Modes of decay

Understanding the modes of decay of sandstone is an essential prerequisite in the conservation of stonework. The successful arrest of decay cannot be achieved without an understanding of the mechanisms that have caused it. The types of decay, and the causes, are many and various.

In almost every instance, the cause of decay is likely to be a combination of several of the factors listed in the table. The more prevalent types of decay and their various causes are as follows.

Disaggregation

The disaggregation of sandstone is characterized by the breakdown of the intergranular clays or other minerals that bind together the grains of silica which are the major characteristic component of Australian sandstones. Where disaggregation occurs, the surface of the stone becomes friable, silica grains fall to the ground, and the stone gradually erodes, (**Fig. 1**). The causes of this type of decay in Australian sandstones are almost always to do with the effects of a phenomenon known for many years in South Australia, (where the problem is prevalent), as 'salt damp'.

Types of Decay	Causes of Decay
Disaggregation	Water
Delamination/Exfoliation	Rising damp
Contour exfoliation	Falling damp
Efflorescence	Soluble salts
Cryptofluorescence	Wind
Cracking	Sunlight
Alveolar & differential erosion	Heat
Preferential erosion	Ferrous fixings
Pitting	Lichens/plants
Flaking	Paints/sealants
Blistering	Incompatible materials/ poor workmanship
Mechanical damage	Incorrect bedding
	Case-hardening

Certain soluble salts have the capacity to be extremely detrimental to the surface structure of Australian sandstones. Borne through rainwater, ground water, stormwater run-off, sewerage leaks, and in coastal areas sometimes airborne through fine sea spray, sulphates, chlorides and nitrates can cause significant damage. Due to the inherent porosity of many sandstones, the soluble salts can penetrate the stone with relative ease. On evaporation, the salts are deposited at or near the surface, where the highly destructive process of crystallization breaks down the physical bonds that exist between the particles of quartz and clays which essentially constitute the sandstone.

In areas of high exposure to salts, disaggregation of stone can be so severe as to undermine the structural stability of the building. Some of the sandstone buildings on Sydney Harbour's Spectacle Island, for example, demonstrate such severe deterioration, (**Fig. 2**). Here the sandstone is not only exposed to airborne salts from the harbour, but also to high concentrations of salts rising in moisture from the ground, much of which is fill dredged from the harbour floor.

The presence alone of these soluble salts does not cause stone to decay. It is the evaporation cycle that leads to deterioration. Sandstones in sea walls, for example, whilst saturated with salts, are likely to be in excellent condition below the mean low water mark where they never dry out. Similarly, walls affected by rising salt damp, but which are in permanent shade often show negligible effects of damage, whilst those stones a few feet away that happen to catch the morning or afternoon sun will exhibit signs of disaggregation. A typical eastern or western church aisle wall characterized by bays of stonework interrupted by protruding buttresses will often exhibit a pattern of decay being absent in the corners shaded by the buttresses and present in the opposing corners that catch the sun.

Disaggregation also frequently occurs on the soffits of cornices. An exposed horizontal surface of a projecting cornice will allow the steady downward passage of rainwater, which due to the effects of atmospheric pollution will frequently contain harmful soluble salts. These salts will ultimately be deposited on the horizontal surface

Figure 1. *Disaggregation of external ashlar in the lower courses of a Hobart building. (Photo: Jasper Swann, 2008)*

Figure 2. *Severe disaggregation caused by salt damp, Spectacle Island, Sydney Harbour. Note the collapse of the vent formerly located in the wall. (Photo: Jasper Swann, 2007)*

of the soffits causing disaggregation at the surface. This condition is often exacerbated by the effects of wind, with localized eddy currents being active in the throat of the cornice, progressively hollowing out the soffits. More commonly, though, the decay takes the form of sheet exfoliation and granular disintegration.

Delamination & Exfoliation

The terms delamination and exfoliation define the delaminating or sheeting-off of layers of sandstone, either on horizontal or vertical surfaces. The layers may be anywhere from 2-40mm in thickness. **Figures 3-5** show examples. If there is any substantial difference between the two, delamination may be said to relate primarily to the natural bedding planes of the sandstone, whilst exfoliation may be said to relate to a loss primarily as a consequence of environmental factors.

