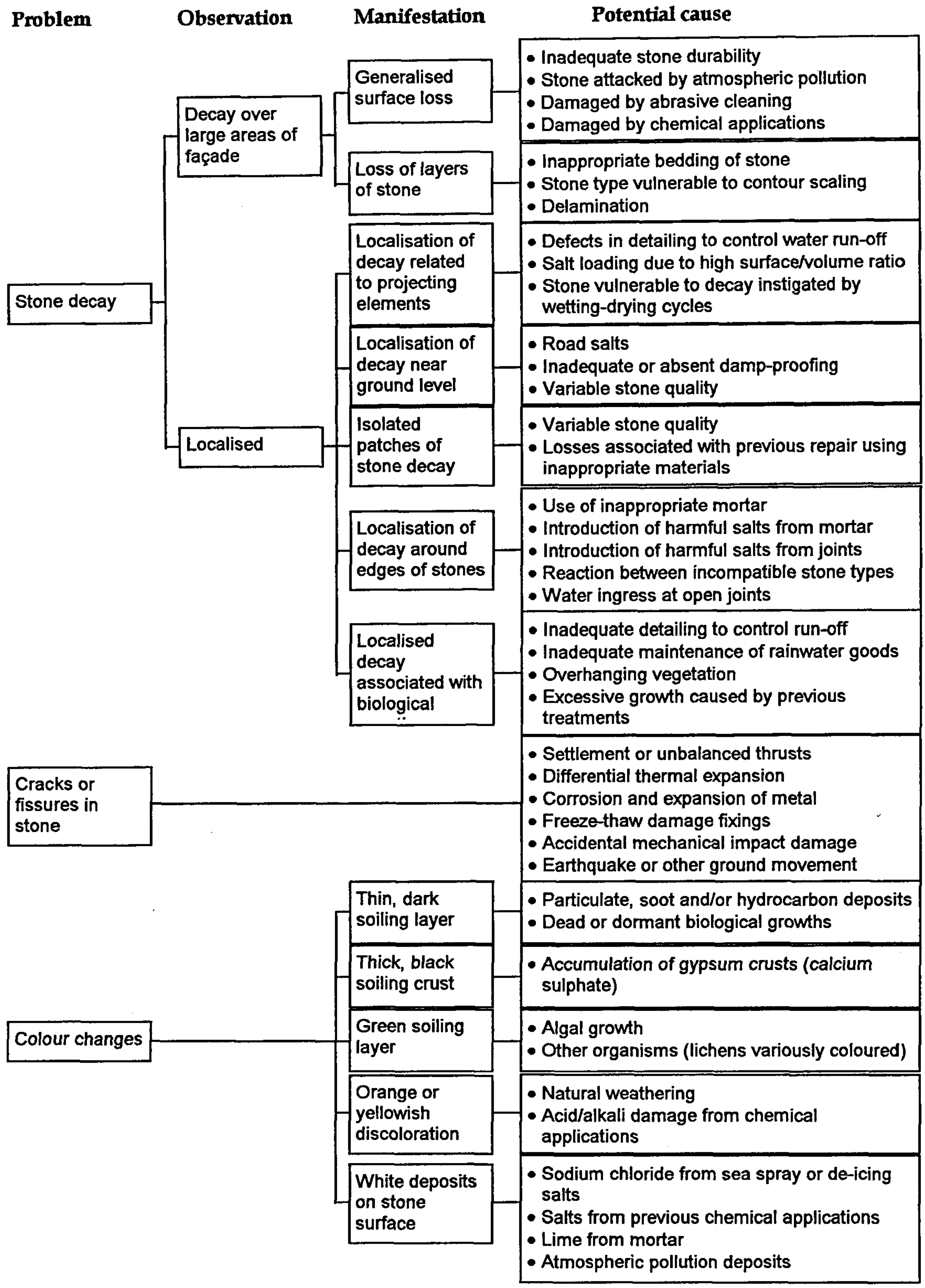
- chemical treatments with unknown long-term effects,
- incipient stone decay that may result in more rapid deterioration at a later stage,
- interfaces between different stone types where differences in chemical or physical characteristics may lead to damaging interaction,
- inappropriate mortar composition,
- inadequate maintenance or control of rain water run-off.

All building façades should be subject to regular inspection. Where there are specific causes of concern these should be flagged up for investigation during future maintenance cycles.

Although it is not possible to put precise figures on the rate of progression of stone decay, the pattern of decay moves through distinct phases (Illus 45). There are points within this progression when particular interventions may be considered appropriate. Stone decay does not become visible until a façade has been exposed to weathering for some time. During this lag

Condition	Potential future consequences	Recommended action
Salts	Subsurface crystallisation often causes decay, including granular disintegration, contour scaling & flaking.	Salt should be identified. If harmful (Table 8) then remedial measures (e.g. brushing, poulticing, etc.) may be possible.
Previous stone cleaning treatments	Abrasive damage & colour changes may occur around the time of cleaning. Long-term changes to stone decay rates may occur following cleaning.	Effects are variable & expert advice should be sought. Often there is little that can be done to reverse or halt induced decay. Colour differences are not reversible, however, iron staining may be treatable.
Previous water repellent treatment	Appropriate use reduces water penetration, but treatments can be mistakenly used where water penetration through stone is not the source of the problem. Moisture penetration problems may still be present. Long-term consequences are poorly understood. Potential effects include accelerated sub-surface decay, salt deposits & colour changes.	Stone condition should be monitored. Most water repellent treatments are irreversible, but some are removable with appropriate solvents. Combination of water repellents with other chemical treatments risks leaving damaging chemical residues below the stone surface.
Previous chemical consolidant treatment	Treatment can stabilise a decayed surface & reduces the rate of decay. Some treatments have water repellent properties. Long-term consequences are poorly understood. Potential effects include accelerated sub-surface decay, salt deposits & colour changes.	Stone condition should be monitored. Most treatments are irreversible. Combination of consolidant treatments with water repellents properties with other chemical treatments risks leaving damaging chemical residues below the stone surface.
Incipient stone decay more	Rate of progression varies greatly depending on stone type & environment. Stone decay is inevitable and observation of its early stages is not necessarily a cause for concern unless there are grounds to expect rapid progression. Stone decay is cumulative but often sporadic.	Stone condition should be monitored. Timely replacement or repair of affected stones will reduce long-term maintenance costs, but unnecessarily aggressive interventions can do harm than good.
Interfaces between different stone types	Harmful interactions may occur between incompatible stones. Where porous stone sandstone) overlies impermeable stone (e.g. granite), trapped moisture may induce decay in the less (e.g. durable stone. Limestone can introduce harmful calcium salts into adjacent stone.	Stones chosen for repair must be compatible with existing stones in their porosity, chemistry & durability. If a harmful interaction is suspected then the source of the problem should be identified and, where practical, treated. Stone replacement may be one option.
Hard mortar	Stone decay adjacent to joints may occur if pointing mortar is too hard & reduces or prevents normal evaporation of moisture through joints.	Replace with a softer, more permeable mortar unless removal of existing mortar would cause unacceptable damage.
Biocides	Short term (few months) colour changes or salt efflorescences can occur with some treatments.	Discontinue treatment & monitor condition if damaging effects are suspected. Most colour changes caused by biocides are temporary.
Inadequate control of run-off	Increased biological growth, salt mobilisation & concentration, staining & accelerated stone decay will eventually result.	Alteration or replacement of damaged functional details may be considered. Water repellents may be useful to control biological growths or soiling on sloping surfaces.

Table 7. Situations in which there may be grounds for concern about the future condition of stone.



Illus 44 Flow diagram for identification of potential causes of stone deterioration.

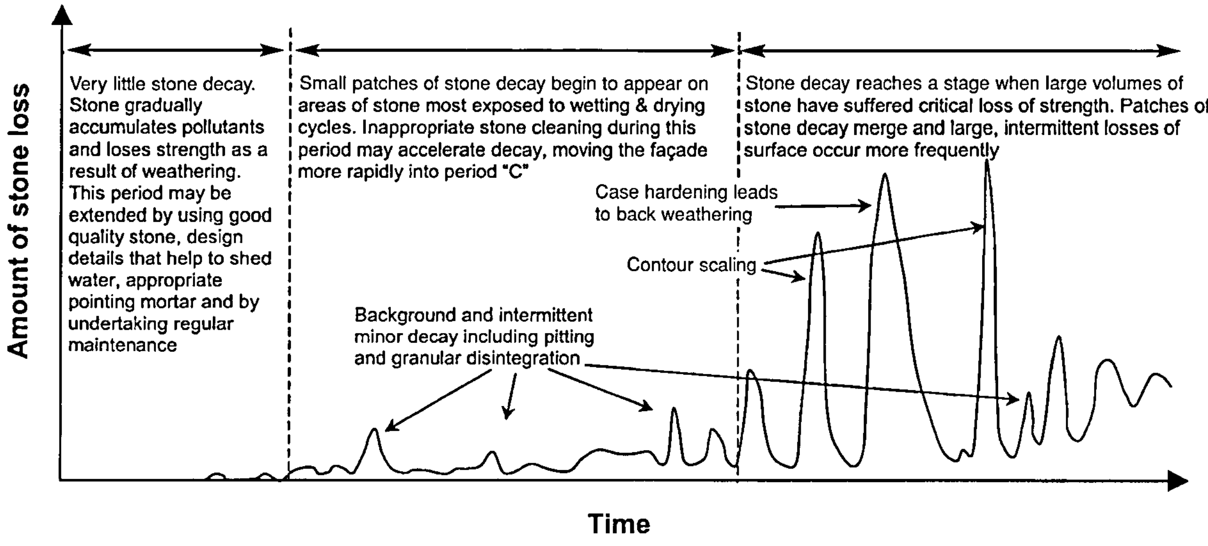
time the stone is building up a reservoir of pollutants and microscopic damage. Eventually, the bonding between mineral grains will break down in the worst affected areas and damage will become visible. The form of damage depends on the stone characteristics, its environment and the forces acting upon it. The effect on the stone may be as slight as loss of individual sand grains or as substantial as fissuring of a whole block. Some forms of decay progress gradually (e.g. granular disintegration), others are discontinuous with periods when the stone surface appears to be stable interspersed with sudden losses (e.g. case hardening). Others forms of decay (e.g. pitting) are self-limiting processes and will not advance beyond a particular stage. Decay that is caused by external factors can spread to cover wide areas of stone, but where decay is caused by weakness in particular stones or elements it may affect only single stones or parts of stones.

While our understanding of the mechanisms of stone decay is fairly well advanced, data on rates of decay are sparse. Decay that is self-limiting in its extent causes the fewest problems. Self-limiting forms of decay occur where deterioration is restricted to particular elements of stone such as vulnerable areas or particular components. The most damaging forms of decay are those that progress most rapidly in both surface coverage and depth.

Estimating the rate of future stone decay is no simple task given the multitude of interacting factors on a building façade. Some stone types (Illus 42) are particularly prone to decay - risk factors are illustrated in Table 12, Section 6. The age of a building and the current surface coverage of stone decay can provide a rough estimate of the rate of progression, bearing in mind that stone decay is usually a discontinuous process and that decay rates may accelerate as the stone condition deteriorates. If the building has previously undergone some form of intervention that should have left the stone in a sound condition (e.g. stone cleaning, indenting, plastic repair) then active decay on the surface must have occurred since that event. However, affected areas do not necessarily represent 'new' areas of decay, since visible stone decay is the end stage of many years of cumulative damage.

It is useful to compare the condition of the property with that of surrounding similar buildings as these can provide clues. Is there any association between facing direction and stone decay? Are cleaned or uncleaned buildings more prone to decay? Does the stone react badly to the presence of plastic repairs? Is there any evidence of deterioration around joints that may be due to the type of pointing mortar used?

It is important to distinguish between superficial decay, which is mainly an aesthetic concern, and decay that affects a greater depth of stone or more critical areas. Stone decay seldom progresses so far as to be a structural problem, but deterioration of functional elements can adversely affect the ability of a façade to deal with water shedding, resulting in accelerating rates of decay and potential problems with water penetration. It is therefore particularly important to pay attention to functional elements when assessing the condition of a property.



Illus 45. Theoretical progression of stone decay throughout the lifetime of a façade. NB Forms of decay shown are for illustration only and may vary in type and intensity depending on stone type.

Some situations may require more in-depth investigation to clarify the source of a problem, to investigate implications for the future behaviour of stone or to recommend interventions or treatments. Sometimes laboratory analysis (Appendix B) can be useful for pinpointing the cause of decay. Potential structural failures require investigation by a structural engineer. Some forms of analysis are non-destructive or require only small or superficial sampling, but samples may also be required for destructive analysis such as extraction of stone cores (e.g. analysis of water repellent treatment) or powdered drilling samples (e.g. depth profiling of soluble salts). Samples should be taken from representative material, but it may be possible to sample stones which are scheduled for removal, repair or replacement. Otherwise, inconspicuous areas should be chosen for sampling. Sections of stone cores should be retained to plug holes after coring.

4.3.2 Previous interventions that may affect stone deterioration

Previous stone cleaning

The potential immediate and longer-term effects of stone cleaning were identified in Section 3. Decay induced by cleaning will often be noticeable by comparison with nearby uncleaned buildings in the same stone and style. Care should be taken to distinguish active stone decay from damage (e.g. abrasion) caused at the time of cleaning.

Biocides

Biocides are used to control or prevent the growth of organisms on stone surfaces. A wide variety of chemicals have been used in biocides including inorganic substances (e.g. borate, copper, tin) and organic treatments (e.g. quaternary ammonium salts and amines). Chemicals that are now banned, but may have been used previously include tin and mercury compounds.

Biocides could have unforeseen deleterious interactions with other chemical treatments. Few biocide treatments are effective for more than one or two years and chemical residues are likely to be present in only very small amounts. There is little evidence that biocide treatments can affect the rate of stone decay although some have pHs such that they are significantly acidic or alkaline and this may be a cause for concern. Some cause slight (usually temporary) colour changes. Because of their potential side effects, biocides should not be applied to stone without adequate testing. A guide to control of biological growths on stone surfaces is available in this series of Technical Advice Notes (Cameron et al., 1997).

The low concentration and complex nature of many biocidal compounds makes their identification in stone difficult and expensive. Analysis for these compounds is not recommended unless there is specific reason to suspect their involvement in decay or alteration of stone.

Chemical water repellents

Chemical water repellents may have been previously applied on façades where there has been a problem with water penetration, especially if there are substantial areas of the façade with upwards-facing sloping surfaces. On sloping surfaces water repellents are useful for reducing moisture loading of the stone, subsequent biological colonisation and water penetration of the building fabric. On most vertical façades water repellents would not solve moisture penetration problems which are likely to be caused by building defects or inadequate maintenance of gutters or downpipes. Water repellents that are applied in inappropriate situations can accelerate stone decay by trapping within the stone, fluids that have penetrated the building fabric through existing defects.

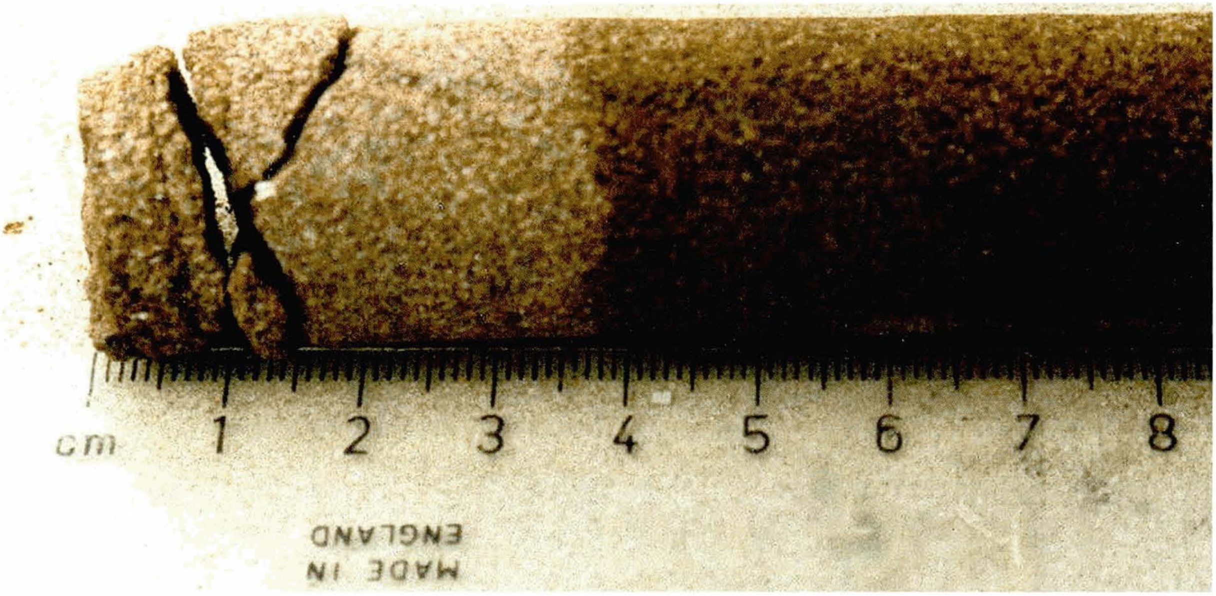
The long-term effects of water repellent treatments are poorly understood. Regular inspection of treated areas for changes in appearance or structural condition is advisable. Localised efflorescences, especially of gypsum, are an occasional side effect of some treatments.

Water repellent use on surfaces may be detectable by its water repellent effect. Where this effect is less pronounced, water repellency may be visually observed in core samples by wetting the sample and seeing the depth at which the stone changes colour by absorbing water. Water repellency can also be measured by laboratory testing in which the time for absorption of water droplets is measured at various depths along a core sample.

