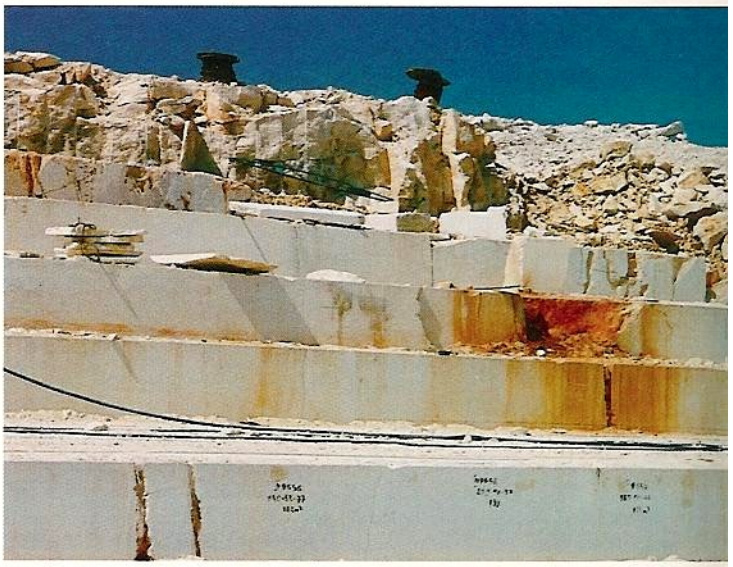
Designing

Lime runs on stone discoloured by the effects of long term pollution.



Dark discolouring materials can be seen at source spreading from large joint structures into the surrounding lighter stone. Selection of the stone at the quarry means you can exclude stone containing the unwanted colour.

Discoloration or staining? Materials may be rising into the stone from the bedding sand and cement or being drawn from the stone itself with the passage of liquids.

out the problem

Stone is generally used in construction because the designer likes the look of it. That look can be ruined by staining or discoloration. But it need take only minor design modifications to eliminate the problem. Consultant stone specialist Barry Hunt explains.*

NATURAL STONE evokes a feeling of permanence and grandeur in construction. It appears unchanging in a world that is forever moving forward. Stone possesses a depth of colour and wildness of natural features which cannot be matched by man-made rivals which are flat by comparison. But natural beauty always has a price and stone's is an unpredictable and temperamental nature which must be attended to carefully if the stone is not to become spoilt.

Modern, cost-effective construction demands innovative stone use to reduce the cost-intensive regimes normally associated with traditional stone masonry. Stone has become more accessable and the variety of situations in which it is used has multiplied rapidly. New resources have been tapped to meet supply and, increasingly, new materials have been employed within the masonry. These factors have added a greater complexity to stone use and with it both new problems and the re-birth of old problems in new guises. One of these problems is an unexpected change in appearance of the stone, sometimes with dramatic and disastrous effect.

Looks are everything with stone but, rather surprisingly, stone research to date has concentrated on strength and durability characteristics and not the factors that may affect the all-important appearence. Strength and durability are merely afterthoughts to stone selection. Thorough assessment combined with good design, installation and maintenance should eliminate strength and durability problems. But there is little guidance when addressing appearance.

Staining and discoloration have become an unwanted overnight sensation, encapsulating everything that is fragile and unpredictable with stone. Lack of guidance has meant that such problems were often written off as something that would disappear naturally. This was rarely the case. General use might tone down the effects, but it does not remove them. Poultices and other proprietary products can be tried and do work on some kinds of staining. Even if a stain or discoloration is removed, there could be a high risk of recurrence without addressing the cause.

Staining and discoloration are terms which are often used synonymously. But they describe distinctly different phenomena, although the results often look similar. Staining occurs when foreign materials are introduced, such as the spread of rust from a metal fixing. Discoloration, on the other hand, occurs as a result of a change in part or all of the natural stone constituents using foreign materials as a catalyst. A good example of discoloration is alkaline water passed from cement to limestone. In the stone the water dissolves out dark organic materials which are naturally contained by the limestone and redeposits them on the stone surface.

Discoloration must be regarded as the more undesirable of the two phenomena as it involves some degree of stone deterioration which can effect the strength and durability quite seriously.

