Accelerated Salt Weathering Studies on Marble Stones from Elefsis, Greece, and Soapstones from Grytdal, Norway

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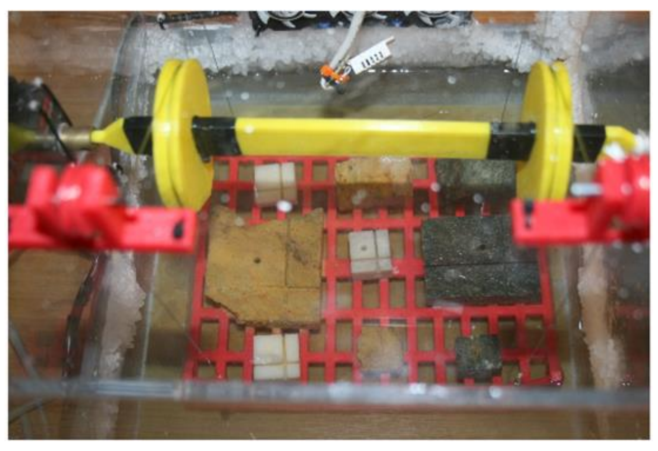
Introduction

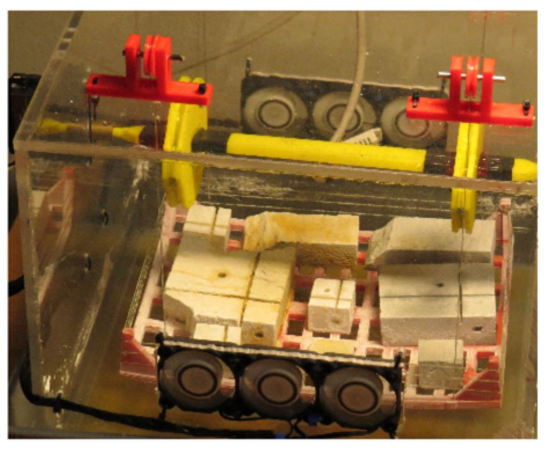
The weathering experiment reported is part of a broader project that, among other aims, investigate innovative ICT solutions to quantify and characterize stone monument degradations. As an output, models would be developed for forward and inverse weathering prediction based on targeted high-accuracy surface scans and accelerated weathering experiments. The salt weathering experiment, along with similar experiments on other factors of deterioration, would help to gain insight into the deterioration processes at microscopic and macroscopic levels. The results would be used to better explain observed deteriorations\weathering and, thus, their prediction.

Accelerated salt weathering setup

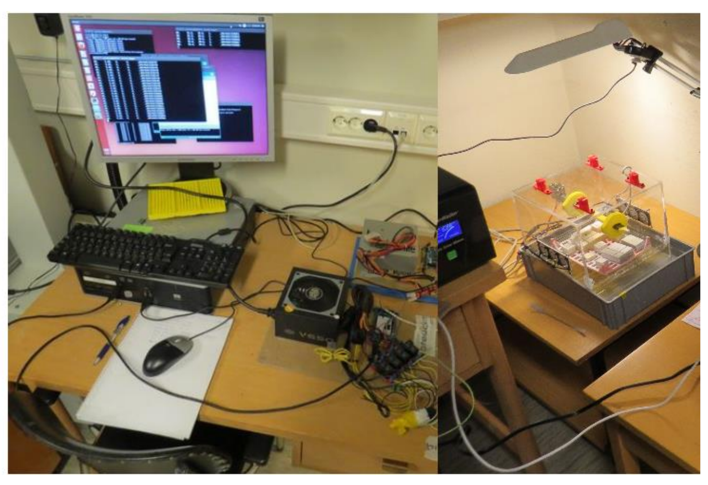
A low cost, small-scale automatic chamber was constructed using off-the shelf components for the control system.