Chemical consolidants

Consolidants are used to stabilise decaying stone surfaces. They are intended to perform a similar function to natural cements in sandstone and help to bind grains together. In addition to this cementing effect, some consolidants also have water repellent properties. Similarly to water repellents, the long-term effects of consolidants are poorly understood and regular inspection of treated areas for efflorescence and other changes in appearance or structural condition is advisable.

Chemical consolidants are difficult to detect in stone as they form very thin surface coatings that bind tightly to mineral surfaces. Some treatments are moderately water repellent and this may be used to detect their



Illus 46. The depth of penetration of water repellent into this sandstone can be determined by wetting the core sample and observing the depth at which the sandstone absorbs water. In this case the water repellent treatment has penetrated to about 36mm depth.

presence (see above). Consolidants with no water repellent properties require more complex analytical techniques appropriate to the particular treatment (e.g. location by measurement of changes in ultrasonic velocity) (Appendix B).

4.3.3 Issues that may cause concern

Soluble salts

Efflorescence at the stone surface is a transient feature, occurring at times when rates of supply and evaporation of water from the stone allow crystallisation of salts at the surface. Although superficial efflorescences are unsightly they do not cause stone decay. Damage occurs when salts crystallise inside stone since pressures can build up which lead to breakdown of the stone structure. Salt deposits on a stone surface are however a sign of excessive salt loading in the body of the stone or mortar and are often accompanied by localised decay on or adjacent to the efflorescence (Illus 20). The effects of salts vary. Stone cleaning residues that include sodium salts are often particularly damaging, as are road salt and sea salt. Road salt leaves residues of sodium chloride, calcium carbonate is likely to be derived from lime in mortar, calcium sulphate (gypsum) is common on building stone and is formed by reaction between sulphates in atmospheric pollutants and calcium from mortar. Other sodium salts, fluorides or phosphates may be derived from residues of stone cleaning chemicals. Sodium sulphate and sodium chloride are particularly damaging salts in terms of their effects in accelerating rates of stone decay.

Salts efflorescences mainly occur on porous stone (e.g. sandstone). Stone types with very low porosity (e.g. granite) cannot retain sufficient salts to develop efflorescences derived from the interior, although superficial deposits may occur from localised sources (e.g. road salts). Many salts are highly mobile within porous stones and tend to be concentrated within particular areas by fluid flow through the stone. The general tendency is for salts to move down through the stone as fluids flow under gravity (Illus 9), concentrating salts at lower levels of the façade or above less permeable materials (e.g. a harder mortar or a less porous stone). Common areas for efflorescences are sheltered zones adjacent to stone that intercepts relatively large volumes of rainwater. This includes the area immediately below windows, below cornices and the area surrounding projecting stone elements.

The likely source and potential consequences of salt efflorescences can be determined by analysis. Identification of efflorescent salts is normally done by X-ray diffraction. This requires a sample of a small amount of salt. A sample of a few grams is ideal, but smaller amounts can also be analysed. It is possible to obtain depth profiles of soluble salt concentrations within stone by dry coring or by taking drilled rock powder samples from various depths. Soluble salts can be extracted from the powder and analysed giving a profile showing salt concentration within the stone.

Salt	Source & known effects
Calcium carbonate	Present in mortar, limestone, marble and some sandstone. Also used in some abrasive cleaning systems. Superficial deposits are caused by wash out from mortar. Not normally a cause of decay unless it reacts with sulphates.
Calcium sulphate (gypsum)	From reaction between sulphates (in atmospheric pollution) and calcium from mortar or stone. Forms black, encrusted soiling that may exacerbate stone decay.
Sodium chloride (common salt)	From sea spray and de-icing salts. Implicated in honeycomb weathering and other forms of decay. Accelerates stone decay, particularly in combination with other salt types.
Sodium sulphate	On some chemically cleaned façades this salt is formed by reaction between alkalis (sodium hydroxide) and sulphate in the soiling layer. Causes rapid decay of many porous stones by granular disintegration, scaling or flaking.
Magnesium sulphate (Epsom salt)	From reaction between sulphates (in atmospheric pollution) and magnesium from dolomitic limestone or sandstone. May be involved in some forms of stone decay.
Sodium carbonate (washing soda)	Sodium carbonate is used in some abrasive cleaning systems. In this form it is not known cause stone decay.

Table 8. Some of the more common salts and their known effects on masonry. A variety of other less common salt types may be derived from atmospheric and ground water pollution, sea spray, mortar or adjacent building materials. The effects of mixtures of salt types may be more damaging than that of single salts.

Biological growths

Biological growths may be unsightly, but are often relatively benign on stone surfaces. Algae seldom cause any problems. Lichens occasionally cause localised decay, but this is slow to progress. Woody plants can cause extensive damage by penetration of joints and cracks, leading to structural instability.

Contour scaling

This form of decay (Illus 26) can progress rapidly on stone surfaces. In its early stages the only outward manifestation may be thin lines of cracking around joints. At a later stage small patches of surface may be lost around the joint. By this stage the scaling is likely to have weakened a surface layer across much or all of the affected stone. The detaching surface may bulge slightly and sound hollow when tapped. Stone underlying the scale is often deteriorated and rapid decay is likely after the scaling surface is lost. On some clay-rich sandstone types, multiple scales may form. Provided the surface is not disturbed it may be possible to stabilise scales by application of a suitable consolidant. Otherwise repair or replacement of the affected stone will be necessary.

Case hardening

Mineral dissolution and redeposition near a stone surface results in development of a hardened surface crust over a weakened stone interior (Illus 36). The stone may appear sound until the crust is breached after which rapid loss of the weakened stone below the crust is likely to occur. This form of decay is most common on calcareous sandstone.

Back weathering

This is a form of decay (Illus 37) in which single stones are eroded to a much greater depth that surrounding stones. This form of decay may occur rapidly after a prolonged period of relatively slow decay (e.g. case hardening or contour scaling) and could lead to structural instability. Its presence on a few stones on a façade should be assumed to signify that other vulnerable stones might be present. Regular monitoring of such façades is advised.

Calcareous stone in contact with other stone types

Calcareous stone types, including limestone and some sandstone release calcium salts when they are wetted and when they react with atmospheric pollutants. These salts can be transported into surrounding (often lower) stones by rainwater run-off or moisture migration. On non-calcareous stone types (e.g. granite and some sandstone) this can cause accelerated stone decay adjacent to the calcareous stone.

Porous stone in contact with less porous stone

Where porous stone overlies a less porous stone, downward moisture movement is likely to be restricted and decay may occur in the porous stone adjacent to the contact.

Localised concentration of water run-off

Stone decay is most common around the wetting limits of run-off concentrations on façades, as these are areas where the rate of change from wet to dry is most rapid and most common, and where salts tend to become concentrated by evaporation close to the stone surface.

Hard cement mortars

Where pointing is of an inappropriately hard mortar, decay of the adjacent stone is very likely to occur due to diversion of moisture flow from the less porous mortar into the more porous stone.

Illus 47. Enhanced widespread decay on this Glasgow tenement resulting from severely abrasive stonecleaning.

5 MAINTENANCE AND REPAIR ISSUES

5.1 Legislation

Since 1992, a proposal to stone clean a listed building has required listed building consent because of the danger of causing irreversible damage or unacceptable changes to the external character or quality of a building. Unfortunately, this legislation was introduced too late to exercise control over the cleaning of the stonework of a large number of listed buildings. Before carrying out any work on the façade of a listed building owners and practitioners should recognise the requirements of the Planning (Listed Buildings and Conservation Areas) (Scotland) Act 1997. Stone cleaning of buildings within conservation areas requires prior planning permission; listed buildings in any area also require listed building consent. Planning permission may also be required for works on unlisted buildings where radical changes in their external appearance are proposed.

The routine repair of a listed building does not require listed building consent where proposed works are of a minor nature and will replicate in all aspects what is to be repaired. However, there are a number of possible interventions that might be employed to deal with the damage caused or exacerbated by stone cleaning which themselves may pose an additional risk to the stone work of the façade and may be considered to be a material alteration. In such cases, listed building consent may be required and early consultation with the planning authority is strongly advised. Interventions to stone façades that may require listed building consent are listed below. Further guidance is available in the Memorandum of Guidance on Listed Buildings and Conservation Areas (Historic Scotland, 1998).

- surface repair with mortars ('plastic' repairs),
- painting façades,
- harling or rendering,
- stone indenting,
- redressing stonework,
- rebuilding,
- stone cleaning.

It is the case, however, that many of the stone façades that have been affected by poorly executed stone cleaning are not subject to listed building control. Nevertheless, these buildings, including many of the stone tenements of our cities, form an important part of the built heritage, and poorly planned and executed repairs will have an adverse effect on this heritage. Proposed interventions to the stone work of these buildings should therefore follow the guiding principles of the Memorandum in the approach to repairs to decayed, or otherwise damaged stone work. In some cases, planning permission for repairs to unlisted buildings may be required where the planning authority considers that the proposed works could fundamentally affect the appearance of a façade.

5.2 Conservation charters

Because of the damaging effects of past stone cleaning, which has resulted in the erosion of ashlar stonework on many buildings, there is a need to consider the conservation implications that arise. Of course, not all masonry surfaces fall within the scope of conservation charters, but a very considerable proportion is so covered; the stone work of the Edinburgh New Town, as a World Heritage site, being a case in point. The tenets of the appropriate conservation charters, particularly the Stirling Charter in the case of Scottish sites, should direct policy in reaching decisions for dealing with the consequences of stone cleaning.

In dealing with damaged stonework, the principal conservation issues that must be recognised are as follows:

1. Incur only the minimum degree of intervention considered appropriate (The Stirling Charter 2000).

2. Use appropriate materials, skills and methods of working (The Stirling Charter 2000).

3. The work should be carried out in accordance with a conservation plan, which brings together all of the information and research necessary to guide the proposed action. (The Stirling Charter 2000).

4. Materials and techniques should respect traditional practice (various charters).

5. The (architectural) heritage is in danger. Urban planning can be destructive when authorities yield too readily to economic pressures. Misapplied contemporary technology and ill-considered

restoration may be disastrous to old structures (European Charter of the Architectural Heritage, Council of Europe 1975).

6. From the Historic Scotland Guide to International Conservation Charters (Bell, 1997) the following extract is relevant.

The use of modern substitute materials is appropriate only when:

- they provide a significant advantage that can be identified,
- their use has a firm scientific basis and
- has been supported by a body of experience,
- the new material is compatible with the expression, appearance, texture and form of the original.

7. The Burra Charter (1992) advises that reconstruction is limited to the completion of a depleted entity and should not constitute the majority of the fabric of the place (Article 18). In this context it offers the example of the erosion of ashlar stonework that has damaged the aesthetic quality of a building. This is seen to be a depleted entity and the aesthetic significance of the building would be revealed by replacing damaged stone blocks with new material of the original dimensions and profiles (Illus 64).

5.3 Routine maintenance

Regular façade maintenance can reduce the requirements for repair. In the long term, problems that are neglected are likely to cost more to put right, as small defects or localised decay will gradually spread to affect a larger volume of stone. Although regular maintenance and repair are vital to the well-being of a building, inappropriate interventions can be harmful. Building owners should avoid unnecessary or overly aggressive remedies for 'problems' that may be non-existent (e.g. stone cleaning of a relatively clean property), where the cause is undiagnosed (e.g. water repellent treatment for moisture penetration) or where the cure may cause more damage than the condition (e.g. low quality plastic repair to superficial decay).

Regular four or five yearly inspection and maintenance programmes are carried out on many historic buildings. Routine, seasonal and annual inspection is also advisable to prevent problems arising. Specific guidance on routine inspection and maintenance can be obtained from the British Standard guide, BS 7913:1998 and from the Maintenance Manual for Edinburgh New Town (Davey et al., 1995). A thorough analysis of the façade condition should enable a programme to be drawn up that identifies problems requiring immediate treatment and problems whose treatment is less crucial. Issues that do not required immediate intervention can be placed within a planned maintenance programme, allowing them to be addressed as finances permit. As a general guide, the following maintenance schedule would be appropriate with respect to the stone work of many building exteriors:

6-12 monthly:

- roof (inspect for missing/damaged slates),
- gutters (keep clear of debris, check for leaks),
- downpipes (check for blockages),
- walls (inspect for damp penetration).

5-yearly:

- inspection and report on condition or stone and pointing,
- prepare repair schedule as necessary.

It is advisable to seek professional guidance with respect to reporting on building condition. Where the building concerned is a historic property it is desirable to seek the advice of an architect, building surveyor or a consultant who specialises in conservation of historic buildings. An architect will also be able to oversee repairs, advising on the need for other consultants, recommending suitable contractors, obtaining estimates of repair costs, arranging for tenders and supervising the work. The architect should also have knowledge of grants, which may be available to help with repair costs. Some grants are only available on condition that conservation professionals are employed.

Preventative measures to reduce future stone deterioration not only preserve as much as possible of the original building fabric, but are clearly more cost effective in the long-term than large-scale repair and replacement of decayed stone (Section 6). Preventative intervention should ideally take place as part of a planned façade maintenance strategy designed to ensure façade performance.

An effective maintenance programme should contain the following elements:

1. Regular inspection of the building fabric.

2. Monitor deterioration to gauge the rate of decay and intervene only when necessary.

3. Undertake repointing where necessary to prevent structural instability or moisture penetration.

4. Maintain roof covering, gutters, downpipes, lead flashings and other weathering preventative details to ensure rapid water shedding.

5. Maintain functional elements of stonework to ensure rapid water shedding.

6. Remove plant growth where this is likely to cause harm to the building fabric.

7. Repair or replace structural failures in stones (e.g. cracks and fissures).

Appropriate and timely repairs to a façade should reduce the rate of stone decay in the long-term; however inappropriate interventions can accelerate decay processes. It is therefore essential that the cause or causes of stone deterioration are understood before remedial action is undertaken. While regular maintenance should enhance the life span of a building, excessive levels of intervention could be harmful. Damage that may result from excessive intervention includes:

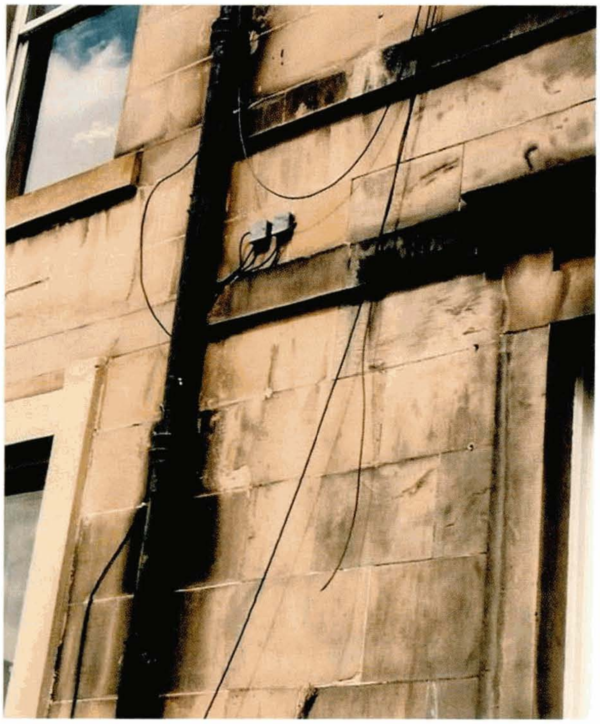
- unnecessary repairs to stones where decay presents no immediate functional or structural threat,
- loss of sharpness or detail,
- loss of historically or culturally important surfaces,
- damage to stone during raking out of pointing,
- mechanical damage during scaffolding erection and dismantling,
- cumulative damage from multiple episodes of stone cleaning,
- chemical loading of stone from repeated chemical treatments (e.g. stone cleaning, biocides, water repellents, chemical consolidants) or where there is a large surface to volume ratio.

Decay may affect a façade aesthetically, functionally or structurally. Aesthetic effects, including soiling, colour changes and biological growths, may be considered disfiguring but they do not constitute a physical threat to the building fabric. Soiling is a purely aesthetic effect, although components derived from soiling may be implicated in various decay processes. Decay affecting important elements of a façade may negatively affect its functional performance. Factors affecting functional performance includes blockage of gutters and down pipes, loss of pointing, damage to string courses, sills, drips and other elements of the façade that are designed to deal with water shedding. Deterioration of functional elements leads to increased rates of decay through increased moisture levels in stone. Decay exacerbated by deterioration or failure of functional elements is often located on predictable areas of the façade. These include areas under cornices and string courses and other areas affected by or adjacent to rainwater run-off zones (Illus 47 & 48). The surface area of stone affected may be a significant proportion of the façade; however, that decay may come to be a structural threat only if the volume of stone affected is significant. Structural failure of stone is rare due to the slow progress of deterioration. Action to repair or replace affected stones is normally taken before decay has progressed to a sufficient extent to affect the structural stability of a façade.

