1.0 Decay mechanisms associated with natural sedimentary stones and masonry substrates

- **Problems associated with O.P.C and its deteriorological effect upon porous substrates**

Traditionally lime was the only binder used for building. This dominance prevailed until the early 19th Century, and although the lime was attained in a myriad of types the technology did not alter greatly for over 7000 years.

OPC was invented in 1824 by J Aspdin, a brick manufacture from Leeds, who's patent for 'artificial stone….ref'. is generally what we consider as modern cement. Although J. Aspdin is credited with its discovery, it was actually his son William who set up his own independent cement works in Gateshead (North Eastern England). Unknown to the Aspdin family, OPC had various detrimental consequences for traditionally built structures that relied upon the principles of low strength, higher flexibility and solid mass masonry construction for their holistic performance.

- **Impermeability Issues**

Lime based materials whether non-hydraulic or hydraulic all allow the building to 'breathe' that is to say they allow the transmission of water and water vapour to occur (ref hughes work). Any disruption to the flow of moisture from internal environments and or the surface of the wall will lead to the development of higher moisture contents within the stone. This is primarily caused by the use of OPC repointing and or harl coats / renders that act as 'plugging material'.

The problem of moisture entrapment primarily occurs when impermeable materials are placed upon a structure which relies upon free or relatively free moisture dissipation (moisture equilibrium)

When relatively impermeable materials are used in for repairs upon traditional buildings the following situations may arise:

i) Repointing (pics)

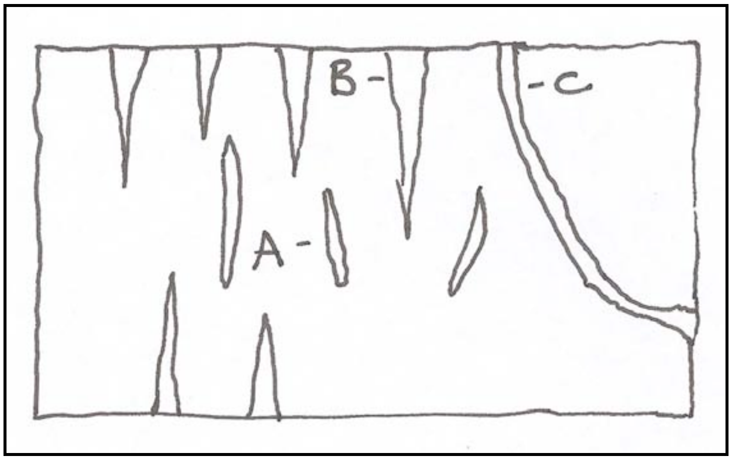
ii) Cementitious harl coats, delamination and moisture entrapment issues (pics for all)

- **Frost damage**

In its most basic form when water enters a porous material the pore structure may be either partially or fully saturated. If the temperature stays constant no significant problems should ensue, however, when the temperature drops the possibility of ice formation may become prevalent.

The type of pore structure in the material is essential in determining the response to frost and other forms of deteriorological mechanisms. Banfil has suggested 3 primary forms of pore structure, namely, unconnected with outside (A), connected with outside (B) and finally interconnected – allowing passage for moisture (C). These may be seen diagrammatically represented in figure x.

Figure x: 3 primary forms of pore (author after Banfil)



When a material becomes saturated and is then exposed to frost as the temperature drops the water turns to ice with a volumetric increase in the region of 9%. This ice formation follows that seen in figure x

Figure x: hydraulic forces (author after Banfil)