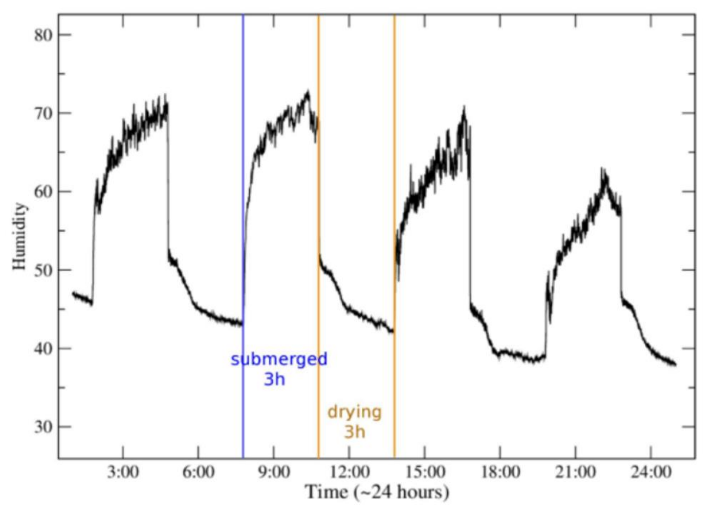
During immersion in 14% $NaSO_4.10H_2O$ solution



In the drying stage



The weathering chamber with the electronic controlling system



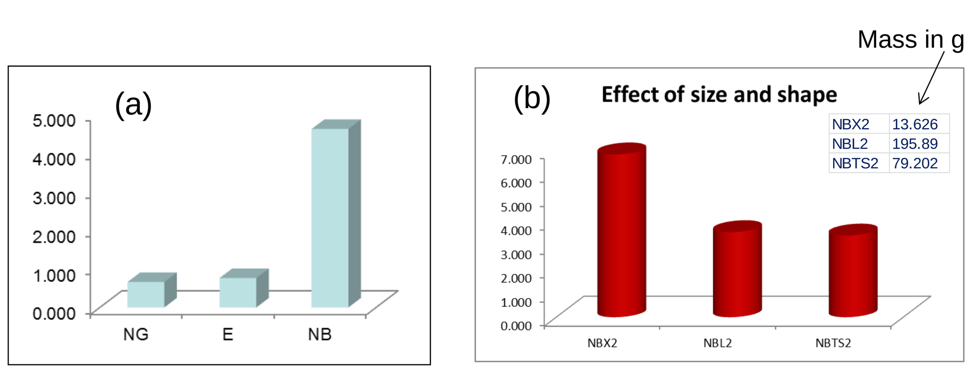
The change in humidity of the weathering chamber during the 4 cycles per day

Characterization techniques

Physicochemical characterizations before and after accelerated weathering through the use of multiple analytical and imaging techniques:

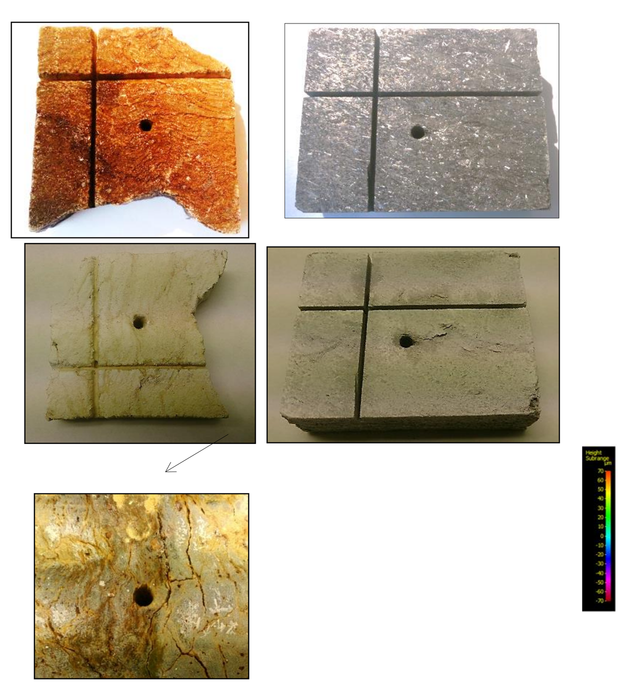
Quantitative Evaluation of Minerals by Scanning Electron Microscopy (QEMSCAN), 3D Microscopy, Scanning Electron Microscope and Energy Dispersive X-Ray Spectrometry (SEM-EDX), High precision optical 3D scanning using Breukmann 3D scanner, Micro Computed Tomography (Micro-CT), X-Ray Diffraction (XRD) and Petrography.