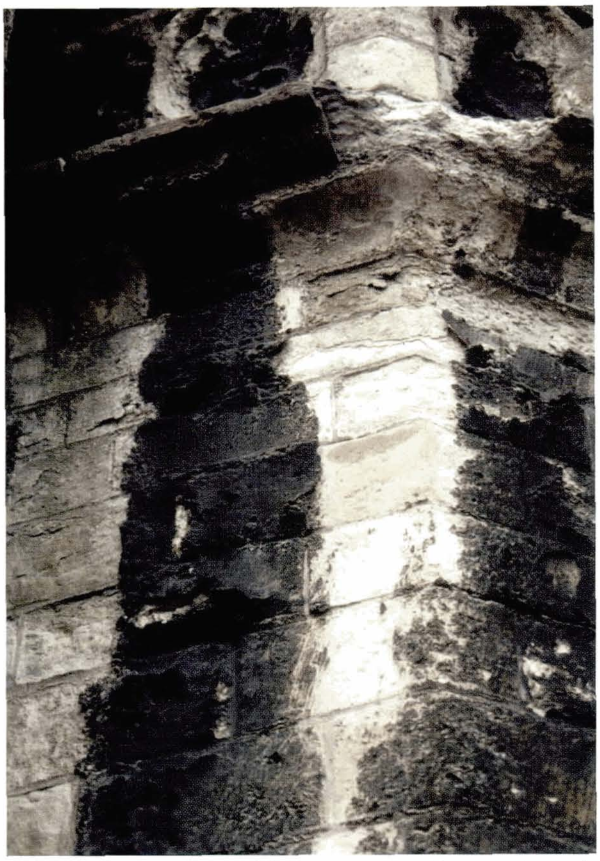
Maintenance and repair should be informed by an understanding of the likely progression of the existing façade condition and the consequences of the intervention. This requires an understanding of the behaviour of building materials and their interactions with each other and with the environment. A façade survey, and analysis of the causes and effects of defects must be carried out by an appropriately qualified person. Only when the causes of deterioration have been established can a decision be made about the appropriateness of intervention. The financial, historical or cultural value of a building or its components will clearly influence this decision.

The effect of stone decay can be described as follows:

Effect on building facade	Description of effect
Structural:	The degree of stone decay presents an immediate or imminent threat to the structural stability of the façade.
Functional:	Stone decay has impaired functional elements of the building façade (e.g. preventing adequate water shedding).
Aesthetic:	Stone decay and/or soiling has negatively affected the visual appearance of a façade.



Illus 48. The earlier decay and removal of the string course from the facade, above left hand window, has caused decay to the stone facings around the windows. The facings have been 'repaired' using plastic repair mortar.



Illus 49. Deterioration of this string course has accelerated decay of underlying limestone due to increased flow of rainwater over the surface.

In the case of a structural threat to the building, intervention is urgently required on grounds of safety. Repairs to functional elements are necessary, but are of secondary importance to structural elements. Decay affecting functional elements is likely to accelerate as the performance of the façade becomes further impaired. Unless functional elements are adequately maintained, repairs to stone affected by their failure will be futile. Other elements of the façade, such as internal timber structures, may also be affected by functional failure. Early intervention in the case of functional failure will prevent or reduce costly intervention at a later stage; however, no remedial action should be undertaken unless the cause of decay has been identified and treatment must address causes rather than symptoms.

In addition to structural, functional and aesthetic considerations, other factors that will impinge on intervention decisions include:

- listed building consent;
- planning regulations;
- conservation guidelines;
- the predicted durability of surrounding stone;
- availability of suitably matched materials;
- future accessibility of affected area;
- planned maintenance schedules - i.e. it may be anticipated that stone that does not presently require repair may have seriously deteriorated before the next planned intervention;
- present and future cost implications.

It is not the purpose of this advice note to provide detailed information on maintenance and repair techniques used on building façades. Further information on these methods can be obtained from many other sources including: Ashurst and Ashurst (1988), Ashurst and Dimes (1990), Davey et al. (1995), Rickards and Urquhart (1993). The following Sections provide a broad outline of the interventions that may have been and may be used on façades.

5.4 Potential interventions and their effects

Intervention may be considered necessary on the grounds of structural or functional deterioration of the building fabric or for replacement of previous incorrect or inappropriate repairs. The primary aim should be to maintain a façade so as to avoid the need for repairs. Original stonework should preferentially be maintained rather than replaced, but if replacement is necessary then new stone should match the original as closely as possible.

Where the effects of soiling and/or decay are purely aesthetic, this is considered insufficient grounds for significant intervention. Where practical, limited action to reduce aesthetic damage may be appropriate, e.g., in the case where previous misguided repair work has been carried out. Inappropriate existing repairs or interventions may or may not be reversible and their effects may range from the aesthetically inappropriate to being potentially or actually damaging to the building fabric. Situations that may require treatment or reversal include:

- chemical residues or debris from stone cleaning;
- physical damage to functional façades elements;
- significantly reduced permeability of porous stone;
- incorrect mortar mixes;
- non-matching stone with respect to chemical or physical characteristics;
- material incompatibility with existing building fabric;
- poor quality or damaging plastic repairs;
- other circumstances deemed likely to cause functional or structural damage to the façade.

5.4.1 Remediation of effects of inappropriate stone cleaning

Where damage is observed within a short time following cleaning (i.e. within a few weeks or months), remedial treatment may be viable, although for some forms of damage no remedial treatment is possible. There are, for instance, no effective treatments for abrasive loss. Bleaching caused by washing out of coloured minerals following chemical cleaning cannot be reversed (although the degree of bleaching may become less obvious as the façade re-soils). Even where remedial treatment is possible, complete reversal of damage is seldom achievable. Nevertheless, prompt action can sometimes reduce the longer-term effects and financial consequences of inappropriate cleaning.

Remedial work should not be attempted before an assessment is made of the façade. Only then should a detailed programme and specification of repairs be prepared by properly qualified and experienced persons. This type of work should not be left to the local builder or to professionals with little experience in the field. In some situations, the most appropriate strategy may be to do nothing as any additional intervention may provoke further deterioration. In all cases, however, it is good practice to commission regular (e.g. quinquennial) inspections of the stonework so that any further deterioration is recorded and repairs initiated, if appropriate. Table 6 and Illus 49 provide guidance on possible actions for a range of situations.

Many façades have been subjected to post-cleaning repairs, some of which are of extremely poor quality and themselves pose an additional risk to the stone.

Residual soiling and re-cleaning

Careful re-cleaning may be possible where soiling residues have been left on the stone through lack of care. However, it must be established that re-cleaning will not cause further cumulative damage to the stone. Re-cleaning to improve soiling removal is not acceptable where more aggressive cleaning is required to remove ingrained soiling or staining, as this is likely to result in an unacceptable degree of damage to the stone. Complete soiling removal is not normally possible or desirable and should not be attempted.

In urban situations, especially in city centres and adjacent to major roads, it is inevitable that previously stone-cleaned façades will attract particulate soiling from atmospheric pollution. Over time, therefore, the stone will begin to lose its recently-cleaned appearance and there may be pressure from a building owner to re-clean a façade, to 'improve' its perceived dirty appearance. However, since the clean air legislation of the 1960s, the levels of atmospheric pollution that resulted in heavy, black soiling of stone have been dramatically reduced and buildings are unlikely to become soiled to the degree that prompted the initial round of stone cleaning. It is therefore difficult to establish a case that will justify any further cleaning of a previously cleaned façade, especially where the stone has been damaged by past cleaning.

Residual debris from abrasive cleaning

Cleaning debris should always be thoroughly washed off immediately after cleaning as it can harden onto the surface if left. Low pressure water washing should be sufficient to remove loose debris. Hardened debris requires more aggressive treatment and testing would be necessary to determine whether an appropriate method was available.

Staining

Orange, pink, brown or yellowish staining may be caused by application of chemical cleaning agents at too great a strength or for too long a period of time. This type of staining is caused by dissolution and redeposition of iron or manganese compounds at the stone surface, especially where alkaline residues remain in the stone after cleaning. Where the staining occurs within a few days or weeks of treatment, pH papers should be applied to the wetted surface to test for the presence of chemical residues that are not pH neutral (pH7). If the surface is found to be excessively alkaline or acid then it should be washed down with copious amounts of water. Application of a neutralising chemical may also be necessary (if recommended by a properly qualified person). Where staining cannot be easily washed off the surface there are chemical treatments that can reduce iron staining. Careful testing would be required to determine whether any additional use of chemicals might harm the stone (e.g. by increasing salt loading or by harmful interaction with previous treatment). The longer such staining remains on the stone, the more difficult it is to remove.

Salt efflorescences

Salt efflorescences may result from chemical residues left in porous stone types (e.g. sandstone) or in joints. While it is not possible to completely remove salts from stone, salt loading may be reduced by dry brushing of affected surfaces or by some poulticing techniques (Section 5.4.6). Water washing is ineffective at removing salts since they are simply washed back into the stone and will re-emerge at some future time. Some salt residues are particularly damaging and are likely to cause significant acceleration in stone decay (e.g. sodium sulphate and sodium chloride).

Biological growths

A clean façade will attract re-soiling from biological growths, particularly algae. Such growths will have been present before the façade was cleaned but will not have been so apparent. For further information on treatment of biological growths on sandstone buildings, reference should be made to Historic Scotland Technical Advice Note 10, Biological Growths on Sandstone Buildings (Cameron et al., 1997).

Excessive levels of biological growth (often green algae) may be observed some months after cleaning. Abrasive cleaning may increase the amount of growth by providing a rougher surface which organisms can more easily colonise, however, the greatest amount of post-cleaning biological growth is observed on chemically cleaned porous substrates where residues of phosphate-bearing chemicals remain in the stone. Phosphate provides a vital nutrient encouraging growth of organisms. Phosphate residues are difficult to remove from stone as they bind to iron compounds. Although phosphate levels will eventually decline, this may take more than a decade on iron-rich substrates and the soiling and potentially damaging effects of biological growths will remain present for a considerable time. Biological growths can be removed or reduced by careful water washing and brushing. In some circumstances biocide treatment may be appropriate although it is unlikely to be effective for more than a year or two on exposed surfaces.

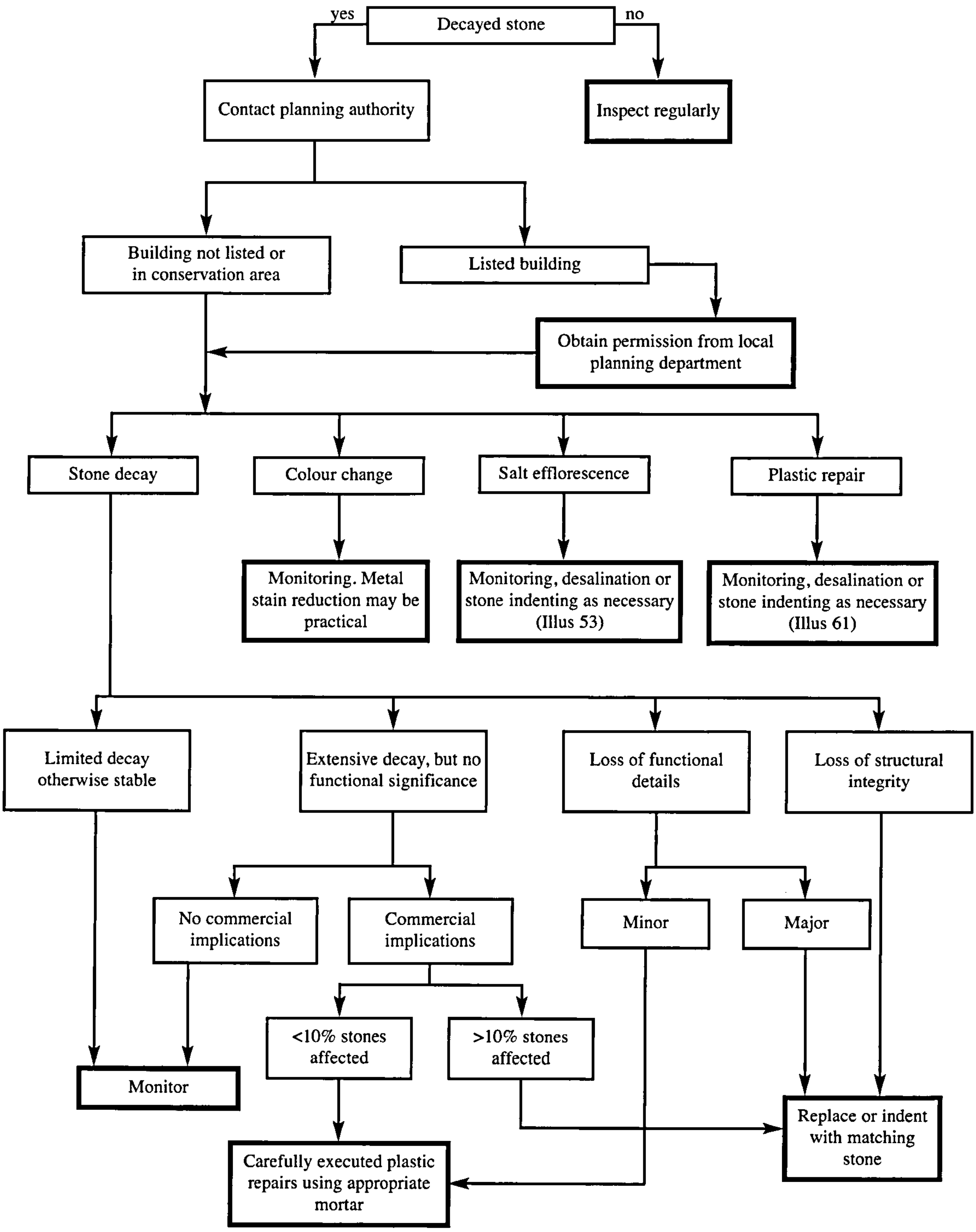
5.4.2 Re-pointing

Repointing is required where mortar has been lost or has deteriorated. Missing or damaged pointing risks water penetration of the building fabric and increased decay of surrounding stone. It can be difficult to remove hard mortar or repoint fine joints without damaging arrises. Whenever possible, raking out of joints must be done by hand since use of power tools could result in damage to adjacent stones (Illus 50) or to bedding mortar. Pointing mortar is normally applied to the outer 25mm of joints. Ashlar stone with fine joints is normally pointed with lime putty in the outer 5mm.

Mortar mixes for fixing repairs and for repointing must have appropriate permeability and durability with respect to the well being of stone. To keep stone decay to a minimum, most moisture movement should take place through the mortar joints. The mortar is therefore sacrificial to the stone and should be less durable and more permeable. Unless the existing mortar is harmful to the stone, new mortar should match the existing mortar in composition, hardness, aggregate type, aggregate size and colour. The correct colour should be achieved using mineralogical material; artificial colouring agents should be avoided.

Intervention	Appropriate situation	Inappropriate situation
Stone replacement	Structural instability. Imminent structural instability. Impairment of functional element/s of façade.	Aesthetic deterioration of functional elements. Aesthetic deterioration caused by soiling.
Plastic repair	In certain circumstances (Section 5.4.7) plastic repairs may be acceptable for minor or superficial repairs to prevent deterioration or replacement of a larger, valuable element.	Large scale use (e.g. >5% coverage) over a façade.
Stone cleaning (abrasive)	Gentle methods may be appropriate with care where soiling is shown to be associated with progressive or severe stone decay.	Polished stone. Culturally valuable surface. Carved or inscribed stone.
Stone cleaning (chemical)	Gentle methods may be appropriate with care on impermeable surfaces where soiling is shown to be associated with progressive or severe stone decay.	Porous stone types (e.g. sandstone). Polished stone. Stone vulnerable to dissolution or salt decay.
Biocide treatment	Where biological growths have been identified as being actively involved in decay likely to lead to structural or functional failure.	Biological growths on a substrate not associated with structural or functional failure.
Water repellent treatment	Problems with moisture penetration through porous stone or where problems with biological growths do/could occur on extensive areas of sloping stone.	Problems with moisture penetration of external walls from an unknown cause, or associated with penetration at wall head, joints or with capillary uptake from ground water.
Chemical consolidation	Imminent loss of a historic surface is shown to be likely.	Any situation where the consolidant cannot be shown to penetrate deeper than the decayed layer.

Table 9. Appropriate and inappropriate intervention situations. This table does not include a comprehensive list of interventions, but illustrates some of the more common situations. Where action is deemed to be potentially appropriate, the individual circumstance of each façade will ultimately determine the suitability or otherwise of any proposed intervention.



Illus 50. Actions to deal with the consequences of stone cleaning.

Pointing is normally flush or slightly recessed. Pointing should not spread over the edges of rounded stones or be worked into ridges of projecting 'ribbon' pointing. Both these methods risk increasing the rate of decay of the stone by trapping of moisture.

Illus 51. The edges of these granite ashlar blocks have been damaged during raking out of joints prior to repointing.

5.4.3 Control of rainwater run-off

Water is involved in most stone decay processes as well as in promoting biological growths and soiling. Regular maintenance of gutters, downpipes and water shedding functional detailing is therefore essential.

Where localised stone deterioration is exacerbated by exposure of the stone it may be appropriate to provide some form of protective cover to the affected area. This might involve fixing lead flashings, weather-proofing exposed wall tops or fitting protective covers, screens or roofs over valuable pieces of masonry (Illus 51).

5.4.4 Chemical treatments

The effects of many chemical treatments are irreversible; this includes most chemical consolidants, water repellents and residues from chemical cleaning. Irreversible chemical treatments should normally be avoided; however some treatments may be appropriate in exceptional situations. The purpose of such a treatment should be to enhance the durability of stone, to extend its life or to preserve an original surface.

Justification of chemical treatments will be specific to the particular circumstances of a building, but treatments may be acceptable in the following situations:

- Water repellents: These can reduce moisture loading of stone and may be required where there are large areas of porous, horizontal or sloping stone. There are many different chemical types of water repellent that vary in their effectiveness and in their consequences for behaviour of treated stone. Changes to colour and reflectivity of surfaces may occur. Salt efflorescences, most probably caused by redistribution of pre-existing salts within the stone,

Illus 52. Protective covering. Lead sheeting has been used to prevent water penetration at roof level.

occasionally occur following treatment. The long-term effects of these treatments are poorly understood.

