



‘Paula’s Papers’: Salts in Porous Construction and Building Materials

Paper 2 – Salts Distribution in Walls And Decay of Building Materials

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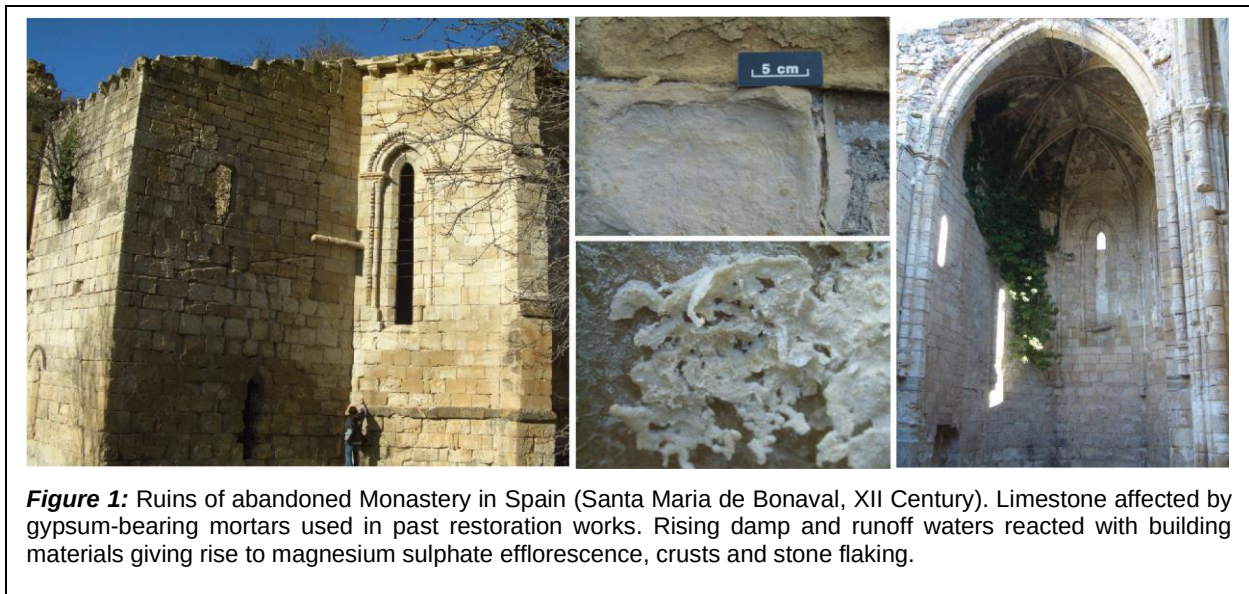
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1. HOW DO THE SALTS INTERACT WITH POROUS MATERIALS?

Depending on the source, salts can be mostly concentrated at the surface or more deeply inside the substrate. Either water by rising damp or ingress from rain penetration can both concentrate lower or higher amount of salts depending on the nature and condition of the rural or urban area of concern. Building materials above ground waters and soils affected by salts (e.g. naturally salty geological settlement or affected by the addition of de-icing salts, fertilisers, animal excrements, etc.), or located in big cities with large air pollution, or coastal areas with marine aerosol, will get higher concentration of salts.

Besides the original source, additional salts can be generated during water ingress and reactions with building materials. While most of the damage from salts is physical, salt solutions may enhance the dissolution of some minerals from the materials that go through. The final composition, concentration and distribution of salts will depend on the amount and type of water ingress, the composition and solubility of the components of all materials, the solubility of the salt mixture, the porosity of the substrates, and the effect of the surrounding environment. Salt damage does not necessarily occur where the maximum amount of salts is found. All the aforementioned factors will condition the final decay of the building materials affected by salts (**Fig. 1**).



1.1. Type and distribution of sales in walls and substrates

When salt solutions get supersaturated (i.e. excess of solute (salt) in a saturated solvent (water with salts), no more salts can be dissolved and these crystallise when evaporate, on or beneath material's surfaces forming efflorescence or sub-florescence, respectively. The solubility and concentration of the salt solution, the porosity of the substrate and the environmental conditions, will control what height and depth will reach the salts in the wall. The most hygroscopic and soluble salts are usually concentrated at the highest height (e.g. chlorides and nitrates) at the top of the rising damp. These cause undesirable aesthetic effects while other salts at lower heights (e.g. sulphates) can disintegrate the building materials.

1.1.1. How the salts look like in the substrates?

Salts may be visible as white efflorescence or crusts forming different aggregates of crystals with all kind of shapes on the surface of materials. Needle-shaped whisker crystals, forming longer (fluffy) or shorter (bristly) efflorescence, grow from almost dry substrates. Salts crusts may have all sort of compositions under the proper conditions, but these are generally formed by the less soluble salts (e.g. calcite, gypsum).

Salts can also be in the form of sub-florescence when hidden below the surface or partially visible underneath decayed material flakes. When present as salts in aqueous solutions, they can be visible as damp areas on the surface or just being circulating within the porous materials. The chemical composition and concentration of the salt, and the environmental conditions for evaporation will condition the physical behaviour causing different crystallisation pressures inside the porous materials (**Table 1**).

