Experimental studies of temperature cycling and surface wetting of stone and its implications for near-surface salt weathering


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Catastrophic retreat of granular limestones – salt weathering controlled by temperature and moisture regimes and how they change as retreat takes place

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Thermal Shock or fatigue?

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Fatigue traditionally linked to diurnal temperature cycles

Typical diurnal temperature regimes used in weathering simulation experiments (Goudie and Viles, 1997)

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Surface Rock Temperatures, Limestone, Southeast Morocco

Recognition of seasonal differences, micro-environmental variability

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Temperature variations at different altitudes on Tenerife
Surface rock temperatures at three altitudes on Tenerife: the importance of short-term variability.

Surface and subsurface rock temperatures and air temperature, Death Valley Floor, August.

The assumption of a smooth decline in temperature range with depth.

Short-term temperature variability and change as individual blocks retreat.

Experimental Design
- Stoke Ground Base Bed, Cotswold limestone.
- Porous granular limestone, 27% porosity.
- 15x15x8cm block.
- Surface temperature with IR thermometer.
- Thermistors at 0.5, 1.0, 2.0, 5.0 & 10.0cm.
- Resistance based moisture sensors at same depths.

Experimental regimes
- Test block dried at 50°C before each test.
- Placed in cabinet and allowed to equilibrate to ambient temperature.
- Two ambient temperatures: 20°C and 5°C (Summer and Winter in southern UK).
- 50% relative humidity.
- Heated under lamp for 15 minutes, cooled for 30 minutes.
- Surface wetting for 5 minutes prior to heating.
- Airflow induced across surface of stone by angled fan.

Temperature profiles with depth: dry conditions at 20°C ambient.
Temperature profiles with depth: with surface wetting at 20°C ambient

Temperature profiles with depth: with surface wetting and airflow at 20°C ambient

Key characteristics: ‘Summer’
- Most rapid change within the outermost few mm – the zone of active weathering on many stones.
- Establishment of shallow zone of stress concentration.
- Overall reduction in temperature by evaporation of moisture, but high near-surface temperature range maintained.
- Further ‘suppression’ of temperature by airflow – enhanced evaporation.

Temperature profiles with depth: dry conditions at 5°C ambient

Temperature profiles with depth: with surface wetting at 5°C ambient

Temperature profiles with depth: with surface wetting and airflow at 5°C ambient
Key Characteristics: ‘Winter’

- Reduction in absolute temperatures.
- Retention and possible enhanced concentration of rapid temperature change within outer few mm.
- Possibly greatest rate of surface change at beginning of cooling phase.
- Reduced/negligible temperature reduction effect from evaporation.
- Very slight temperature reduction associated with increased airflow.

Arrival time of the wetting front under different conditions

<table>
<thead>
<tr>
<th>Ambient temperature (°C)</th>
<th>Wind conditions</th>
<th>Arrival of wetting front (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet / windy</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Wet / windy</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>Winter (5 °C)</td>
<td>Wet / windy</td>
<td>9</td>
</tr>
<tr>
<td>Winter (5 °C)</td>
<td>Wet / windy</td>
<td>12</td>
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</tbody>
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Temperature waves?

- Key observation is the use of detailed measurements to identify complex wave-like subsurface temperature regimes, attenuated with depth.
- Interference patterns as ‘ingoing’ and ‘outgoing’ temperature waves interact with each other?
- Will be tested by altering the duration (frequency) of heating and cooling phases.

Implications?

- Rapid temperature change in outer few mm in excess of diurnal rates of change
- A multiplication of possible fatigue effects in the zone in which much weathering is created.
- Seasonal variations: evaporation under warm air conditions, enhanced wetness in ‘winter’.
- Establishment of multiple stress zones with depth within the near surface zone.

Links to weathering phenomena

Contour Scaling of a Quartz Sandstone With Gypsum Cryptoflorescence

Salt efflorescence on granular limestone and associated granular disaggregation
Moisture and salt Migration in Response to Surface Wetting and Drying

Multiple phases of scaling and gypsum crust stabilisation, St Matthias Church, Budapest

Contour scaling and multiple flaking in quartz sandstones

Contour scaling followed by multiple flaking of a granular limestone

Multiple flaking associated with development of a cavernous hollow in granular limestone

The impact of block retreat on temperature and moisture regimes
Explain multiple scaling and you are some way towards understanding the mechanics of catastrophic cavernous weathering.

The effects of block retreat and shading on peak temperatures after wetting: 15 minute heating cycles.

Change in surface peak temperatures with water spray.