- Chemical consolidants: These may be required to strengthen bonding within a stone where loss of an important surface would otherwise occur. Like water repellents, there are many chemical types, some can affect colour, reflectivity and salt efflorescence, and the long-term effects are poorly understood. Depth of penetration can vary widely depending on substrate, treatment and application method. It is essential that consolidants penetrate beyond the zone of deterioration to avoid producing a hardened surface over a decayed interior.
- Biocides: These may be necessary where biological growth would cause a hazard (e.g. on walking surfaces) or where an important surface may be damaged or obscured by growths. Many types are available. Some are effective only at the time of application, others have a longer-term preventative action. Biocides are activated against organisms when the surface is wetted and can be expected to wash out of stone. Most will be rendered ineffective after less than two years. The acidity, alkalinity or salt content of some biocides may be a cause for concern.

This list of chemical treatments is not exclusive, but irreversible treatments must be clearly justified in each individual case.

5.4.5 Painted stonework

There are examples of stone façades where stone cleaning has revealed or caused large-scale damage to stone surfaces and where extensive plastic repair has been used to face-up decayed ashlar. Subsequent to this, the façade has been painted to conceal its resultant patchwork appearance.

Painting a sandstone façade, especially one incorporating extensive plastic repair, should only be considered as a last resort and, on a listed building, listed building consent will be required. Treating a sandstone façade in this way can result in a number of additional problems that may cause further damage to an already vulnerable façade. Typical problems that may arise include:

a) Where the paint used is not of a micro-porous type, moisture will be sealed into the stone which can cause further decay to the stone and disrupt the paint finish.

b) When the plastic repairs start to break down, they will have a high visibility on the façade and encourage a quick and perhaps unsatisfactory replacement plastic repair, with further painting.

c) As the paint deteriorates, there will be pressure to apply further coats of paint to conceal the defects. This, in turn, will reduce the ability of the masonry to 'breath' and promote additional stone decay.

There are, however, situations where painting may be the only means of maintaining the economic viability of a stone building, for example, where the cost of stone replacement or indenting would be a large percentage of, or even exceed, the commercial value of the building.

The restoration of a stonecleaned, painted façade, having a large area of plastic repair, is a very difficult task. Often the only practical solution, where there is extensive stone decay, will be the complete rebuilding of the façade with new stone. Paint removal from porous sandstone, especially where the stone surface has been damaged by previous stone cleaning, will require analysis of the paint layers prior to selection of the removal method. However, the normal chemical, paint-removal systems containing methylene chloride should only be used after trials on inconspicuous stones. A poultice prepared from an absorbent material such as clay (kaolinite or sepiolite), mixed with a cleaning solution to form a paste may also be considered but the process of removing the poultice can cause damage to fragile surfaces. The least damaging system for the removal of large areas of paint from a sandstone façade may be by the use of a very low-pressure micro-abrasive system.

Illus 53. Painted sandstone façade, Park Terrace, Glasgow.

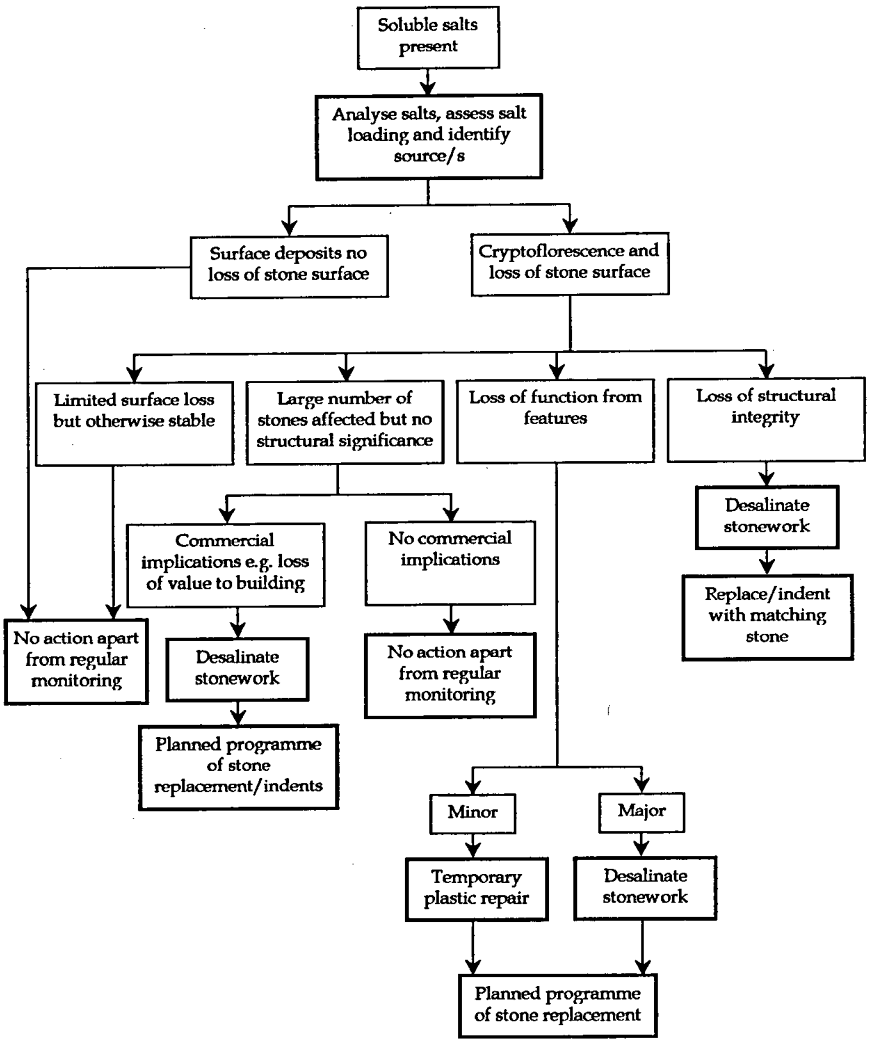
5.4.6 Desalination

Excessively high salt content in stone may arise from contamination of the stone from salty ground water, sea spray, road salts and residues from chemical applications. Salt efflorescences present an aesthetic problem, but there may also be associated stone decay, in which case desalination of the stone may be considered (Illus 53). Complete removal of salts is impractical, but significant reduction may be possible in the right circumstances. Some desalination methods are described by Ashurst & Ashurst (1988).

Desalination by saturating stonework in clean water and poulticing with absorbent clay (e.g. attapulgite or sepiolite) can reduce salt loading but it is a lengthy process with limited applicability. The salt is drawn into the clay by evaporation at the surface. The clay poultice may remain on the stone for a month or more while drying proceeds and the process may need to be repeated several times. This technique cannot be used where water saturation of stonework would cause problems or where the stone surface is in a fragile state.

Sacrificial renders have also been used for desalination. Like the action of the poultice, salts are drawn from the stone into the render by evaporation. The render deteriorates, taking the salts with it.

Where poulticing or the use of sacrificial renders is not possible, significant reduction of salt loading of stone cannot be practically achieved. Salt efflorescences are transient features. Where affected areas are accessible, gentle dry brushing can remove some salts from the stone surface, but the amount removed in this way is likely to be insignificant compared to the amount of salt that remains internally. Washing of stone is ineffective since the salts will dissolve in the water and be drawn back into the stone.



Illus 54. Actions to deal with salts from stone cleaning chemicals.

5.4.7 Plastic and other minor repairs

Plastic repair uses mortar to replace lost or damaged stone. Plastic repair can be perceived as being cheap and fast, but a repair that is cheap and fast because of poor workmanship is likely to fail. Plastic repair that is poorly carried out or uses inappropriate materials may deteriorate within a short period of time and can exacerbate decay of the remaining stone.

Because stone cleaning has now a relatively long history and much of this work was done prior to the publication of research and advice on the dangers of poorly executed work, the damaged stonework has tended to be 'repaired' using the least expensive methods that provided a superficial match to the original stone. Throughout our cities, large areas of sandstone façades have been repaired using plastic repair systems. So much so, that we have now the situation where some façades contain more exposed areas of plastic repair than original stone. While small areas of plastic repair, that have been properly executed using well-designed and suitable mortar mixes, may be acceptable where they provide a good match with the stone, it is unfortunately the case that much repair work is of poor quality. It is now evident that this simplistic approach to the repair of cleaned and decayed stonework will not provide a long-term solution to the damaging consequences of stone cleaning and may be causing further injury to fragile stone surfaces.

A summary of the problems associated with the use of plastic repairs on sandstone is given below.

a) Poor workmanship. For a plastic repair to be effective, the decayed stone must be carefully dressed back to a sound surface and the edges undercut to provide a key. Unfortunately, in many cases, the underlying stone has not been properly prepared and the mortar is simply plastered-on and finished with a 'feather' edge, which becomes detached very quickly. It is also common for the mortar to be taken across joints in the stonework and an artificial 'joint' formed on the surface of the mortar (Illus 60). Plastic repair should be carried out by persons with experience of working with stone, and certainly not by inexperienced stone cleaning operatives. For more information on repair with mortar, it is useful to refer to Ashurst and Ashurst (1988).

b) Unsuitable mortars. The most difficult task is to prepare a mortar that matches the characteristics of the stone being repaired. There are numerous examples of mortar repairs that have failed because the mortar used does not permit moisture evaporation to the same extent as the natural stone. Moisture trapped behind the mortar causes detachment of the repair and further damage to the underlying stone. Proprietary mortars with acrylic resin binders and matching crushed stone aggregate are claimed to be 'breathable', but their long-term performance has still to be assessed. It should be noted that, whilst lime mortars are appropriate for limestone, lime-based plastic repair mortars may be inapropriate on non-calcareous sandstone (illus 57).

c) Poorly matched colour. Accurate colour matching of plastic repairs is difficult to achieve. Where a pigment additive has been used it is likely that, even when there is a reasonable colour match when first applied, there will be colour change over time that will clearly distinguish the area of plastic repair. This colour is intrinsic to the mortar and will not be removed along with the soiling should the façade ever be cleaned (Illus 56). Plastic repairs on façades that are subsequently cleaned normally require to be replaced with new colour-matched repairs after cleaning.

d) Texture. It usually possible to identify the repair area by differences in the surface texture between the repair and adjacent stone.

e) Face-bedded stones. Stones with beds aligned in the wrong direction are common, especially on utilitarian tenement buildings, and any plastic repair applied to such stone will tend to fail quite quickly and may also cause further detachment of the vertical face.

f) Different soiling characteristics. Inevitably, as a façade re-soils after cleaning, the area of plastic repair will exhibit different soiling characteristics and further distinguish the repair from the natural stone. Plastic repair will not soil in the same manner as the surrounding stone and cannot be expected to blend in over time, as would be the case with repairs using natural stone. This difference in weathering characteristics is especially significant on non-calcareous stone types (i.e. many sandstones and granites). Lime and cement mortars are calcareous materials that are slightly soluble in rainwater. Rain washed areas of mortar are therefore relatively cleaner than sheltered areas. On non-calcareous substrates soiling accumulates more rapidly on wetted areas than on sheltered areas. On soiled, non-calcareous façades, plastic repairs can therefore stand out because of their different weathering characteristics (Illus 57).

g) Salt loaded stone. If chemical cleaning has been used and salts have been retained in the stone, failure of the repair can be caused by salt crystallisation behind the repair, resulting in detachment of the mortar. The stone face that becomes exposed may be further damaged by this action. Salt loading of stone may also occur from other causes, including road salt and sea spray in coastal locations.

While this technical advice note is concerned with the consequences of stone cleaning, it is clear that the secondary problem of poorly executed plastic repairs must be addressed. The life of a plastic repair on sandstone will be relatively short when compared to the life of a stone façade. In a Scottish climate, even a well-executed repair is likely to show signs of deterioration after approximately twenty years. Illus 61 identifies the recommended action to deal with plastic repairs to stonecleaned buildings. Given that the long-term solution which best meets the need to conserve the stone heritage will be a programme of stone replacement, there is a requirement for building owners to put in place a planned programme of repairs. This, in turn, will impose an increased financial burden on owners and increase the demand for matching stone.

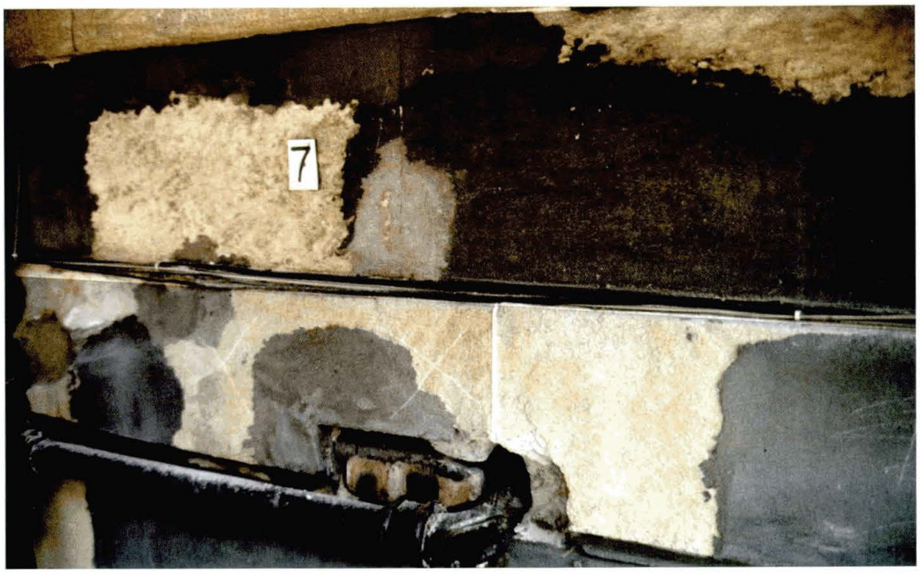
On listed buildings, the advice of the local planning department or Historic Scotland should always be sought before embarking on a programme of repairs of this type. Generally, the use of plastic repairs will not be accepted unless it is for the temporary, minor repair to carved work, mouldings and the like where it is not realistic to indent or replace the feature at the time. Grant aid may be available for stone replacement.

Cracks and fissures

Cracks and fissures in stone caused by structural problems cannot be alleviated by repairs to individual stones, however epoxy resin can be effectively used to treat localised cracking or delamination of stone. Detailed descriptions of repair methodology can be found in Ashurst & Ashurst (1988) and in the Glasgow Conservation Trust Conservation Manual (Rickards & Urquhart, 1993). Epoxy repair is a specialised method requiring a high level of skill and training in the operative.

Illus 55. This poorly executed plastic repair on a sandstone facade has failed to bond with the underlying stone.

Illus 56. The bond between the thin PVA-based repair coating and the underlying sandstone has failed resulting in slumping and detachment of the repair.



Illus 57. This plastic repair was coloured to match soiled stone. The colour no longer matches when the façade has been cleaned.

Illus 58. Plastic repair on a non-calcareous sandstone. Note that the rain washed patches of repair are clean in comparison to the surrounding sandstone. This occurs because the calcareous minerals in the repair mortar are slightly soluble in rain water.

Illus 59. Part of the façade of a city-centre building, Glasgow, showing an extensive area of plastic repair.

Illus 60. City-centre building, Glasgow. Close-up view of part of the façade in Illus 59 shows the crude nature of the repair after circa fourteen years exposure.

5.4.8 Redressing to a new face

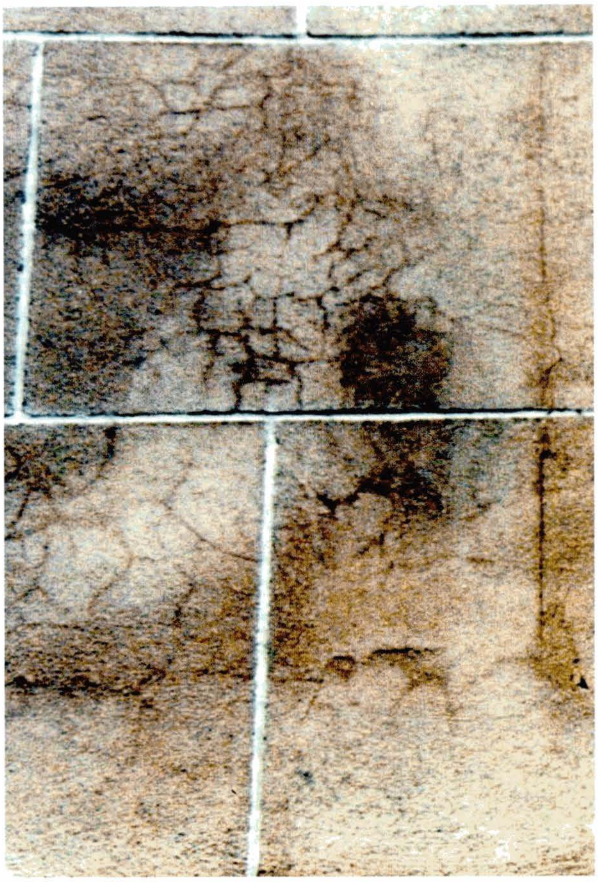
Redressing (Illus 62), also known as dressing back, of a stone surface has occasionally been used where large scale repairs to a façade have been impracticable. Redressing is often carried out where decay is widespread but superficial; for example, where contour scaling or flaking is present over large areas of stone. It requires a high level of skill in the operative to produce a satisfactory outcome. This practice is discouraged on historically or culturally valuable buildings since it inevitably results in loss of the original surface. Loose surface material can often be satisfactorily removed by gentle brushing using a natural bristle brush. Power tools should never be used for redressing.

Weathering processes on some building stones cause surface alteration that can affect the success of redressing. Weathering can result in 'case hardening' of some stone types, where a hard outer crust conceals the weakened interior of the stone. Removal of the weathered outer layers of such stone results in loss of this stable crust and consequent rapid decay.