Material	Megapascals (MPa)	Salt	Molar volumen (cm ³ /mole)	Crystallisation pressure C/Cs=2 (supersaturation degree)	
				0°C	50°C
Granite	97 - 310	Bischofite (MgCl ₂ ·6H ₂ O)	129	119	142
Basalt	110 - 338	Epsomite (MgSO ₄ ·7H ₂ O)	147	105	125
Limestone	14 - 255	Hexahydrate (MgSO ₄ ·6H ₂ O)	74	282	334
Sandstone	34 - 248	Gypsum (CaSO ₄ ·2H ₂ O)	28	554	654
Quartzite	207 - 627	Halite (NaCl)	130	118	141
Marble	69 - 241	Mirabilite (Na ₂ SO ₄ ·10H ₂ O)	220	72	83
Slate	138 - 207	Natron (Na ₂ CO ₃ ·10H ₂ O)	199	78	92
Concrete	5.5 - 69	Thenardite (Na ₂ SO ₄)	53	292	345

Table 1. Compression strength (MPa) ranges of some building materials and crystallisation pressures (atm) of some salts

All forms of salts can react with time by cycles of dissolution and crystallisation processes with changing weather and environmental conditions. Efflorescence on surfaces when affected by rainwater, damp or water vapour may be also harmful to the adjacent materials. These salts can be dissolved and reintroduced into the porous system, recrystallising and causing further damage inside.

1.1.1. Salts from capillary rise, groundwater and soils

Water rising by capillarity takes place either from ground water with higher or lower water table levels (depending on the geomorphology, hydrology and seasonal weather changes) or from accumulation of rainwater, floods etc. and filtration through the soil and building materials. In rising damp cases moisture in walls increases with depth and decreases with height. Salts affect the whole depth of the structure, but these are slightly more concentrated at the evaporation front, at the surface of the wall and up to the top of the rising damp (near the apex of rise). But this also depends on the location of building materials acting as sources of salts. The concentration regarding the type of salt might be slightly higher at the surface for chlorides and increasing with depth for nitrates. Concentration of both usually increase with height up to the top of the rising damp front due to their higher solubility.

On a wall with rising damp, soluble salts crystallise at different heights depending on their solubility. There are four main zones from the bottom to top of the wall:

- (1) area close to the ground where less damage is usually observed; there is presence of more insoluble salts (e.g. gypsum and calcium and magnesium carbonates)
- (2) mid area, frequently the most decayed by granular disintegration, scaling, flaking, of building materials, with possible efflorescence and crusts (e.g. of potassium nitrates, magnesium and sodium sulphates)
- (3) “darker” area, which marks the upper limit of the moisture rise. It displays the most soluble salts (e.g. sodium nitrate and chloride) and other deliquescence salts such as magnesium nitrates and chlorides (e.g. MgCl_2). These deposits of soluble salts create mostly surface “hygroscopic damp patches” by absorbing water from the air (by condensation or high air humidity levels) as RH increases. These wet patches can spread over larger surface areas of the walls, reaching sometimes heights of up to 2 or 3 meters. They could also leave the water evaporate as relative humidity (RH) decreases. If the conditions are dry enough (e.g. by heating systems drying the air or if the outside climate becomes very dry) salt crystallisation and deterioration can occur. But most of the solutes in this zone will always stay in solution. That means that these salts are locally concentrated and accumulated over the whole lifetime of the building unless these are removed. Sometimes white veils of gypsum (micron size crystal aggregates) may be observed at the top of the rising area. This higher location is correlated to the presence of the hygroscopic salts that would allow the slow migration of gypsum to this location
- (4) Area not affected by rising damp nor salts above all the aforementioned areas (**Fig. 2**).



Figure 2: Santa Maria de El Pualar Monastery (XI century) where a combination of different building materials (granite, dolostone, bricks and lime mortars) have been affected by rising damp and runoff waters. Nitrates mostly from the ground affected the whole deep of the wall whereas sulphates concentrate at the surface (where remains of gypsum plaster patches are still covering the stone).

1.1.3. Salts from the atmosphere, marine spray or air pollution

Either wind and rain may carry salt particles or acidic components that can be deposited on the surface of building materials reacting with them. These are mostly concentrated on the first few millimetres from the surface of these substrates

In the case of buildings located under polluted environments, mainly sulphates and nitrates are crystallised on the building surfaces, while in marine areas these salts are mostly chlorides that decrease with depth. The concentration of all these salts in both cases usually decreases with depth (**Fig.3**).



Figure 3: The Spanish Tower of Bizerte, XVI century (Tunisia) exposed to sea-spray action and several restoration works leading to differential weathering of the stone masonry (top pics). Howden Minster Cathedral (UK) affected by past pollution leading flaking of magnesium limestone (down pics).