It takes very little of the ▶

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	Erratic Spotting	Overall Discoloration	Patchy Discoloration	Related to Stone Features	Related to Construction Features
Quarrying and Finishing Processes	cutting residues – iron shot	acid cleaning	oil, ink and other spillages	weathered materials entering stone	uneven finishing
During Construction	welding/grinding spatter	general dirt and dust	decay of packaging		reaction with protective sheetong
		fire damage	moisture		dirt in joints etc.
Post-Construction	alteration of flame-textured constituents, then decay, heel impact damage	Introduced contaminants from shipping/transport		dirt concentrated in high porosity areas	rust of fixings etc. uneven loss of polish growth of organics
		abrasion,surface attack, pollution	efflorescences, general usage, spillages	growth of organics	
Inferior Stone Materials	trace mineral decay	ageing, bleaching		deleterious minerals in veins and other discontinuities	
		reaction with cleaning materials – maintenance	decay in moisture – affected zone		
Associated Materials		organic growth, wax discoloration	migration of materials by moisture flow	incorrect impregnation	joint mastic/silicone decay, ageing of epoxy resins

Table 1. Aesthetic reasons often dominate the choice of a given stone but there are many factors which can upset the final appearance, as illustrated here. Inferior stone and associated materials can affect aesthetics at any stage in the life of a stone.

staining or discolouring reaction products to cause a dramatic change in the appearance of the stone as the reaction products typically include a number of essentially amorphous (non-crystalline) solids which are characteristically opaque – ie they do not exhibit the light-transmission properties of the bulk stone crystals. Analysis of the reaction products, therefore, is difficult. And the difficulty is compounded by the stone constituents which will often contain the same elements.

Now, though, surface technology developed for the semiconductor and other industries has allowed the true nature of reaction products to be ascertained and the causes traced.

Different stain and discoloration occurences have been found to be specific to certain stages in a stone's life – from its position within a quarry to its place in construction. Certain problems could occur at any time but require specific environmental conditions or combinations of other material effects. Five different general forms have become apparent (Table 1).

Table 1 is not exhaustive but is a reasonable first guide to identifying the cause of a particular stain or discoloration.

Having identified the ways by which stains and discolorations may manifest themselves, a closer eye could then be turned to the underlying factors and how to reduce them to avoid similar occurences in the future.

Many examples of staining and discoloration are the products of issues involved in general care, and are thus beyond the scope of this article. Designing out discoloration and staining, however, necessitates close examination of five major factors: stone properties; other material properties; action of liquids; surface wear; maintenance regimes. These factors are often found to be linked in a variety of ways.

The key to controlling the effects of staining and discoloration is the control of stone's ability to take on stains or spreading discolorations. The materials causing these problems have to reside somewhere. If they sit on the surface they can be removed easily but if they get into the stone, filling crystal grain boundaries, cleavage traces and other natural features, they may be unremovable.

Method	Reasons for carrying out test	Potential disadvantages
Quarry inspection	Identifies fresh and weathered materials, potential for discoloration and presence of alien materials.	Incorrect interpretation of the geology may prove expensive.
Petrographic Examination	Determines mineral types and possible evidence of deterioration.	Assessmnet is at an instant in time. Discolorations may be 'invisible' to methods.
Wetting and Drying Cycling	Simple test to promote oxidation.	May not work other than for highly reactive mineral forms.
Solution Testing	Partial immersion in acid, alkaline and neutral solutions to promote possible discolouring mechanisms.	May not work but will indicate a reasonable degree of resistance.
Block Testing	Setting of small stone blocks with mortar, silicones, impregnators etc and partially immersing in different pH solutions to promote possible discolouring mechanisms.	Can be time consuming, particularly with respect to assessing spread of silicone oils. May not mimic exact conditions of use.
Ink Spot Test	Very simple test to assess ability for stone to take up staining or discolouring materials.	None – an indicative test.

Table 2. Principal methods of assessment for staining and discoloration properties of stone and associated materials.

The spread of stains and discolorations into stone requires water, or some liquid phase, and if a barrier can be put up to such transmission then stain and discoloration products will remain on the surface where they can be removed. There are, then, two options: seal or impregnate.

Sealing may not be desirable in many instances as residual coatings may deteriorate or need to be re-applied intermittently. Additionally, sealing may stop the stone from 'breathing', trapping unwanted materials and leading to other problems.

Correct impregnation does not leave residual surface films and with the right materials will allow vapour transmission. Impregnation is also less likely to affect colour.

The art of impregnation is employing materials of different molecular size and finding out which suits a particular stone best.

Silanes, siloxanes and silicones are all used for impregnation. Silanes exhibit the best penetration as a result of their small molecular size. Silanes will penetrate deep into porous stones such as limestone. But they will be unable to fill the larger pores for which a siloxane or even silicone may be required. There is still scepticism over the use of impregnating agents and further research is required, but there may be a good future for these materials.