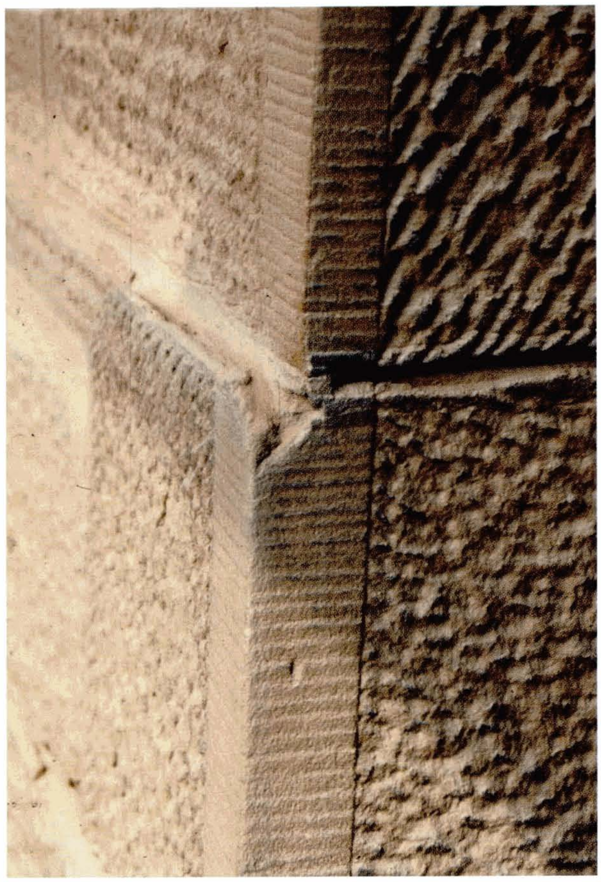
5.4.9 Stone replacement

Stone replacement, whether small or large scale, should conform to recognised guidelines with respect to the ethics of conservation (Section 5.2). Full records should be kept, showing which stones were repaired or replaced and detailing the methods used. Priority should be given firstly to maintaining the structural stability of a building, and secondly to preserving its functional performance. The historical, cultural and financial value of a building will clearly influence the methods of repair and the degree to which effort is made to retain the original building fabric.

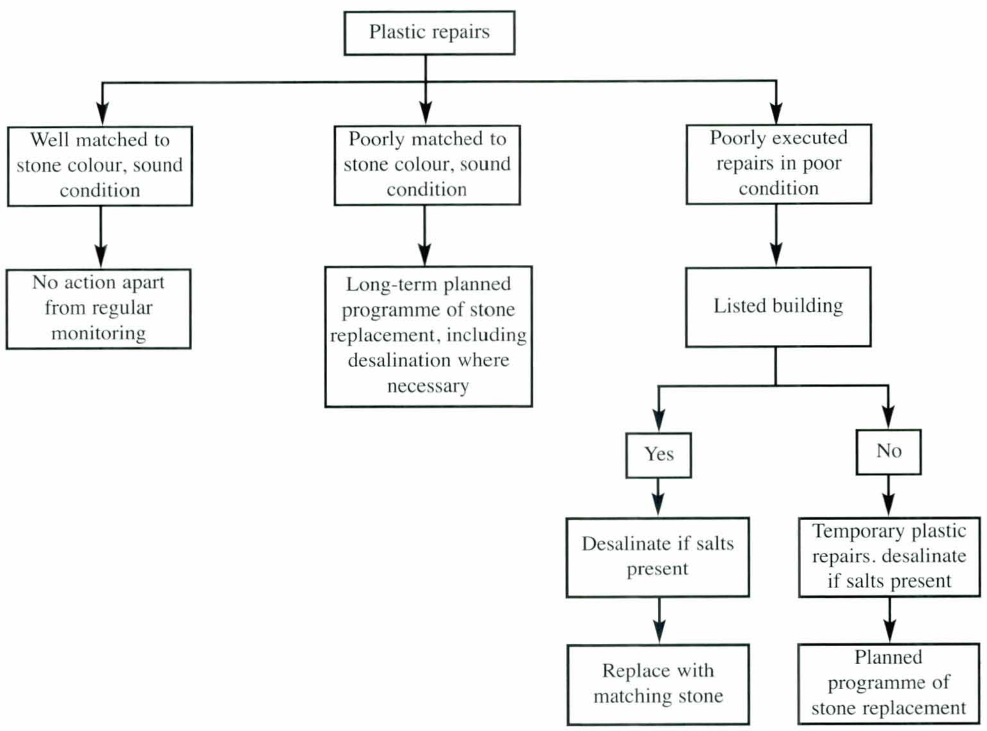
The method used for removal of decayed stone will be determined by the particular situation and the need to avoid damage to surrounding materials. Hand tools are preferred to power tools as they allow more control of the process. Repair may involve replacement of whole blocks or indentation involving only partial replacement of blocks. Where indenting takes place, the amount of stone cut out must be sufficient to remove the full depth of decayed or damaged stone, leaving a sound base for bonding of the repair.



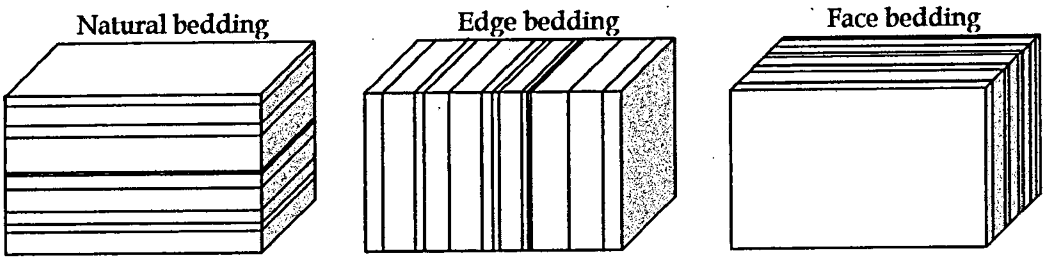
Illus 61. Crazing of plastic repair. Note the way in which the cracks extend across the artificial 'joints'.



Illus 63. Redressing stone. The difference in alignment between these two stones was caused by redressing of the upper stone face.



Illus 62. Dealing with plastic repairs to stonecleaned buildings.



Illus 64. Bedding directions for building stone.

Replacement stone should wherever possible replicate the original block size and surface finish. Stones should be placed to conform to existing joint lines and to the original façade profile (Illus 64). Indentation (Illus 65) can be significantly less expensive than replacing whole stones; however where a whole stone face requires repair it may be more cost effective to cut out and replace the whole of the damaged stone.

Sourcing stone

Best practice in matching stone for replacement or indenting is to use stone with the same characteristics from the same quarry. The costs associated with obtaining stone for replacement can vary widely depending on availability. Most buildings (except the most prestigious) utilise local building stone, which may still be available. Where the original quarry is closed but remains accessible it may be possible to obtain permission to temporarily re-open the quarry for extraction of the necessary quantity of building stone. A case study illustrating the procedure for temporary re-opening of a quarry is shown in (Appendix A). Suitable stone may also be obtained by re-using local material from building demolitions. If the original stone cannot be obtained then it will be necessary to find an alternative stone that matches the characteristics of the original stone - replacing like with like.

Where a suitable quarry can be identified, it is necessary to establish the following:

- are the required sizes of stone available,
- can sufficient volume be produced,
- what is the time scale for supply of stone,
- what is the consistency of the material (remembering that stone is a natural material and some stone types normally vary in appearance).

Practitioners should be aware that there may be restrictions to the size of stone blocks that are available. Block size is controlled by the spacing of bedding layers and joints in the quarry. This may restrict the ability to reinstate damaged stones with replacements of identical dimensions. Freestone is a stone type with no obvious planes of weakness that may be worked in any direction. Although freestones may be worked in any direction, their natural bed may still form a plane of weakness with respect to long-term weathering. Consequently the laying of freestones should also conform to the normal principles of bedding (Illus 63).

A list of stone types recently and currently used within Scotland for repair is provided in Appendix E. It should be noted that the availability of stone changes and this list should not be regarded as comprehensive. Restrictions on the size, colour and availability of stone from some sources may limit use.

Matching stone characteristics

Advice on identifying and matching building stone can be obtained from the British Geological Survey, the Building Research Establishment Ltd or the Stone Federation of Great Britain (Appendix F). Extensive information on building sandstones, their characteristics and sources is contained in "Building Stones of Edinburgh" by McMillan et al. (1999). The Building Research Establishment also maintain an online database of stone test results and characteristics.

Replacement stone must be carefully chosen, since an incompatible material could itself decay rapidly or cause accelerated decay of surrounding stone. Higher durability stone is not in itself a good thing if it is incompatible with surrounding materials. Differences between adjacent stones in porosity and permeability will result in differential moisture contents and result in localised concentration of moisture movement. Water movement through a porous, permeable stone may be blocked by a more impermeable one leading to localisation of decay at the interface due to extended periods of dampness and concentration of salt deposition. Matching mineral cements is especially important for sandstones with calcareous cements since these weather relatively rapidly and can introduce potentially harmful salts to surrounding non-calcareous stone types. Matching the mineralogy of the stone and its cement is important with respect to durability. In sandstone especially, durability is closely related to mineralogy.

Illus 65. Repair involving replacement of damaged stone. The new stone conforms to the original profile and surface finish of the façade.

Illus 66. Repair involving partial replacement or indenting of a damaged stone (shown prior to bedding and pointing).

Illus 67. Indented stone will stand out when new but within a few years natural soiling and weathering processes should blend the new stone in with the old.

The mineralogy of stones also controls their colour. In matching stones for repair it is more important to consider the weathered stone colour than the fresh stone colour. Replacement stone will stand out when new but within a few years natural soiling and weathering processes should blend the new stone with the old (Illus 66). Existing buildings in the same stone type can be used to predict weathering colour changes. Alternatively, if the new stone has been derived from a quarry then weathered outcrops at the quarry site can provide an indication of a stone's weathered appearance. If the replacement stone has been well chosen then its weathering and soiling characteristics will be a close match with the remaining stone. Matching stone is especially important where repair involves indenting part of a larger block. The indent should ideally be indistinguishable from the surrounding stone.

It is most important to match the following stone characteristics:

- porosity;
- permeability;
- mineral cement in sandstone;
- mineralogy of stone;
- colour (the weathered colour is more important than the fresh colour);
- weathering characteristics;
- soiling characteristics;
- grain size;
- fabric (e.g. bedding or foliation).

Where repairs are required on a few, isolated stones on a façade then they may have deteriorated because they were significantly less durable than the majority. Where single stones have decayed because they were originally flawed or less durable then they should be replaced with a stone of similar durability to the surrounding stones. It should be noted however that, like the weakest link in a chain, the least durable stone may have decayed sacrificially to the surrounding stones. This might occur if, for example, moisture flow has been concentrated through a more porous stone. Replacement of a single decayed stone under these circumstances may result in acceleration of decay in surrounding stones.

Where repairs are required to large areas of stone or to a significant proportion of particular elements of a façade (e.g. sills, string courses) it is possible that the stone durability was insufficient to cope with the environmental demands. Highly exposed stones are required to be more durable than stones with relatively little exposure. While it might appear sensible to replace deteriorated stone with more durable stone, resultant changes in patterns of moisture movement could cause problems in the remaining stone unless care is exercised in choosing a compatible replacement.

6 COST CONSIDERATIONS

6.1 Cost implications of stone cleaning

Stone cleaning should not be regarded as a single stage event, but rather the beginning of a long term process. Depending particularly on the stone and method of cleaning, the long-term consequences of stone cleaning clearly have the potential to influence financial costs and the programming of maintenance and repair work. As the effect on financial value will often be uppermost in the mind of a building owner, this section explores suitable approaches to long term financial assessment and the wider context of resource issues. It has been recognised for a number of years that the financial assessment of all building work should include reference to long-term consequences. It has earlier been described (Section 3) how stone cleaning can lead to alterations in the decay rates of stone with obvious financial consequences. There may also be financial implications arising from repair work carried out at the time of cleaning or arising at a later date.

6.1.1 Costs associated with stone replacement and repair

Excessively large amounts of stone repair may result from stone cleaning in circumstances where the method was improperly specified in the first instance, or where inadequate quality control supervision was available on site. In Scotland, stone cleaning took place with little control for a number of years prior to 1993 when it became a building alteration requiring Scottish Listed Building Consent. Recent research indicates that a large number of previously cleaned buildings exhibit an increased rate of decay, and that this decay will require repair to maintain the functional integrity of affected building façades. Where the ultimate outcome of stone cleaning is that large-scale stone replacement is required, the conclusion must be that the process had been a failure. If short-term gains are outweighed over a time by subsequent losses, then the rationale supporting the initial work is clearly flawed.

Using data from Table 10 and estimates of costs involved in cleaning, scaffolding and repairs, it is possible to estimate the average long-term costs that may be attributable to stone decay in the decade following stone cleaning.

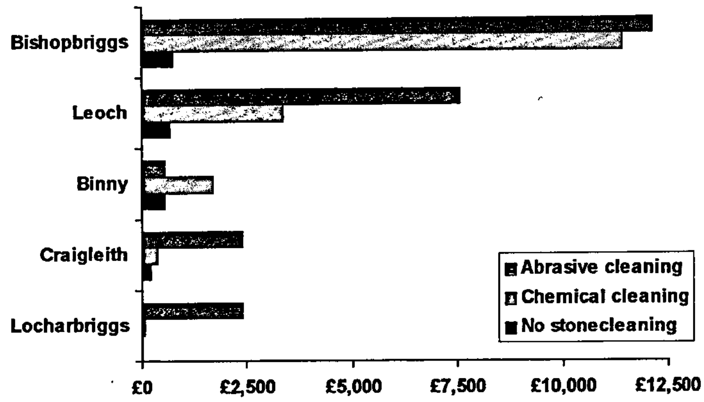
	Percentage surface decay per decade (%)		
Sandstone type	No stone cleaning	After chemical stone cleaning	After abrasive stone cleaning
Locharbriggs	0.05	0.1	3.4
Craigleith	0.3	0.5	3.4
Binny	0.8	2.4	0.8
Leoch	0.9	4.8	10.8
Bishopbriggs	1.0	16.3	17.3

Table 10. Average estimated coverage of stone decay on cleaned and uncleaned building façades ten years after stone cleaning. (Data from measurements of decay on Scottish sandstone façades, Young et al., 2000)

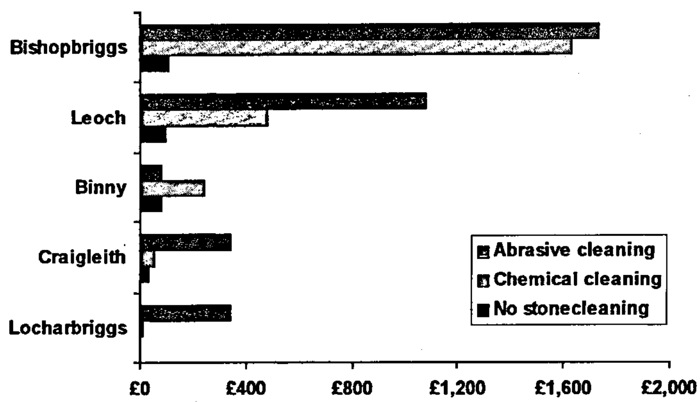
For example, a sandstone façade with:

- surface area of $200m^2$ of stone,
- cleaning costs of £6 per m^2,
- stone indenting costs of £350 m^2,
- plastic repair costs of £$50m^2$.

Excluding scaffolding costs, the following graphs (Illus 67) illustrate the average predicted costs of repairs (indenting and plastic repair) to the stone after ten years. These predictions are derived from data on actual coverage of stone decay measured on existing building façades. Depending on the cleaning method used, the amount of decay on individual façades may differ significantly from that shown. Costs for indenting repairs assume that all stones exhibiting decay are replaced. This must be assumed to represent maximum costs, as some stones are likely to suffer superficial decay and would not require indents. These diagrams (Illus 67) illustrate the potential costs that may be incurred following stone cleaning. While more durable stone types may be little affected, less durable stone types may experience considerable acceleration in the rate of decay, with consequent cost implications when the façade requires repair. The costs shown are related only to stone decay subsequent to cleaning. There may be other costs associated with physical damage caused at the time of cleaning, or with other effects such as bleaching, staining or replacement of plastic repairs.



Illus 68a. Mean predicted costs of indenting repairs to a 200m² ashlar sandstone façade ten years after stone cleaning. Data show the predicted behaviour of five different sandstones from the most durable (e.g. Locharbriggs) to the least durable (e.g. Bishopbriggs). Excludes scaffolding and repointing costs.



Illus 68b. Mean predicted costs of plastic repairs to a 200m² ashlar sandstone façade ten years after stone cleaning. Data show the predicted behaviour of five different sandstones from the most durable (e.g. Locharbriggs) to the least durable (e.g. Bishopbriggs). . Excludes scaffolding and repointing costs.

Costs shown in Illus 67 do not take into account life cycle costs associated with different types of repair. Indenting has a much greater initial cost, but the predicted life span of replacement stone may be in excess of 100 years. Indenting of detailed stone is likely to be significantly more expensive than repairs to plain ashlar. Plastic repairs vary widely in cost and durability. Their life span may be 20 years or less. Poor quality repairs may fail after a few years and are likely to exacerbate stone decay, incurring further costs.

A structured maintenance programme will ensure that stone is kept at its optimum condition, reducing the need for widespread and expensive repairs. Any major work completed on a stone surface, of whatever nature, will inevitably have a corresponding impact on maintenance requirements. Requirements may include: repointing of joints in the stonework, stone replacement, repair or application of other treatments including biocides, water repellents or chemical consolidants.