Exfoliation if often caused by a phenomenon that occurs frequently in certain sandstones, (and limestones), and especially Sydney yellowblocks, known as case hardening. Case-hardening is an important physical characteristic of sandstone to understand. The phenomenon occurs most frequently in those stones rich in iron and manganese, and involves deposition of a thin layer of oxides of either or both of these elements at the surface. Some of these minerals will migrate to the surface as the initial 'quarry sap' dries out. Equally, as most sandstones allow the free movement of water within them due to their relatively high porosity, minerals within the stone can be readily dissolved and transferred to the surface on an ongoing basis as the stone repeatedly wets and dries.

The outer hardened layer that results – the 'case-hardening' – may serve to temporarily protect the surface of the stone from the effects of weathering. For this reason, it is sometimes represented as being a beneficial and desirable characteristic of a stone. This outer layer, being less permeable to moisture, often prevents the migration of soluble salts to the surface, causing a sub-surface build-up and crystallization of deposited salts and a consequential sheet-delamination of the surface. The deposition of salts at the surface will in any case eventually cause some deterioration of the stone, but where case-hardening is present, the effects of deposition *beneath* the surface can be more dramatic and more severe. This is a common occurrence, particularly in Sydney yellowblock sandstones, and examples are plentiful. The presence of salts, however, is not a prerequisite for the surface delamination of the case-hardened layer. Differential rates of thermal expansion in the harder and softer layers of stone can be sufficient to cause it to occur.

Figure 6. *The southwest (left) and northeast faces of a Sydney church spire, showing sheet exfoliation of the faces exposed to the sun. (Photo: Jasper Swann, 2010)*

A recently restored Sydney church spire demonstrated this well. All faces of the spire had been exposed to the same levels of pollution for 140 years, but the south western faces, never being exposed to the sun, remained in sound condition, whilst the faces exposed to the suns rays had suffered extensive sheet exfoliation, (**Fig.6**).

Contour Exfoliation

Contour exfoliation of stone is characterised by loss of the surface along the sectional contours of a profiled stone. Whilst a stone is in this mode of decay, and may lose anything from 1-20mm of its surface in a single exfoliation, it nonetheless retains its profile, albeit in a more weathered and less well defined state, (**Figs. 7** and **8**). An ogee moulding, for example, may lose its surface along a continuous plane

Figure 3. *Delamination of face-bedded ashlar, St David's Cathedral, Hobart. (Photo: Jasper Swann, 2008)*

Figure 4. *Sheet exfoliation of Donnybrook sandstone, WA Government Stores, Perth. (Photo: Jasper Swann, 2009)*

Figure 5. *Severe exfoliation of Barrabool sandstone, Newman College, University of Melbourne. (Photo: JS)*

Figure 7. *Contour-delamination in the cornice mouldings and carved frieze below, Queen Victoria Building, Sydney, caused by deposition of salts, (visible), beneath case-hardened layer. (Photo: Jasper Swann, 2008)*

Figure 8. *Contour delamination of a Sydney yellowblock string course, Mitchell Building, University of Adelaide. (Photo: Jasper Swann, 2009)*

Figure 9. *Heavy efflorescence on the internal walls of a decorative grotto built into the natural bedrock, Elizabeth Bay House, Sydney. (Photo: Jasper Swann, 2007)*

Figure 10. *Efflorescence below the balcony of the former Children's Hospital, Camperdown, NSW. (Photo: Jasper Swann, 2006).*

running parallel to the profile, as though the stone had been 'grown' to that profile, the process appearing akin to peeling the layers off an onion. This, of course, is not the case. Again, this decay process results from a combination of case-hardening, differential thermal expansions, and the deposition of soluble salts that have entered the stone via any of the sources described above.

Efflorescence

Efflorescence manifests as a visible deposition of salts at the surface of a stone, deposited in solution, but having crystallized on evaporation. Soluble salts are carried into the stone usually via ground water or rainwater, but occasionally being airborne, or from other site specific sources, and crystallize at the surface when the water evaporates.

The example in **Fig.9** shows the internal walls of a decorative grotto built into the natural bedrock. Here the salts have percolated through the ground and bedrock above and been deposited on the surface of the stonework. The continually active supply of salts to the internal stonework has resulted in a considerable accumulation at the surface, clearly visible here as heavy white deposits against the green algal blooms that have also accumulated due to the damp conditions. Despite the heavy salt deposits, decay of the stone is quite minimal, as evaporation rates in this environment are very slow and the salts have crystallized on the surface rather than in the stone itself.