If impregnation is not an option, then a more rigorous approach to the selection of a particular stone and the materials to be used around it is required. Working examples for a given design should be identified and assessed for their success in preventing staining and discoloration.

Changes in material qualities (especially stone's), subtle differences in environmental factors and design detailing all mean that a stone must undergo some form of further investigation into staining and discoloration properties. An outline of the investigation methods available and the types of test that can be devised is presented in **Table 2**. The stone can be tested either separately and rejected if problems are found, or in combination with other materials which may prove that a potential discoloration mechanism can be controlled.

Whether or not liquids are able to penetrate or be transmitted by a stone, the surfaces still present themselves for reaction and surface staining effects. The most common discolouring reaction is that involving iron-sulphur mineral compounds which are found in all rock types, though in variable forms and concentrations.

Iron-sulphur mineral reaction is still not fully understood and there is no indicative test to promote the reaction, although wetting and drying cycling and lime water testing may show up some highly reactive forms.

Petrographic examination methods become important for identifying potentially problematic iron-sulphur mineral forms and any other potentially discolouring minerals.

Acidic and alkaline conditions are both found to increase iron-sulphur mineral decay and, indeed, most other mineral reactions, and must be avoided. If liquids cannot be avoided, they must be controlled to a neutral pH.

The materials used around a stone present a permanent threat of staining or providing a catalyst for discoloration. They fall broadly into three categories: bedding; jointing; fixing materials.

Bedding materials may contain aggregate which can release coloured compounds. Aggressive alkali-hydroxides within the cement may attack certain stone constituents. Joints may be cementitious but silicones and other mastic materials may be used, especially in cladding systems. Silicones can slowly release oils into stone causing localised darkening, but this problem largely has been combated by the manufacturers of these materials.

Unforeseen problems do still occur. One instance involving mastics happened when floor joints literally dissolved under the attack of alkali-hydroxides derived from underlying bedding materials, the reaction products spreading across the marble floor. Fixing may also be by cements, but adhesives or metal fixings, which must be stainless, are otherwise expected. I have yet to experience a problem with substrate glues or resins.

Physical abrasion can have a dramatic effect on floor appearances, most notably for dark stones. As surfaces become scratched, light is increasingly reflected and scattered from the surface rather than penetrating the stone and picking up the natural colour. This light scattering causes a lightening in colour. For a white stone the effect is imperceptible, but for a black stone ▶

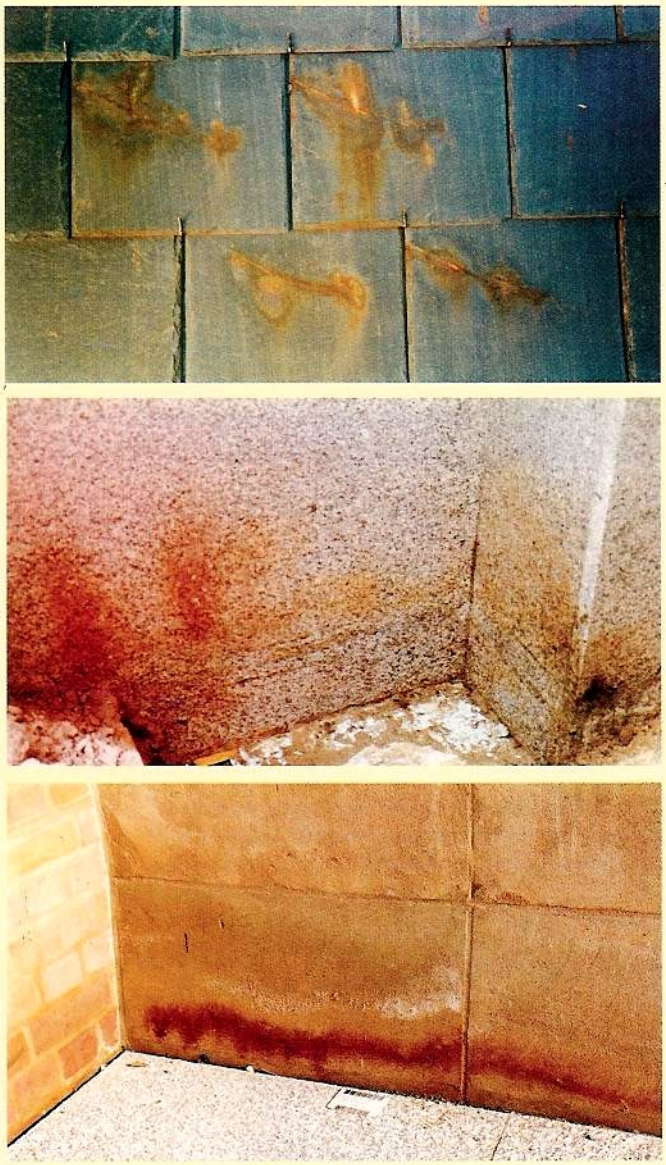
even minor surface roughening can make it appear light grey.