6.1.2 Other maintenance costs following stone cleaning

Following stone cleaning, a building will be exposed to ambient soiling and decay as before, although the nature of the weathering process may be different due to changing stone condition, pollution levels, or changes in the building's environment. Resoiling rates may be very slow, but in polluted environments significant resoiling may occur within as little as ten years, leading perhaps to a desire for re-cleaning. Re-cleaning can result in cumulative damage to a façade and there may be unforeseen, potentially harmful interactions between different cleaning methods.

Algal colonisation of stone leads to an often rapid and obvious change in the appearance of a building. Some chemical cleaning residues can accelerate biological colonisation. This may be especially obvious on cleaned stone surfaces. The regular application of biocide treatments to a post-cleaned stone surface as part of an ongoing maintenance programme will reduce the amount of algal growth although the costs incurred are likely to be high since most biocides have an effective life span of less than two years. In addition, the effects of regular chemical applications are poorly understood and may have implications for future rates of stone decay or colour changes.

6.1.3 Effects on property market selling prices

The property markets are affected by many factors, and selling price can only be effectively predicted by associating a large number of variables with each other. An understanding of the extent to which stone cleaning might affect property market selling prices is an essential step towards the better understanding of the whole-life costs associated with cleaning (Laing and Urquhart, 1997). A clear link has been demonstrated between inappropriate stone cleaning, accelerated decay and the subsequent need for repair intervention. The very large number of buildings already cleaned in Scotland implies that many buildings will exhibit increased rates of decay. The potential for accelerated rates of stone decay on previously cleaned properties should be considered by buyers, and recognised as likely to incur future expense.

6.2 Predicting long-term costs associated with stone cleaning

Although it is clear that the physical properties of the stone façade will change as a result of cleaning, forecasting what might happen in a number of years can be difficult, even where data is available from previous projects. The longer-term effects of stone cleaning, either positive or negative, may not become apparent for a number of years. The immediate benefits, in terms of apparent aesthetic improvement, might be seen to represent a complete gain in overall value prior to the surfacing of any physical problems. Forecasting the effects of cleaning over a building's residual life span therefore carries with it a great deal of risk and uncertainty. It should be recognised that this situation exists with all life cycle cost studies, but life cycle costing is not based on 'guess work' and can supply the decision maker with significant and useful information. The frequency of work required should be related to predictable decay rates (Section 3.2.2), as well as consideration of functional and structural integrity.

With regard to the methodology to be adopted, it is suggested that the following items be considered:

1. the most appropriate timing for maintenance operations;

2. the amounts which should be spent to maintain a certain standard;

3. the strategies which should be followed with regard to rehabilitation.

The timing of maintenance operations (1.) should be determined by a regular programme of façade inspection, bearing in mind that stone behaviour may change as a result of cleaning. A realistic approach towards the costs (2.) is related to the protection extended towards a building by Statute, and the motivations of those parties responsible for its upkeep. While it is possible to produce a maintenance programme for any building, the application of such a programme might vary, certainly in the private sector. Listed building consent and the conservation policies of grant-aid providers will to a large extent determine strategies adopted with respect to rehabilitation (3.) of many properties. Current conservation policies and guidelines are summarised in Section 5.2.

The general effects of cleaning on building stone were outlined in Section 3. As a result of recent research it is possible to make broad predictions about the likely outcome of stone cleaning based on known stone characteristics. Examples of such prediction are shown in Table 10. These data are based on average results for a large number of façades; predicting the effects of cleaning on any one façade is more problematic as it depends on the interaction of many factors. In practice the care taken by practitioners during cleaning has a significant effect on the outcome, which may outweigh all other risk factors. Known risk factors associated with particular stone types are shown in Table 12.

Table 11 shows the range of effects that stone cleaning may have on the long-term decay rates of sandstone. The rate of decay of most building sandstone is relatively slow, often progressing at less than 1% affected surface area per decade of exposure. Nevertheless, this can add up to a significant amount of decay over a 100 or 200 year façade life span and this long-term average does not take account of short-term accelerations in decay that are often interspersed in a background of slow, cumulative damage. Sandstones vary widely in their quality and poor sandstone can decay at least an order of magnitude more rapidly than high quality sandstone. Of the sandstones that have been commonly used in Scotland, Leoch, Kingoodie, Bishopbriggs and Giffnock are amongst those prone to the most rapid decay. Locharbriggs, Craigleith and Redhall are more resistant to the effects of weathering and to damage by stone cleaning and other inappropriate interventions. The rate of decay of less resistant sandstone can be significantly accelerated in the decade or so following cleaning and even high quality sandstone can be badly affected if the cleaning method is badly chosen or carried out. However, where cleaning is carried out with care using an appropriate method there may be no increase in the rate of decay post-cleaning.

	Predicted range in surface area affected by stone decay					
Time after cleaning	**5 years**		**10 years**		**20 years**	
Low durability sandstone	Mean	Range	Mean	Range	Mean	Range
No cleaning	0.5	0 - 1	1.0	0 - 2	1.5	0 - 5
Abrasive cleaning	10	1 - 18	13	1 - 27	20	2 - 32
Chemical cleaning	5	1 - 15	8	1 - 46	9	1 - 47
High durability sandstone						
No cleaning	0	0 - 0.5	0.5	0 - 1	0.5	0 - 2
Abrasive cleaning	1	1 - 3	2.	1 - 7	4	1 - 14
Chemical cleaning	1	1 - 3	5	1 - 17	6	1 - 17

Table 11. Prediction of the amount of stone decay (% surface cover) that may be expected to occur on sandstone façades before and after stone cleaning (Young et al., 2000). NB The care taken in choice and application of cleaning method will have a significant effect on the outcome of cleaning.

There are insufficient data from which to calculate the long-term effects of stone cleaning on the rate of decay of granite. The natural rate of decay of high quality granite on building façades is extremely low and there has been insufficient time for any significant effects of stone cleaning (in terms of rate of decay) to be detected. Lower quality granite, with a higher porosity, is more vulnerable to damage and generally responds similarly to non-calcareous sandstone of an equivalent permeability. The degree of decay on good quality granite is normally more superficial than that on sandstone, and a granite surface affected by, for instance, granular disintegration does not necessarily require any intervention in terms of repair or replacement. However, the absence of definitive evidence does not exclude the possibility that increased rates of decay are one of the potential side-effects of stone cleaning of granite façades.

A very great number of sandstone buildings in Scotland have already been cleaned, and the argument is no longer whether that should have happened, but what provision is being made to cope with the likely emergence of stone decay as a result. The ready availability of funding, skilled labour and materials to deal with the emerging need for repair must be addressed. A relationship between stone cleaning and stone decay has been clearly demonstrated. The potential for cleaning to result in decay and subsequent repair demands that planning for resources (financial and otherwise) should be recognised.

	Dominant minerals				Porosity characteristics		
	Siliceous (quartz) cemented sandstone	**Calcareous sandstone**	**Argillaceous (clay-rich) sandstone**	**Ferruginous (iron-rich) sandstone**	**High (>15%)**	**Moderate (10-15%)**	**Low (<10%)**
Natural weathering and decay	Normally durable.				*Varies depending on stone composition.*		
		Moderate-low durability. Gypsum crusts. Occasional pitting.					
			Low durability. Spalling common with swelling clays (e.g. smectite & chlorite).				
				Normally durable when present with siliceous cements.			
Chemical retention		Calcium salts can be formed by reaction with applied chemicals or pollutants.			Substantial risk.		
			Retention of alkalis by some clay minerals.			Significant risk.	
				Retention of phosphate (present in some cleaning chemicals).			Moderate risk.
Chemical dissolution		Dissolution of carbonate minerals by acids.					
				Dissolution of iron minerals.			
Salt decay		Honeycomb weathering in coastal locations.			Vulnerable if stone has low strength.		
			Multiple spalling, especially in coastal locations.				
Roughening or pitting		Dissolution or pitting by acids or abrasives.			Risk of erosion of soft stone.		
			Erosion of soft stone if clay content high (e.g. >15%)				
Colour change	Alkaline residues can cause staining on light coloured stone by dissolving iron minerals.				High volume of water throughput increases likelihood of colour change.		
		Alkaline residues can cause staining on light coloured stone by dissolving iron minerals.					
Biological growths		'Alkaline' surface commonly colonised.					Discouraged by low water content.
				Increased colonisation if phosphate residues are present.			
Long-term decay post-cleaning		Substantially increased risk of accelerated decay - including dissolution, salt formation & abrasive loss due to soft cement.			Strength may be reduced.		
			Substantially increased risk of accelerated decay. Risks include loss of soft stone & chemical retention.				
	Siliceous (quartz) cemented sandstone	**Calcareous sandstone**	**Argillaceous (clay-rich) sandstone**	**Ferruginous (iron-rich) sandstone**	**High (>15%)**	**Moderate (10-15%)**	**Low (<10%)**
	Dominant minerals				**Porosity characteristics**		

Table 12a. Significant known risks associated with stone cleaning of sandstone. N.B. These are commonly encountered risks. Highly aggresive or inappropriate cleaning can damage stones that would not normally be affected by these phenomena.

	Pre-existing condition		Vulnerable minerals		Porosity		
	Unweathered	**Weathered**	**Mica**	**Feldspar**	**High (>5%)**	**Moderate (2-5%)**	**Low (<2%)**
Natural weathering and decay	Low risk. Flaking and minor spalling or granulation.			Normally very slow.	High moisture penetration & uptake of pollutants. Highly vulnerable.		
		Increased risk with increased weathering. Moderately weathered granite, behaves more like sandstone. Spalling and granulation.				Increased vulnerability.	
			Substantial amounts of mica on grain boundaries can reduce granite strength.				Low rate of decay. Outer surface only.
Chemical retention		Significant risk.			Significant risk.		
	(Be aware that chemical retention may occur in joints)						
Chemical dissolution		Weathering products may be attacked.			Weathering products may be attacked.		
Salt decay		Vulnerable to granulation and spalling.			Vulnerable to granulation and spalling.		
			Superficial damage by salt growth inside mica grains.				
Roughening or pitting		Vulnerable to abrasive cleaning.			Vulnerable to abrasive cleaning.		
Colour change	Alkaline residues can cause staining by dissolving iron minerals.			Pink feldspars vulnerable to bleaching.		Slightly increased risk of staining or bleaching.	
		Alkaline residues can cause staining by dissolving iron minerals.			Pre-existing staining likely to be present. High risk of with chemical cleaning.		
Biological growths		Increased colonisation if phosphate residues are present.			Increased colonisation if phosphate residues are present.		
						Increased colonisation if phosphate residues present.	
Long-term decay post-cleaning		Vulnerable to granulation and spalling.			Vulnerable to granulation and spalling.		
	Unweathered	**Weathered**	**Mica**	**Feldspar**	**High (>5%)**	**Moderate (2-5%)**	**Low (<2%)**
	Pre-existing condition		**Vulnerable minerals**		**Porosity**		

Table 12b. Significant known risks associated with stone cleaning of granite. N.B. These are commonly encountered risks. Highly aggresive or inappropriate cleaning can damage stones that would not normally be affected by these phenomena.

7 SUMMARY OF RISK TO THE STONE HERITAGE

The effects of stone cleaning on sandstone and granite buildings have been defined in the previous sections. Some of the effects can be to the advantage of the building by displaying the true colour of previously obscured stone and by revealing the quality of carved detail. Consequently, properly executed cleaning can help to preserve the commercial viability of a building by maintaining its attractiveness to clients. However, the wholesale cleaning of stone façades over the past thirty or more years has left a legacy of damage to a significant proportion of the stone heritage of our towns and cities, to the extent that there may be a long-term risk to the value of this heritage.

Sandstone is particularly vulnerable to decay by both natural and induced processes, especially stone cleaning. However, not all sandstone types are equally at risk; those which are classified as siliceous being generally strong and durable and less prone to large-scale surface damage from stone cleaning intervention. Craigleith sandstone and some of the Moray sandstones fall into this category, although even these strong and durable stones have been observed to suffer reduced surface sharpness from poorly executed abrasive cleaning. The most vulnerable sandstone types are those classified as argillaceous (clay cements) and calcareous (calcium carbonate cements). Unfortunately, many buildings in Scotland are built with these sandstones and the generally poor weathering performance of such stones means that surface decay is ubiquitous. To this natural process of decay must be added the effects of stone cleaning which have greatly increased the extent of surface damage and long-term decay rates. Sandstones known to be at particular risk are those from the Bishopbriggs and Giffnock quarries, used on many buildings in the Glasgow area, Kingoodie (Fife) and Leoch (Dundee). Sandstone type is therefore an important factor in the assessment of risk.

The fact that a building is listed is no guarantee that it will be free from risk as a consequence of stone cleaning intervention. The façades of many such buildings were cleaned before the current restrictions, imposed by the need for listed building consent, were in place and as a result the stonework of many listed buildings now shows evidence of enhanced decay. A lack of awareness of the vulnerable condition of many ashlar façades and the actual or potential loss to the stone heritage adds to the risk of further degradation of heritage value.

The stone heritage is not confined to only those buildings that are listed; the contribution made by the large number of unlisted, utilitarian tenement buildings must also be taken into account in assessing risk. Most of these buildings have been cleaned and many have extensive areas of decayed stonework that has been patched with plastic repair. The risk of continuing deterioration of stone condition is high and, as the cost of large-scale stone replacement is likely to be beyond the means of most individual owners, the potential to cause further damage through ill-advised intervention is high.

The nature of the ownership of a building has the potential to increase risk to vulnerable stone. Many buildings in towns and cities are in multiple ownership, which means that there is greater difficulty in reaching agreement between owners to find the level of funding necessary to carry out the most appropriate repairs to stone façades. Also, because ownership of city-centre commercial buildings is likely to be transient, the long-term health of the stonework tends not to be a primary concern and repair decisions will reflect this situation. Too often repairs to stonework, carried out post-stone cleaning, are of a cosmetic nature and are unlikely to be to the long-term benefit of the stone heritage.

Poor quality stone repairs to hide the effects of natural decay, and decay induced by stone cleaning, are common. The use of poorly matched and badly executed plastic repairs is a case in point. Much of the repair work that as been carried out has a limited life and will require the implementation of a planned programme of stone repairs, using stone replacement and indents as the preferred approach. Failure to develop a strategic plan to address this issue is likely pose a significant risk to the quality of Scotland's stone buildings.

Any large-scale programme of stone repairs will require the availability of matching stone if an unsatisfactory appearance is to be avoided. While there is no real shortage of stone for new build, there may be difficulty in obtaining suitable matching stone due to the closure and loss of the original quarries. In addition, given the likely volume of stone repairs that will be required over the coming decades, the shortage of properly trained and skilled stone masons will prove to be an inhibitory factor unless this is addressed as an issue of strategic importance.

In the case of granite buildings, the consequences of stone cleaning have been much less severe than is the case with sandstone buildings. Generally the risk to the granite heritage as a result of stone cleaning is minimal and, in many cases may have been beneficial to the long-term durability of the granite. The exception to this is in older buildings built from weathered granite, where the surface is loose and friable. Cleaning in these cases has caused a further loss of surface that cannot be repaired.

8 CHECK LIST OF GOOD PRACTICE

The following points identify the important issues that need to be considered when dealing with the consequences of stone cleaning.

- In dealing decayed stonework that has been caused or made worse by stone cleaning, only those solutions that will be to the long-term benefit of the stone should be considered. Repairs that are based on low-cost methods with a relatively short life span may cause further damage to vulnerable stone.
- Where a building is in multiple ownership, a long-term strategy to deal with the consequences of poorly executed stone cleaning should be agreed by all owners, including where appropriate the method of funding repairs.
- Sandstone is more vulnerable to damage than granite. Façades constructed from argillaceous sandstone, such as from the Leoch and Kingoodie quarries, are particularly vulnerable to decay, and the only satisfactory method of repair is likely to be by stone replacement when the decay has advanced to the extent where structural integrity or functional performance are compromised.
- Chemical cleaning can leave significant soluble salt loading in porous stone that results in long-term surface deterioration. Desalination of the stone may be required before repairs to the stone can be carried out but complete removal of salts may not be achievable.
- Stone that has decayed to the extent that there is a risk to the structural stability of the façade must be replaced quickly with stone having similar properties to the surrounding stone. Replacement stone that is denser and less permeable than adjacent stones may cause more rapid decay of these stones.
- Stone elements, such as drips and mouldings, which have a functional role in shedding water from a façade or in controlling water flow over a façade should be given a high priority for repair. Loss of function can lead to stonework at lower levels being subjected to increased amounts of water flow and moisture retention leading to accelerated rates of decay.
- A detailed assessment of each stone in a façade should be made before carrying out any repairs to the stonework. The assessment and a detailed programme and specification of repairs must be carried out by properly qualified and experienced persons.
- No remedial action should be taken until the extent of the decay is known, the cause of the decay identified and a suitable method for treatment or repair has been established.
- For some forms of damage, no remedial treatment is possible and the best option will be to do nothing apart from routine maintenance to pointing and removal of any damaging vegetation.
- Mortar used in pointing must be sufficiently permeable to allow evaporation of moisture through the joint and to help 'drain' moisture from the surrounding stone. Avoid the use of hard, dense mortar that will reduce the rate of moisture evaporation from the stone.
- It is important to maintain accurate records of the results all inspections, assessments and any repair interventions carried out on the façade.
- In the case of listed buildings it will be necessary to obtain listed building consent for repairs which the planning authority consider may affect the external character and quality of the buildings. In instances where the planning authority considers that works proposed to unlisted buildings could radically affect their external appearance, planning permission may be required. Early consultation with the planning authority is strongly advised when considering any proposed works other than minor repairs.
- Where the effects of soiling and decay are purely aesthetic, this is insufficient reason for significant intervention such as stone replacement.
- Repairs to stone façades should be carried out only by experienced stone masons. Inexperienced stone cleaning operatives should not execute mortar repairs and the like as part of a stone cleaning contract.
- Frequently, plastic repairs to stonecleaned façades, having been badly executed, are in poor condition and have caused further decay to the underlying stone. Before carrying out remedial repairs a full investigation and assessment of the condition of the stone must be made and a repair methodology

prepared that best conserves the stone façade. Further patching with mortar may not be the most appropriate solution.