1.2. Influence of materials' physical properties on salt weathering

The porous system of building materials is one of the most important physical features that control the movement of fluids and salt solutions. Therefore, it will condition their physico-chemical weathering. Under the same chemical composition, concentration of salts and influence of equal environmental conditions some substrates are more deteriorated than others. Decay and durability of building materials will mostly depend on their porosity and strength.

The actual distribution of moisture within materials depends on the connectivity of the pores, pore-size distribution, and environmental conditions. The shape of the pores is also important, since irregular and coarse pores hinder the movement of fluids. Furthermore, the higher the surface area the larger the area exposed to weathering agents. In inhomogeneous media, accumulations of salts become irregular according to the effective pore structure. If a salt solution evaporates from a mortar coated by a paint layer, the salt may precipitate preferentially between the paint layer and the substrate.

In general, materials more prone to decay by salt crystallisation processes are those with larger porosity and a greater number of connected micro-pores, high water sorption coefficients and low mechanical properties (e.g. low crystalline limestone, some sandstones, low fired bricks or mortars with high sand:binder ratios).

1.3. Influence of environmental conditions in salt decay

Apart from the physico-chemical properties of the substrate, salt weathering cannot be understood without considering the interaction between climate, surrounding environment and salt concentrations. The damage to porous materials will be conditioned by the saturation degree of the salt solution, which depends on the concentration and the environmental conditions (i.e. RH and Temperature (T) for evaporation to occur). All these factors will control if the salt crystallises at the surface or in the interior of the material. The more salt crystallises underneath the surface the more decay is produced.

Salts crystallise when salt solutions evaporate, while the RH of the surrounding environment decreases. Changes in the environmental parameters (T and RH) are the driving forces triggering salt damage. This may occur in the outdoor environment where materials are subjected to cycles of rainfall and subsequent drying, and both outdoor and indoor influenced by daily or seasonal fluctuations of T and RH. Some salts may dissolve and recrystallize periodically according to the oscillation of these parameters. Normal fluctuations of T and RH may cause damaging cycles of repeated phase changes, causing hydration-dehydration and/or crystallisation-dissolution cycles. The severity and frequency of environmental fluctuations are important in determining rates of salt damage.

2. TYPES OF DAMAGE AND DETERIORATION PATTERNS

Decay of porous materials takes place by a combination of factors and the presence of salts significantly increases deterioration rates. The amount and type of water ingress, the kind and concentration of salts and evaporation rates, the pore structure and strength of the substrates and the dissolution-crystallisation cycles by environmental fluctuations, will all condition the decay and durability of building materials. While deterioration is considered a physical process controlled by hydric behaviour (which depends on the porosity system) further weathering maybe enhanced by additional chemical processes (e.g. leaching of key elements and oxidation-reduction reactions of water solutions through soil and building materials).

2.1. Water: driving force triggering salt damage

The presence of water and/or moisture is the key factor for salts as harmful deteriorating agents. Moisture can reduce the mechanical strength of some materials and its distribution within their porous system determines where deterioration occurs. Knowing the type or source of water ingress (e.g. direct rain and run off, penetrating damp water leaks, rising damp, water vapour and condensation, etc.) is essential to understand salt damage processes.

Moisture transport through the pore system and changes in environmental conditions are key to understanding the development of the observed deterioration patterns. The maximum moisture content from wet-dry cycles is closer to the surface in denser stones, and deeper and broader in coarse porous materials. The resulting expansion and contraction to wet-dry, or moist- dry cycling can induce material fatigue.

2.2. Salt-bearing substrates: deterioration patterns

In addition to water, the effect of wind has also an erosive effect on the weathering process of building materials. Wind, salts and related rapid drying may result in honeycomb weathering. However, the two most common decay patterns of porous materials are flaking (or contour scaling) and powdering. The presence of soluble salts, such as halite, can induce both flaking and sanding. Flaking has been also observed in many decayed sandstones and limestones affected by magnesium sulphate salts. Humidity fluctuations may accelerate the flaking process. Salts concentrate in areas that retain moisture longer. These zones are mechanically stressed, leading to disruption and eventual powdering with the detachment of surface flakes. For longer drying periods, salts accumulate in sheltered areas with lower evaporation rates leading to flaking (**Fig.4**).



Figure 4: Torrelaguna, Magdalena church, XIV Century (Madrid, Spain). Granite affected by rising damp after failure of slate DPC.

Acid attack, including carbonic acid in unpolluted rain, results in the migration of Ca^{2+} ions of building materials to the surface, inducing formation of gypsum or calcium carbonate crusts. The underlying depleted area loses mechanical strength and powders. Even more crystalline less porous stones such as granite maybe decayed by salts giving rise to flaking, or marble stone affected by sodium chloride lean on sanding weathering (i.e. known as sugaring decay).

The presence of clays in sandstones or limestones, particularly if concentrated along bedding planes, will induce delamination and scaling. This phenomenon is enhanced by the presence of soluble salts that will contribute to increased moisture absorption. These could change their behaviour causing expansions and contractions and eventual stress and disruption of these materials under the effect of environmental fluctuations.

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