Impact damage from metal shoe heels can cause star-marking in softer stones which can lighten stone appearance, even for white stones, and which cannot be avoided if stone is to be trafficked. On large expanses of dark stone variations in pedestrian traffic can cause trafficking lines to appear within a matter of weeks. Uneven wear will also result when slabs are not laid flush in relation to each other as raised edges will abrade more quickly, leading to a lightening of the stone close to these zones. Surface evenness must be checked to achieve less than 0.5mm difference in level between adjacent slabs. For these reasons, large expanses of dark stone are best avoided for flooring.

Stone maintenance can only be carried out properly once the limitations of the stone and associated materials have been addressed. The maintenance must complement any precautions against staining and discoloration that have been taken while considering the in-service environmental conditions. Unless moisture is trapped behind a stone, which is an example of a straightforward design fault, maintenance should be carried out only on external faces.

Maintenance will vary with the amount of day-to-day wear and tear in combination with the stone type and whether the stone is internal or external, flat or featured, horizontal or inclined. The principal factors involved in maintenance are the avoidance of liquids at all costs and keeping dirt off surfaces. Where liquids cannot be avoided, their impact must be kept to a minimum and, if possible, they must be kept to a neutral pH. Regular dry brushing and/or wiping and carefully placed entrance matting are typical simple measures which can greatly reduce longer term maintenance costs, including complete stone replacement.

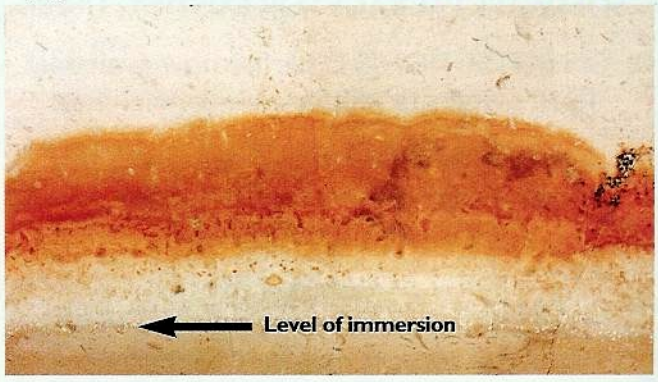
With a modicum of initial care and relatively small modifications to design concepts, the occurrence of staining and discoloration, wherever it might occur, could become significantly reduced. ■

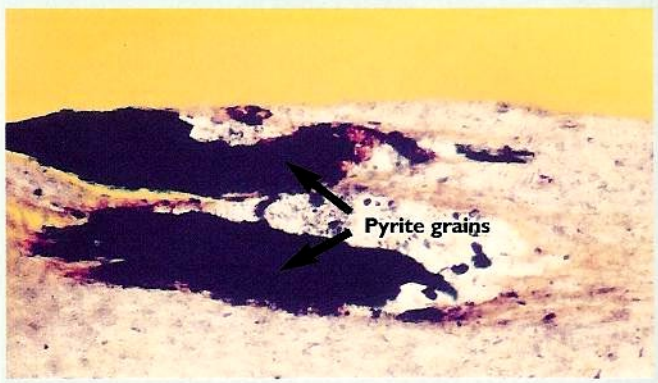


Discoloration and staining spoils the all-important look of stone. Shown here are the spread of the oxidisation of pyrite in slate on a roof (top), bedding materials on granite (middle) and staining on limestone.

Right. Ultra-violet light fluorescence of a discoloured slate impregnated with UV-sensitive dye resin highlights sub-surface delamination (approx x150 magnification).

Below. Light buff/cream limestone subjected to partial immersion testing in an alkaline solution mimicking the effects of solutions that might be drawn through the stone from adjacent Portland-type cements. Organics present within the stone are rapidly drawn to the surface where they are deposited in the drying zone.





Surface and near-surface pyrite grains in slate which are oxidising resulting in the spread of iron oxide and hydroxide compounds.