- Redressing stone to a new face is not an appropriate repair on culturally valuable buildings.

- As a rule, sandstone façades that have been previously cleaned should not be subjected to further stone cleaning.

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APPENDIX A
CASE STUDY. PROCEDURES TO OBTAIN PERMISSION FOR TEMPORARY OPENING OF A QUARRY FOR BUILDING STONE

Binny sandstone having been promoted by the associated listed building consent for repairs, a planning application was made to the Strategic Services Committee of West Lothian Council for a "proposed quarry to extract a limited amount of Binny stone at Oakridge College, Ecclesmachan". Planning permission was granted for a temporary period subject to certain conditions (below). A Section 50 agreement was approved with the applicant and landowner to secure control over traffic routing, the amount and use of stone to be extracted and to restrict future quarrying at the site. The proposal identified:

The proposals

- an area of land adjacent to the old working face of the quarry,
- the size of the extraction area (20m x 15m),
- the volume of stone to be extracted ($75m^3$) and taken to a cutting yard,
- the volume of stone likely to be required to obtain the necessary amount (up to 450 m^3),
- the time predicted for stone extraction (4 weeks),
- the time predicted from start to restoration complete (9 weeks),
- there would be no blasting,
- the route for transport of quarried blocks,
- the number of lorry movements per day (3-4) over a given period (10 days),
- the load to be carried in each load (max. 10 tonnes),
- working hours (8am to 5pm, Mon to Fri only),
- the land to be reinstated to grazing land.

The use of the stone

- for repairs to the Scott Monument, Edinburgh,
- the monument being constructed of Binny sandstone,
- Binny sandstone having been recommended by Historic Scotland in granting planning permission for repairs due to its unique appearance and weathering characteristics,
- the intention to quarry only the minimum amount of stone necessary.

Representations

Local Community Councils were consulted to discuss the application and ensure that they were satisfied with arrangements for extraction and transport of the stone. Letters raising concerns about environmental disturbance were noted and environmental concerns were dealt with in the proposal as follows:

Environmental health, highways and planning issues

- predicted noise levels were shown to be not intrusive and unlikely to cause nuisance to nearby residents,
- vibration would not occur as no blasting would take place,
- dust extractors to be used on drills,
- location of drilling and weather conditions would prevent dust nuisance,
- vehicle routes would be acceptable due to the small number of movements each day,
- the applicant would meet the expense of any damage from traffic to roads and verges along the route,
- no other adverse comment was received from SEPA, Scottish Natural Heritage, SOAFD and East of Scotland Water.

Although planning policies for the area did not support extraction of rock, the limited nature of the proposal allowed stone extraction without detrimental impact on the environment, amenity of residents or road safety. This exception to planning policies could only be justified in terms of the one-off nature of the proposal and the specific requirement to restore a nationally renowned building. The impact of the operation could be satisfactorily controlled using planning conditions and a Section 50 Agreement with the applicant and landowner. Conditions stipulated in granting planning permission included issues in respect of:

- the time period of operation,
- working methods,

- restrictions regarding buildings, fixed plant, etc.,
- production limits,
- record keeping,
- depth of working,
- hours of operation,
- highway issues,
- fencing,
- environmental protection with respect to blasting, noise and dust,
- water pollution and drainage,
- protection of trees,
- removal and storage of soils and their replacement on completion of extraction,
- restoration, tree planting, soil cultivation and aftercare for a period of five years.

APPENDIX B
METHODS FOR ANALYSIS OF MASONRY MATERIALS

Information required	Technique	Methodology	Effect on sample
Permeability measurement	Gas permeability	Measures the rate of flow of nitrogen gas injected at the surface of a porous substrate.	Non-destructive
Porosity & pore size distribution	Mercury porosimetry	Intrusion of mercury into sample under vacuum. Solid sample at least 1-2 cm^3 required.	Destructive
Water penetration rate	Karsten tube	Measures the rate of water absorption into a porous substrate.	Non-destructive
	Ultrasonic velocity	Quantifies differences in elastic properties & strength from velocity of ultrasound pulses.	Non-destructive
Location of voids & discontinuities in density	Ground penetrating radar	Detects sub-surface radar reflecting layers in walls or ground.	Non-destructive
	Computerised X-ray tomography	Images & quantifies differences in density in laboratory samples up to about 30 cm diameter.	Destructive
Location of voids & inspection of cavities	Borescope	A probe allows visual inspection inside a hollow structure.	Non-destructive
Location of cracks & voids in a smooth surface	Dye testing	Dye is retained in voids when excess is removed.	Non-destructive
Hardness or strength of substrate	Schmidt hammer	Measures rebound of an applied force to a surface. Detects delamination or loss of strength.	Non-destructive
Strength changes with depth	Drilling resistance	Quantifies resistance to drilling which can be correlated with strength.	Destructive
Water repellency	Water droplet absorption	Measures rate of absorption of a water droplet into a surface. Requires core sample.	Destructive
Temperature differences	Infra-red thermography	Records differences in surface temperature & emissivity. Can locate cold bridging or dampness.	Non-destructive
Colour assessment	Chroma meter	Quantitative analysis of colour and brightness of surfaces.	Non-destructive
Salt & other crystalline material identification	X-ray diffraction	Identifies minerals present in powdered samples. Few grams or less required.	Destructive
Soluble salts identification & amount	Depth profiling	Quantifies soluble salts at depths in a powdered drill or dry cored sample.	Destructive
Organic compound identification	Infra-red spectrometry	Identification of chemical compounds. Very small samples (<1g) can be used.	Destructive
Chemical element identification & analysis	X-ray fluorescence	Identifies elemental chemical composition of samples. Portable equipment can be used to identify elemental composition of surface. More accurate analysis is available using laboratory equipment. Sample of several grams required.	Destructive (lab) & non-destructive (portable)
Microscopic topographic & chemical analysis	Scanning electron microscopy	Microscopic images of surfaces (<1mm field of view) & semi-quantitative chemical analysis at selected locations. Requires solid sample.	Destructive
Microscopic stone characteristics, e.g. minerals, porosity	Petrographic analysis	Microscopic examination of thin section of material. Solid sample several cm in diameter required.	Destructive

APPENDIX C
PRO-FORMA FOR FAÇADE CONDITION ASSESSMENT AND RECOMMENDATION OF INTERVENTIONS

1 Details about property

Date: ____________________ ***Surveyor:*** ____________________

Reference No.: ____________________

Address of property: ***Address of clients:***

____________________ ____________________

____________________ ____________________

____________________ ____________________

____________________ ____________________

Age of structure (years): ☐

Type: terrace ☐ tenement ☐ semi-detached ☐ detached ☐ other ☐ ....

Use: residential ☐ commercial ☐ religious ☐ public ☐ other ☐ ....

Façade measurements: width ______ height ______ area ______ (m^2)
width ______ height ______ area ______ (m^2)
width ______ height ______ area ______ (m^2)
width ______ height ______ area ______ (m^2)

No. façades surveyed: ☐ ***No. storeys:*** ☐

Main façade facing direction: ☐

Shape of terrace: curved ☐ straight ☐ n/a ☐

Position in terrace: end ☐ intermediate ☐ n/a ☐

Access to façade/s:

Plan layout of façade(s) and surroundings:

N

Stone:

Stone type	Name	% surface	Notes (e.g. colour, grain size, etc)

Masonry types: e.g. coursed ashlar, uncoursed ashlar, squared rubble, coursed rubble, random rubble, cyclopean, stone facings, rainscreen cladding, etc.)

Masonry type		Location on façade
....	☐	
....	☐	
....	☐	
....	☐	

Surface finishes: e.g. smooth, polished, droved, tooled, stugged, picked, rock-faced, pinched, vermiculated, etc.

Surface finish		Location on façade
....	☐	
....	☐	
....	☐	
....	☐	

Carved details:

Carved detail		Location on façade
....	☐	
....	☐	
....	☐	
....	☐	

Pointing mortar: cement ☐ lime ☐ unknown ☐ other ☐

Width of joints (mm): ☐

Mortar aggregate or inclusions: ☐

Finish of pointing: flush ☐ recessed ☐

smeared over stone edges ☐ projecting ribbon pointing ☐

other ☐

References to photographs, façade drawings, etc. relating to property:

____

____

____

Comments: ____

____

____

2 Condition report (separate sheet for each façade)

Façade examined from: ground level ☐ scaffolding ☐ other ☐

Visible rainwater goods condition: poor ☐ tolerable ☐ good ☐

Any lost or damaged elements: *(e.g. flashings/downpipes)* yes ☐ no ☐

If 'yes', then description: ____

____

Level of soiling: (circle one) extremely heavy heavy fairly heavy moderate light very light none

Distribution of soiling: none ☐ uniform ☐ exposed stone ☐ patchy ☐

Non-biological soiling on façade/s:

Particulate soiling	yes ☐	no ☐	____________
Black gypsum crusts	yes ☐	no ☐	____________
Salts/efflorescence	yes ☐	no ☐	____________
Lime from mortar	yes ☐	no ☐	____________

Biological soiling & growth on façade/s:

Algae	yes ☐	no ☐	____________
Lichens	yes ☐	no ☐	____________
Moss	yes ☐	no ☐	____________
Higher plants	yes ☐	no ☐	____________

Staining of stone due to:

Natural weathering	yes ☐	no ☐	____________
Rainwater run-off	yes ☐	no ☐	____________
Decay of metal fixings	yes ☐	no ☐	____________
Previous stonecleaning	yes ☐	no ☐	____________
Exudate from polymers	yes ☐	no ☐	____________

Other surface effects:

Bleaching	yes ☐	no ☐	____________
Painted stone	yes ☐	no ☐	____________
Graffiti	yes ☐	no ☐	____________

Type:	spray paint	other paint	marker pen	correction fluid	crayon or lipstick	chalk	other ....
Original stone surface:	total loss	largely lost	significant loss	moderate loss	localised losses	largely intact	intact
Sharpness of stone detailing:	total loss	largely lost	significant loss	moderate loss	fairly sharp	largely sharp	sharp
Coverage of stone decay (%):	75-100	50-75	30-50	15-30	5-15	1-5	<1
Coverage of stone replacement or repair (%):	75-100	50-75	30-50	15-30	5-15	1-5	<1
Condition of pointing:	total loss	largely lost	significant loss	moderate loss	localised losses	largely intact	intact

Record information on previous episodes of repair or maintenance: **Y**: yes, **N**: no, **D**: don't know

Intervention	Y/N/D	***Details*** (e.g. dates, method, location, contractor, effects, etc.)
structural repairs	☐	
repointing	☐	
stone replacement	☐	
stone indenting	☐	
plastic repair	☐	
chemical consolidants	☐	
stonecleaning (chemical or abrasive)	☐	
water washing	☐	
chemical water repellent	☐	
consolidation	☐	
other (specify)	☐	

Comments: ______________________________

3 Condition assessment

Ashlar: excellent ☐ good ☐ satisfactory ☐ poor ☐ very poor ☐

Comments: ____

____

____

____

____

Other stonework: excellent ☐ good ☐ satisfactory ☐ poor ☐ very poor ☐

Comments: ____

____

____

____

____

Stone features: e.g. columns, cornices, drip moulds, mullions, pilasters, quoins, string courses, etc.

.... excellent ☐ good ☐ satisfactory ☐ poor ☐ very poor ☐

.... excellent ☐ good ☐ satisfactory ☐ poor ☐ very poor ☐

.... excellent ☐ good ☐ satisfactory ☐ poor ☐ very poor ☐

.... excellent ☐ good ☐ satisfactory ☐ poor ☐ very poor ☐

.... excellent ☐ good ☐ satisfactory ☐ poor ☐ very poor ☐

.... excellent ☐ good ☐ satisfactory ☐ poor ☐ very poor ☐

.... excellent ☐ good ☐ satisfactory ☐ poor ☐ very poor ☐

.... excellent ☐ good ☐ satisfactory ☐ poor ☐ very poor ☐

Comments: ____

____

____

____

____

Joints & pointing: excellent ☐ good ☐ satisfactory ☐ poor ☐ very poor ☐

Comments: ____

____

____

____

____

Rainwater goods: excellent ☐ good ☐ satisfactory ☐ poor ☐ very poor ☐

Comments: ____

____

____

____

____

Causes of soiling:

Natural weathering	yes ☐	no ☐	______
Inadequate maintenance of gutters and/or down-pipes	yes ☐	no ☐	______
Inadequate maintenance of stonework	yes ☐	no ☐	______
Poor detailing	yes ☐	no ☐	______
Moisture retention	yes ☐	no ☐	______
High pollution levels	yes ☐	no ☐	______
Microclimatic effects	yes ☐	no ☐	______
Stonecleaning residues	yes ☐	no ☐	______
Other	yes ☐	no ☐	______

Consequences of soiling:

Causes of stone decay or damage:

Natural weathering	yes ☐	no ☐	______
Poor stone quality	yes ☐	no ☐	______
Moisture retention	yes ☐	no ☐	______
Biological growths	yes ☐	no ☐	______
Hard mortar	yes ☐	no ☐	______
Gypsum crystallisation	yes ☐	no ☐	______
Salt weathering	yes ☐	no ☐	______
Abrasion (stonecleaning)	yes ☐	no ☐	______
Incompatible stone types	yes ☐	no ☐	______
Inadequate plastic repair	yes ☐	no ☐	______
Blockage of porosity	yes ☐	no ☐	______
Metal oxidation	yes ☐	no ☐	______
Anthropogenic	yes ☐	no ☐	______
Other	yes ☐	no ☐	______

Consequences of stone decay:

4 Recommended action & priorities

Are any further tests or investigations necessary to establish façade condition:

Test type	Purpose

Recommended actions:

Immediate:

Urgent: (within 1 year)

Essential: (within 1-5 years)

Desirable: (not structurally or functionally necessary at present)

Predicted outcome of interventions: ______

Recommendations for future façade maintenance: ______

5 Actions and interventions taken on façade/s

Attach façade drawings showing areas where interventions have been carried out and before, during and after photographs. Include any other relevant information including product data sheets and specifications for treatment.

Intervention	*Date*	*Details* (i.e. method, materials, location on façade, contractor)	*Outcome*

Comments: ____

6 Symbols and colours used to map façade condition

Soiling levels

- none
- slight
- low
- moderate
- heavy

Inorganic soiling

- black crusts
- salt efflorescence
- bird droppings
- paint
- graffiti

Organic soiling

- algae
- lichen
- moss
- higher plants

Colour changes

- natural mineral movement
- bleaching (stonecleaning)
- bleaching (other causes)
- staining (stonecleaning)
- staining (metal oxidation)
- staining (sealants/polymers)
- staining (rainwater)
- staining (lime wash-out)

Other features

- inappropriate face bedding
- inappropriate edge bedding
- stone replacement
- indenting
- plastic repair

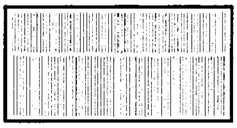
Stone decay types

- granular disintegration
- crumbling
- pitting
- differential decay
- delamination
- blistering
- flaking
- contour scaling
- multiple scaling
- decay of components
- dissolution
- honeycombing
- back weathering
- case hardening
- mechanical damage
- fissures
- abrasion by cleaning

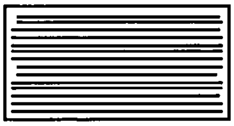
APPENDIX D
SURFACE FINISHES ON STONE

Smooth or polished: A true polished, reflective surface can be obtained on granite and other hard, dense stone types. Sandstone does not take a high polish but is often finished to a smooth surface.

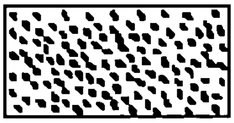
Droved or boasted: Stone is worked with a broad chisel to give a series of wide bands (35-50mm) of faint, parallel tool marks running horizontally, vertically or diagonally. A droved finish is common on the margins of stones with other finishes.



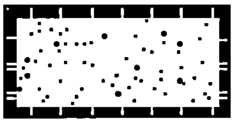
Broached or tooled: The stone is worked with a pointed chisel to form equally spaced (normally between 3-10mm spacing), horizontal or vertical grooves or furrows. A finish with continuous, fine lines is also known as 'tooled'. This example has a smoothly finished, drafted margin.



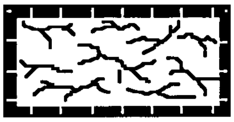
Punched, dabbed or stugged: The rough stone surface is worked with a pointed chisel or mason's punch. Stugged or dabbed surfaces have a coarser, chiselled pattern.



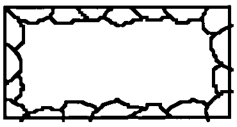
Picked, pointed or jabbed: The stone is worked with a pointed chisel or mason's punch as in the stugged finish, but the pits are finer. A droved margin may be left around the edge of the stone.



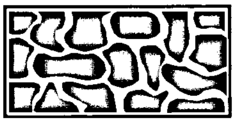
Rock-faced, rusticated, bull-faced or pitch-faced: The stone is worked with a punch to recreate the natural rock surface by producing a central rough raised area with a marginal draft. There is often a droved (as shown here) or drafted margin. This finish is commonly used in basements or base courses.