Figure 11. *Cryptofluorescence, i.e. the build-up of deposited salts behind the surface of Sydney yellowblock.(Photo: Jasper Swann, 2008)*

Figure 10 shows a quite different example. In this instance, much of the salt has its origins in a concrete slab poured above and behind the stonework as part of the original balcony construction.

Concrete contains high concentrations of soluble salts, particularly sulphates, and if not adequately isolated from stonework, the migration of these soluble salts from the concrete to the stone can readily occur in the presence of water.

Cryptofluorescence

Cryptofluorescence in sandstone is somewhat analogous to the problem of white ants in timber, (though admittedly without the structural implications). Crystallized salts are deposited behind the surface of the stone, but are not visible until such time as the stone fails on account of the pressure exerted by them. Sudden surface loss of 3-8mm in sheet form is typical. **Figure 11** illustrates the phenomenon, which, once again, owes much to case hardening of the stone.

Cracking

The cracking of sandstone can be caused by a multitude of factors, and is self evident. The cracking may consist of single or multiple fractures, and may be caused by a large range of factors, most commonly:

- Expansion of ferrous fixings within the stone;
- High frequency of wetting and drying cycles;
- Natural planes of weakness within a stone;
- Ground subsidence; and
- Intrusive vegetation, trees, roots and other vegetable matter.

Expansion of Ferrous Fixings

The use of ferrous fixings, such as dowels and cramps, in the construction of stonework was common practice for many years. Similarly, the introduction of iron and mild steel railings into a sandstone plinth, as in the palisade fences commonly built in the Victorian period, was extensive. The expansion of the steel as it rusts generates a force sufficient to cause cracking and sometimes dislocation of stone elements, and this is a commonly observed phenomenon. Palisade railing bases are frequently found to have split along their entire length. Ferrous fixings used in the fixing of finials and structural tying down of masonry have caused severe cracking of the stones into which they are inserted, (**Fig.12**).

Figure 12. *A rusted iron fixing, originally anchoring the spire, has destroyed the quoins on this church tower in Kiama, NSW. (Photo: Jasper Swann, 2009)*

High frequency of wetting and drying cycles

A stone that is subjected to a high frequency of wetting and drying cycles will typically develop hairline cracks which open up under the continued effects of weathering. This is due to the thermal expansion and contraction that is exerted on stone as it wets and dries. Such cracking is typically found on ornate carvings, such as bosses, gargoyles and grotesques, all of which are generally elements of stone having a high surface area to volume ratio, (**Figure 13**).

Such cracking is very often also present in chimney stacks, where the frequently narrow stones that form the stack, (often just 120-150mm thick), are not only exposed to the atmosphere on both their internal and external faces, but are also highly exposed to the weather, and also to heat rising up the flue, increasing the rate of evaporation of moisture within the stones. **Figure 14** shows an example.

Natural planes of weakness

Despite the best efforts to select the highest quality stone at the quarry, there will be instances when the natural planes of weakness that might be present in a stone cannot be seen. In time, these weaknesses may open up into cracks. Where this occurs in a stone that is under compression, it may be of little consequence, but where a stone has little or no compressive weight bearing upon it, the crack may open up to the point where the stone needs repair or replacement.

Cracking due to ground subsidence

Ground subsidence is a major contributor to the development of cracks within a stone building. Often, subsidence will have occurred within a short time after construction of the building, due to the mass of the structure bearing upon the ground. The foundations of historic buildings were not always as good as they perhaps needed to be. In other instances, excessive drying of clay soils, for example during periods of prolonged drought, will be sufficient to cause building subsidence. When a portion of a building subsides, something has to give, and typically cracking will develop in the joints of the structure. Occasionally, the stone itself may crack, but this is unusual and only occurs when, for whatever reason, cracking along the joints is prevented from occurring by an inherent physical restraint.

Intrusive Vegetation

Cracking due to the upward pressure exerted through a masonry structure by subterranean tree roots is common. Equally frequently in most parts of Australia, the roots of the various prevalent species of fig will find their way into the joints between stones and exert such force as to crack the surrounding stonework.