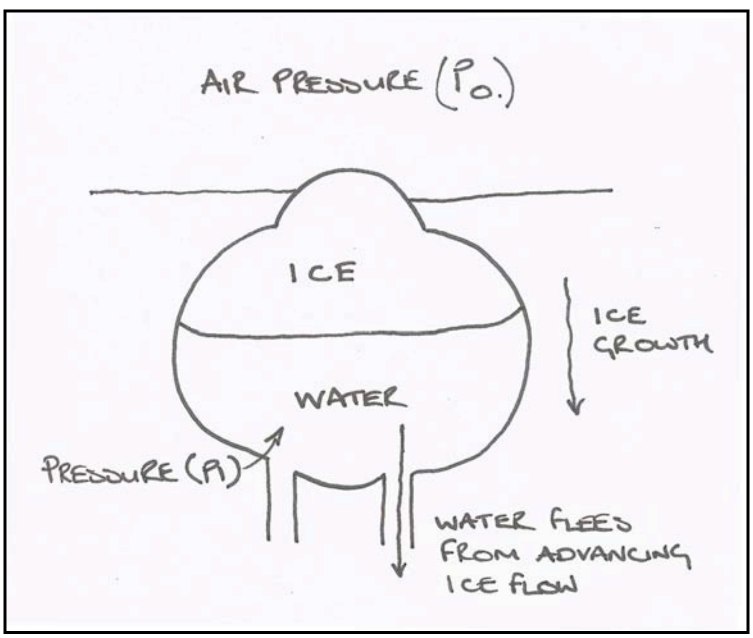
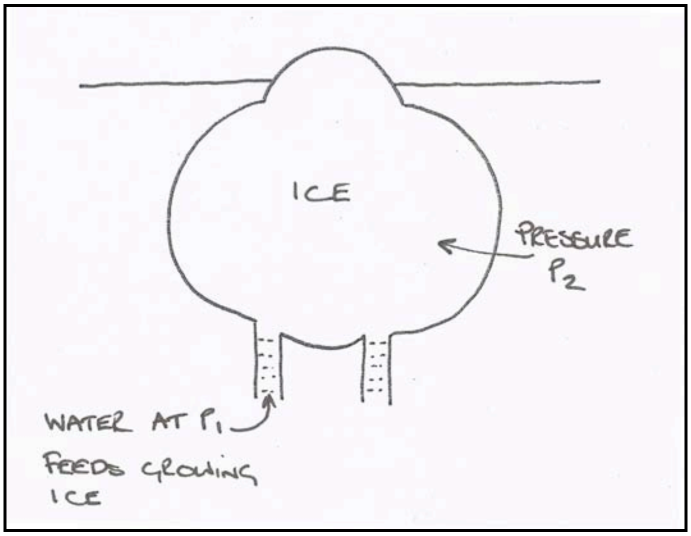


Figure y: Crystal growth forces (author after Banfil)



The advancement of ice forms pressure that will lead to the potential deterioration of the material (depending upon the binding characteristics of the material)

Discuss 2 x failure:
Sheet or mass
Granular materials failure

- **Salt damage (salt crystalisation)**

When undertaking any repair work upon historic buildings it is important to understand that certain fundamental differences occur between OPC and natural hydraulic limes one of the most significant factors is that of soluble salt concentration of cementitious materials. OPC and hydraulic limes both have the aforementioned in varying proportions. However, it must be emphasised that OPC has quantities that are extremely high, whereas, NHL has extremely low to trace element of soluble salt.

When the salts within the material go into solution (via rain water or other forms of moisture) they are relatively harmless, however, the problems ocurr when the material begins to dry out. Upon drying the salts are precipitated to form salt crystals which start to develop within the mortar and or substrate. The energy required for the formation of these crystallites are often greater than the binding matrix of natural stones and soft fired bricks and as a consequence the salts tend to cause spalling of the material.

Banfil [1] has suggested 4 primary mechanisms of decay associated with salts, including,

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[1] Banfil (2001) HWU

1) In many cases decay is due to the deposition of soluble salts at or immediately below the surface of the stone
2) The salts responsible for the decay are formed by attack on the stone by acid constituents of polluted atmospheres or are derived from adjacent materials, from jointing mortar, from the ground or from the air.
3) Stone decay is nearly always worst in sheltered part of a wall since accumulation of salts is less likely to occur when washed by rain.
4) The hard skin, which forms tends to flake off through further crystallisation beneath it or as a result of volume changes.

Certain salts are less damaging than others this is the reason why efflorescence is relatively harmless to the material (unless in exceptionally bad cases when it is then known as crypto-effloresence)

Sources of salts include one or a combination of the following:
1) Saline soils and ground water from rising damp and salt attack
2) Sea spray
3) Air pollutants
4) Biological – pigeon droppings, micro-organisms
5) Leaking sewers etc
6) Salts naturally occurring within the material

Table X: Salts detrimental to porous building materials

Generic salt type	Common Type	Source	Effect
Sulphates	**Gypsum ($CaSO_4$) or Magnesium Sulphate ($MgSO_4$)**	**iii) Present in agricultural land iv) Sea water (mainly $MgSO_4$) v) Contaminates to mortars & plasters**	**5) Enter through capillarity at wall bases etc. 6) Surface deposition to porous material**
Chlorides			
Nitrites & Nitrates			

ICCROM publication salts pic.Heave effect and pore solution feed pic

See salts publication from Dave Austrailia

Plate x: Warwick castle stone erosion

Plate x: errosion of sedimentary stone at Warwick Castle