Pinched: The perimeter of the block is roughly removed with a chisel. The interior of the face is left smooth. This finish is commonly used on base course blocks.



Vermiculated: The finish on the stone produces a continuous winding pattern raised above the inner area of the stone. There is normally a smoothly finished, drafted margin.



APPENDIX E: SOURCES OF BUILDING STONE

Sandstones (including quartzite)

Sandstone	Location	Age	Grain size	Description	Owner, operator or supplier
Appleton	Halifax, West Yorkshire	Carboniferous Coal Measures	Fine	Fawn to darker mottled brown	Marshalls Natural Stone Division
Bearl	Stocksfield, Northumberland	Carboniferous Coal Measures	Fine-medium	White-beige, fairly uniform in colour. Gritty texture, quite hard. Black bands (mafics) on bedding layers. Micaceous	Dunhouse Quarry Ltd
Beestone	Whitehaven, Cumbria	Triassic	Fine-medium	Deep plum red	Block Stone Ltd.
Binny	Uphall, West Lothian	Lower Carboniferous	Fine-medium	Pale yellowish-brown	Temporary reopening of quarry, see Appendix A
Birchover	Birchover, Derbyshire	Carboniferous Millstone Grit	Medium-coarse	Gritstone. Pink to buff	George Farrar (Quarries) Ltd
Black Pasture	Hexham, Northumberland	Carboniferous Millstone Grit	Fine-medium	Light buff, with small ferruginous specks	Scottish Natural Stones Ltd.
Blaxter	Otterburn, Northumberland	Lower Carboniferous	Medium	Yellow/ochre. Also available in striped form	Dunhouse Quarry Ltd.
Catcastle	Lartington, Co. Durham	Carboniferous Millstone Grit	Medium-coarse	Creamy buff/grey, dark speckles & striations, coarser bands	Dunhouse Quarry Ltd.
Clashach	Hopeman, Moray	Upper Permian	Fine	Buff/fawn to streaked yellowish/orange varieties	Moray Stone Cutters
Copp Crag	Byrness, Co. Durham	Lower Carboniferous	Fine	Buff/yellow ranging through to very strong orange/salmon pink	Dunhouse Quarry Ltd.
Corncockle	Lochmaben, Dumfriesshire	Permian	Medium	Red-brown. Grain well rounded, cement supported	Dunhouse Quarry Ltd.
Corsehill	Annan, Dumfriesshire	Triassic	Fine	Red-brown. Presence of iron nodules / inclusions evident	Dunhouse Quarry Ltd.
Cove	Cove Quarry, near Kirk Patrick Flemming, Scotland	Triassic	Fine	Red, some bedding plane markings	Block Stone Ltd.
Crosland Hill	Crosland Hill, Huddersfield, Yorkshire	Carboniferous Millstone Grit	Fine-medium	Light buff	Johnsons Wellfield Quarries Ltd
Darney	W. Woodburn, Northumberland	Lower Carboniferous	Fine	White to pale buff, brown speckles or light veining	Natural Stone Products Ltd.
Doddington	Wooler, Northumberland	Lower Carboniferous	Fine-medium	Light to deep purplish pink with occasional rust coloured markings Speckled	Natural Stone Products Ltd. & Stainton Quarry

Donegal Quartzite	Larcybrack Quarry, Donegal	Carboniferous	-	Pale buff/grey with iron staining	McMonicle & Sons
Dunhouse	Staindrop, Co. Durham	Carboniferous Millstone Grit	Fine	Blonde, uniform colour	Dunhouse Quarry Ltd.
Dunmore	Cowie, Nr Stirling	Carboniferous Coal Measures	Fine	Buff/cream/white, slightly micaceous	Scottish Natural Stones Ltd.
Dukes	Ambergate, Derbyshire	Carboniferous Millstone Grit	Fine-medium	Pink-lilac gritstone	Block Stone Ltd.
Flash	Matlock, Derbyshire	Carboniferous Millstone Grit	Medium	Light buff or cream with some veining	Block Stone Ltd.
Gatelawbridge	Thornhill, Dumfriesshire	Permian	Fine	Warm red to reddish brown	Scottish Natural Stones Ltd.
Grinshill	Clive, Shropshire	Triassic	Fine	Cream to buff	Grinshill Quarries
Halldale Gritstone	Darley Dale, north of Matlock, Derbyshire	Carboniferous Millstone Grit	Fine-coarse	Yellow-brown. Coarser stone is yellow-grey	Stancliffe Stone Co Ltd.
Hillhouse Edge	Holmfirth, West Yorkshire	Carboniferous Millstone Grit	Fine-medium	Fawn with brown speckling	George Grahams Sons & Co.
Locharbriggs	Locharbriggs, Dumfriesshire	Permian	Medium	Pink to warm red, darker bedding plane markings	Stancliffe Stone Co Ltd.
Newbigging	Burntisland, Fife	Lower Carboniferous	Medium	Light yellowish grey	Scottish Natural Stones Ltd.
Peakmoor (formerly Stanton Moor)	Matlock, Derbyshire	Carboniferous Millstone Grit	Fine-medium	Freestone. Buff with occasional pink markings and/or brown iron intrusions	Block Stone Ltd.
Plumpton Red Lazonby	Lazonby Fell, Penrith	Permian	Fine-medium	Pale red to dark pink, sparkling	Cumbria Stone Quarries Ltd. & Stancliffe Stone Co Ltd.
Red St Bees	Whitehaven, Cumbria	Triassic	Fine	Deep or bright red	Cumbria Stone Quarries Ltd. & Stancliffe Stone Co Ltd.
Rockingstone	Bolster Moor, near Huddersfield, Yorkshire	Carboniferous Millstone Grit	Medium-coarse	Pale yellow buff with red/brown veining. Micaceous	Johnsons Wellfield Quarries Ltd.
Scotch Buff	Scotch Corner, Yorkshire	Carboniferous Westphalian	Medium	Warm buff colour with dark bed markings and iron-rich patches	Block Stone Ltd.
Shire	Glossop, Derbyshire	Carboniferous Millstone Grit	Medium	Buff to grey with some clay patches	Block Stone Ltd.
Springwell	Springwell, Gateshead	Carboniferous Coal Measures	Fine	Buff/fawn	Natural Stone Products Ltd. & Springwell Quarry
Spynie	Elgin, Moray	Triassic	Fine	Yellowish grey/buff, calcareous	Moray Stone Cutters
Stainton	Stainton, Co. Durham	Upper Carboniferous	Fine-medium	Buff, fine brown speckles & veining	Natural Stone Products Ltd. & Springwell Quarry
Stanton Moor	Stanton-in-Peak, Matlock, Derbyshire	Carboniferous Millstone Grit	Fine-medium	Buff, with variations of golds and pinks	Stancliffe Stone Co Ltd.
St Bees & Springwell Quarry	Whitehaven, Cumbria	Triassic	Fine	Dark red	Natural Stone Products Ltd.
Stancliffe	Darley Dale, Derbyshire	Carboniferous Millstone Grit	Fine-medium	Buff to pink, compact, micaceous, brown speckles	Stancliffe Stone Co Ltd.

Stokehall	Hope Valley, Derbyshire	Carboniferous Millstone Grit	Fine-medium	Buff coloured	Stoke Hall Quarry (Stone Sales) Ltd
Stoneraise Red	Lazonby Fell, Penrith	Permian	Coarse	Salmon pink with speckle	Block Stone Ltd.
Streatlam Buff	Moresby, Whitehaven, Cumbria	Carboniferous Westphalian	Fine to medium	Pale yellow with brown staining liesegang rings	Dunhouse Quarry Ltd.
"Tenyard" Hard York	Keighley, West Yorksire	Carboniferous	Fine	Pale yellow-brown, laminated	Bradley Natural Stone Products
Torrington	Beam Quarry, Barnstaple, Devon	Carboniferous	Very fine	Dark grey sandstone/ siltstone	Torrington Stone Ltd
Waddington	Clitheroe, Lancashire	Carboniferous Millstone Grit	Fine-coarse	Buff to grey colour	Waddington Fell Quarries Ltd
Wattscliffe	Elton, Nr. Matlock, Derbyshire	Carboniferous Millstone Grit	Medium	Lilac or grey with occasional buff or white intrusions	Block Stone Ltd.
Woodkirk Brown	Morley, West Yorkshire	Carboniferous Coal Measures	Fine	Grey buff to light brown. Darkens as it ages	Britannia Quarries

Granites

Granite	Location	Description	Owner/operator/ supplier
Corrennie	Tillyfourie, Aberdeenshire	Medium-fine, pink, occasional grey shades	Fyfe Glenrock
Creetown	Creetown, Galloway	Silvery grey, medium grained	Galloway Granite
Dalbeattie	Dalbeattie, Galloway	Grey, medium grained	Galloway Granite
Kemnay	Kemnay, Aberdeenshire	Medium-fine, silver-grey, occasional pink shades	Fyfe Glenrock
Shap Pink	Shap, Cumbria	Coarse, light grey-pink to dark pink-brown	Stainton Quarry & Natural Stone Products
Peterhead	Peterhead, Aberdeenshire	Pink	Galloway Granite
Ross of Mull	Tormore Quarry, Fionnphort, Isle of Mull	Biotite microcline granite, warm pink/red with pale grey/brown felspars	Scottish Natural Stones Ltd

APPENDIX F
QUARRY OWNERS, OPERATORS AND SUPPLIERS

Block Stone Ltd. (part of the Realstone Group)
Bolehill Lane, Wingerworth, Chesterfield, Derbyshire, S42 6RG, UK
Tel: +44 (0) 1246 554450
Fax: +44 (0) 1246 220095
Web: www.blockstone.co.uk

Bradley Natural Stone Products
Bradley House, Greengate Road, Keighley, West Yorkshire, BD21 5LH, UK
Tel: +44 (0) 1535 610776

Britannia Quarries
Mike Durkham Britannia Quarries, Rein Road, Morley, Leeds, LS27 0SW, UK
Tel: +44 (0) 113 2530464
Fax: +44 (0) 113 2527520

Cumbria Stone Quarries Ltd.
Silver St, Crosby Ravensworth, Cumbria CA10 3JA, UK
Tel: +44 (0) 1931 715227
Fax: +44 (0) 1931 715367
Web: www.thestancliffegroup.co.uk

Dunhouse Quarry Ltd.
Dunhouse Quarry Works, Staindrop, Darlington, County Durham DL2 3QU, UK
Tel: +44 (0) 1833 660 208
Fax: +44 (0) 1833 660 748
Web: www.dunhouse.co.uk

Fyfe Glenrock
Enterprise Drive, Westhill Industrial Estate, Westhill, Aberdeen AB32 6QT, UK
Tel: +44 (0) 1224 744101
Fax: +44 (0) 1224 743911
Web: www.fyfe-glenrock.com/

Galloway Granite
Sorbie, Newton Stewart, Dumfries, DG8 8EW, UK
Tel: +44 (0) 1988 850350
Fax: +44 (0) 1988 850340
Web: www.GallowayGranite.co.uk

George Farrar (Quarries) Ltd.
Bradford Street, Keighley, West Yorks, BD21 3EB, UK
Tel: +44 (0) 1535 602344
Fax: +44 (0) 1535 606247
Web: www.farrar.co.uk

George Grahams Sons & Co.
Hillhouse Edge Quarries, Cartworth Moor, Holmfirth, Nr Huddesfield, W Yorkshire, HD7 1RL, UK
Tel: +44 (0) 1484 683239 / 684152
Fax: +44 (0) 1484 684153

Grinshill Quarries
Clive, Near Shrewsbury, Shropshire, SY4 3LF, UK
Tel: +44 (0) 1939 220522
Fax: +44 (0) 1939 220285

Johnsons Wellfield Quarries Ltd.
Crosland Hill, Huddersfield, West Yorkshire HD4 7AB, UK
Tel: +44 (0) 1484 652311
Fax: +44 (0) 1484 460007
Web: www.johnsons-wellfield.co.uk

Marshalls Natural Stone Division
Southowram, Halifax, West Yorkshire. HX3 9SY, UK
Tel: +44 (0) 1422 306000
Fax: +44 (0) 1422 306197
Web: www.marshalls.co.uk

McMonicle & Sons
Larceybrack Quarry, Glencolumbkille, Co. Donegal, Eire
Tel: 00 353 073 35061
Fax: 00 353 073 35408

Moray Stone Cutters
Birnie, Elgin, Moray, IV30 8SW, UK
Tel: +44 (0) 1343 860244

Natural Stone Products Ltd.
Darlton Masonry, Stoney Middleton, Hope Valley S32 4TR, UK
Tel: +44 (0) 1833 690444
Fax: +44 (0) 1833 690377

Scottish Natural Stones Ltd.
Edinburgh Road, Springhill, Shotts ML7 5DT, UK
Tel: +44 (0) 1501 823248
Fax: +44 (0) 1501 823058

Springwell Quarry
Tel: +44 (0) 191 4877842 / 4
Fax: +44 (0) 191 4820774

Stainton Quarry
Barnard Castle, Durham, DL12 8RB, UK
Tel: +44 (0) 1833 690444
Fax: +44 (0) 1833 690377

Stancliffe Stone Co Ltd.
Grangemill, Matlock, Derbyshire DE4 4BW, UK
Tel: +44 (0) 1629 650859
Fax: +44 (0) 1629 650996
Web: www.thestancliffegroup.co.uk/

Stoke Hall Quarry (Stone Sales) Ltd.
Grindleford, Hope Valley, Derbyshire, S32 2HW, UK
Tel: +44 (0) 1433 630313
Fax: +44 (0) 1433 631353

Torrington Stone Ltd.
Beam Quarry, Torrington, Devon, EX32 8JF, UK
Tel: +44 (0) 1805 622438 / 01271 343087

Waddington Fell Quarries Ltd.
Fell Rd, Waddington, Nr. Clitheroe, Lancashire, BB7 3AA, UK
Tel: +44 (0) 1200 446334

APPENDIX G
USEFUL ADDRESSES

Architectural Heritage Society of Scotland
The Glasite Meeting House, 33 Barony Street,
Edinburgh EH3 6NX, UK
Tel/Fax: +44 (0) 131 557 0019/0047
Email: glasite@ahss.org.uk
Web: http://www. ahss.org.uk

British Geological Survey (England)
Keyworth, Nottingham NG12 5GG, UK
Tel/Fax: +44 (0) 115 936 3100/3200
Web: http://www.bgs.ac.uk

British Geological Survey (Scotland)
West Mains Road, Edinburgh EH9 3LA, UK
Tel/Fax: +44 (0) 131 667 1000/668 2683

Building Research Establishment Ltd. (England)
BRE Garston, Bucknalls Lane, Garston,
Watford WD2 7JR, UK
Tel/Fax: +44 (0) 1923 664 000/010
Email: enquiries@bre.co.uk
Web: http://www.bre.co.uk

Building Research Establishment Ltd. (Scotland)
BRE East Kilbride, Kelvin Rd, East Kilbride,
Glasgow G75 0RZ, UK
Tel/Fax: +44 (0) 1355 576 200/210

Edinburgh World Heritage Trust
5 Charlotte Square, Edinburgh EH2 4DR
Tel: +44 (0) 131 220 7720
Fax: +44 (0) 131 220 7730
Email: info@ewht.org.uk
Web: http://www.ewht.org.uk

English Heritage
Customer Services Department ,
PO Box 569, Swindon
SN2 2YP, UK
Tel/Fax: +44 (0) 1793 414 910/926
Email: customers@english-heritage.org.uk
Web: http://www.english-heritage.org.uk

Glasgow Conservation Trust West
30 Cranworth Street, Hillhead,
Glasgow G12 8AG, UK
Tel/Fax: +44 (0) 141 339 0092
Email: GLASGOWWEST@cqm.co.uk
Web: http://users.colloquium.co.uk
~GLASGOWWEST/home.htm

Historic Scotland
Longmore House, Salisbury Place,
Edinburgh EH9 1SH, UK
Tel: +44 (0) 131 668 8600
Web: http://www.historic-scotland.gov.uk

Natural Stone Institute
Room 133, Pentlandfield Business Park
The Bush, Roslin
Midlothian EH25 9RE, UK
Tel:+44 (0) 131 440 9473
Fax: +44 (0) 131 440 4032
Email: amckinney@support-services.fsbusiness.co.uk

Royal Incorporation of Architects in Scotland
15 Rutland Square, Edinburgh EH1 2BE, UK
Tel: +44 (0) 0131 229 7545
Web: http://www.rias.org.uk

Royal Institute of British Architects
66 Portland Place, London W1B 1AD, UK
Tel/Fax: +44 (0) 207 580 5533/ 255 1541
Web: http://www.architecture.com

Scottish Stone Liaison Group
Room 133, Pentlandfield Business Park
The Bush, Roslin
Midlothian EH25 9RE, UK
Tel:+44 (0) 131 0313
Fax: +44(0) 131 4032
Email: amckinney@support-services.fsbusiness.co.uk

Society for the Protection of Ancient Buildings
37 Spital Square, London E1 6DY, UK
Tel/Fax: +44 (0) 207 377 1644/247 5296
Web: http://www.spab.org.uk/index.html

Society for the Protection of Ancient Buildings in Scotland
The Glasite Meeting House, 33 Barony Street,
Edinburgh EH3 6NX, UK
Tel: +44 (0) 131 557 1551

Stone Federation of Great Britain
Channel Business Centre, Ingles Manor, Castle Hill
Avenue, Folkstone, Kent CT20 2RD, UK
Tel:+44 (0) 1303 856 123
Fax: +44 (0) 1303 221 095
Email: jane.buxey@nscc.org.uk
Web: http://www.stone-federationgb.org.uk