Preferential Erosion

When an inappropriate material is inserted into a sandstone structure, as often occurs by way of an inappropriate repair, it can have a deleterious effect upon the stone which immediately surrounds it. A typical and common example would be the use of hard grey cement mortar or of elastomeric products for repointing. The mortar between two stones ought to be softer than the stone, and itself erode preferentially to the sandstone. But in the instance of a cement mortar being harder than the surrounding stone, the stone itself decays preferentially, whilst the hard mortar remains, (**Figure 16**). Where elastomeric sealants are used, moisture that would ordinarily evaporate through the joint is unable to do so, diverting instead to the stone immediately either side of the joint, where a localized

Figure 13. *Cracking of a carved boss in Sydney yellowblock. (Photo: Jasper Swann 2008)*

Figure 14. *Cracking in a chimney shaft. (Photo: Jasper Swann, 2007)*

Figure 15. *Cracking along a natural plane of weakness. In this instance, the carved stone has sheared through its width completely, and being under little compression, it is at the point where the upper portion of the stone can be dislodged by hand. (Photo: Jasper Swann, 2008).*

Figure 16. *Preferential decay of a buttress stone as a direct result of the unsuitable grey cement mortar used to repoint its upper bed joint. Hunter Baillie Memorial Church, Annandale, NSW. (Photo: Jasper Swann, 2007).*

Figure 17. *Preferential erosion of sandstone beneath a limestone coping, Elder Hall, University of Adelaide. Note the almost perfect condition of the limestone copings. (Photo: Jasper Swann, 2009)*

Figure 18. *Decay of carved yellowblock sandstone capital due to gypsum run-off from limestone string course and voussoirs immediately above. St George's Cathedral, Perth. (Photo: Jasper Swann, 2009)*

increase in deterioration occurs. A hard cement mortar will have the same effect. The use of hard cement mortars or elastomeric sealants for repointing should never be considered, other than in exceptional and rare circumstances.

The introduction of stone that is significantly harder than the surrounding stone, (i.e. of significantly greater bulk density), can have the same effect, causing deterioration of the stones that surround it.

Sandstone and Limestone – A risky marriage!

In Adelaide, Melbourne and Perth, many buildings have been constructed using both the local limestone and sandstone, primarily for the aesthetic benefit of the polychromatic architectural composition. Certain limestones and sandstones are distinctly incompatible, the limestone leaching out minerals, (predominantly gypsum), that become alkaline in solution and are detrimental to the sandstone. The University of Adelaide's Elder Hall provides a particularly good example of this kind of preferential erosion at work, (Figure 17). Here the gypsum run-off of the limestone copings has caused marked disaggregation and efflorescence in the sandstone below. The use of these two incompatible materials is a significant problem in this particular building and presents a real conservation dilemma. Similar instances are to be found in Melbourne and in Perth, (**Figure 18**), where the concurrent use of sandstones and limestones has also been popular.

Figure 19. *Severe blistering of Sydney Yellowblock, Newcastle, NSW. (Photo: Jasper Swann, 2009)*

The term 'preferential' in reference to the types of decay described here may be slightly misleading, because, of course, we have no preference whatever for failure of the stone.

Pitting, Flaking & Blistering

The pitting of the surface of sandstone occurs as a result of the loss through weathering of the clay binders of the stone at the surface. Once pitting has begun, the surface of the stone becomes steadily rougher over time, as the increased pore size leaves the stone more vulnerable to the effects of weathering. Pitting of horizontal surfaces more quickly accelerates into a more significant form of decay, as the surfaces have a far lesser ability to shed water. As the extent of pitting increases, allowing greater retention of water, the stone may begin to flake at the surface. Such flaking is commonplace in the majority of Australian sandstones, but most common in those that are softer and of lower bulk density.

The blistering of sandstone is a common occurrence, particularly where there is an abundance of falling damp and a coexistent exposure to sunlight. **Figure 19** provides an example of severe blistering in a Sydney yellowblock sandstone.

In the next edition of *Discovering Stone*, I will begin to outline the practical mechanisms for arresting decay and for repairing and conserving our stone buildings. DS

Jasper Swann is an independent masonry consultant.