Highlights of some of the results

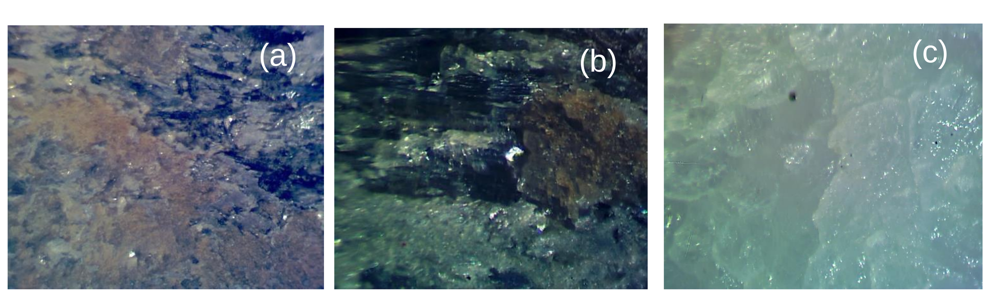


NG – Soapstone not weathered NB- Already weathered soapstone E- Marble

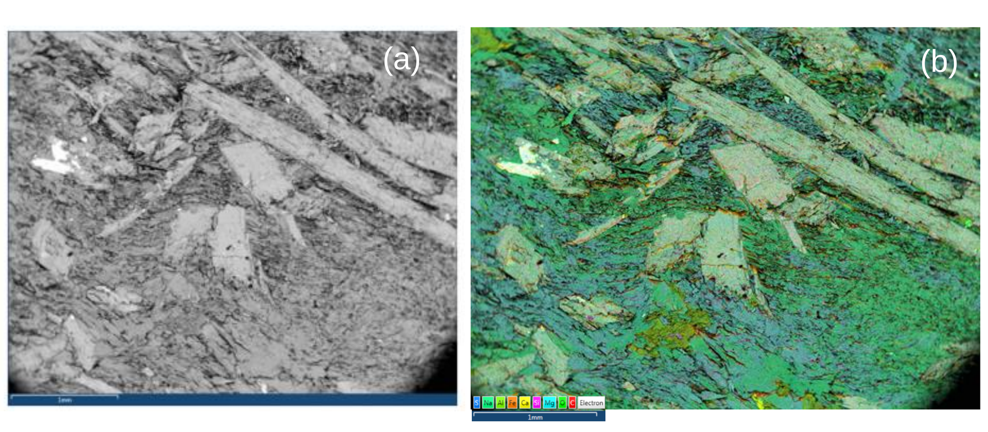
(a) Average percentage change in mass of the three types of stones observed after the first weathering running for a month (b) Effect of the size and shape of three different samples from the more weathered soapstone sample (labelled as NB) in (a)



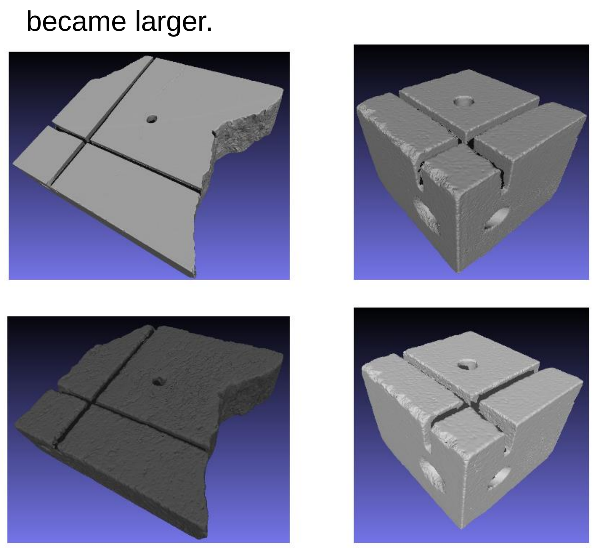
The two types of soapstone samples after weathering (top): one month duration in the weathering chamber followed by rinsing with distilled water and after weathering for one and half month (bottom). The backside of the already weathered soapstone sample is also shown with visible cracks\fissures that became larger.



Microscopic images (reflective mode) of the weathered (a), non-weathered soapstone (b) and marble (c) samples after one month weathering

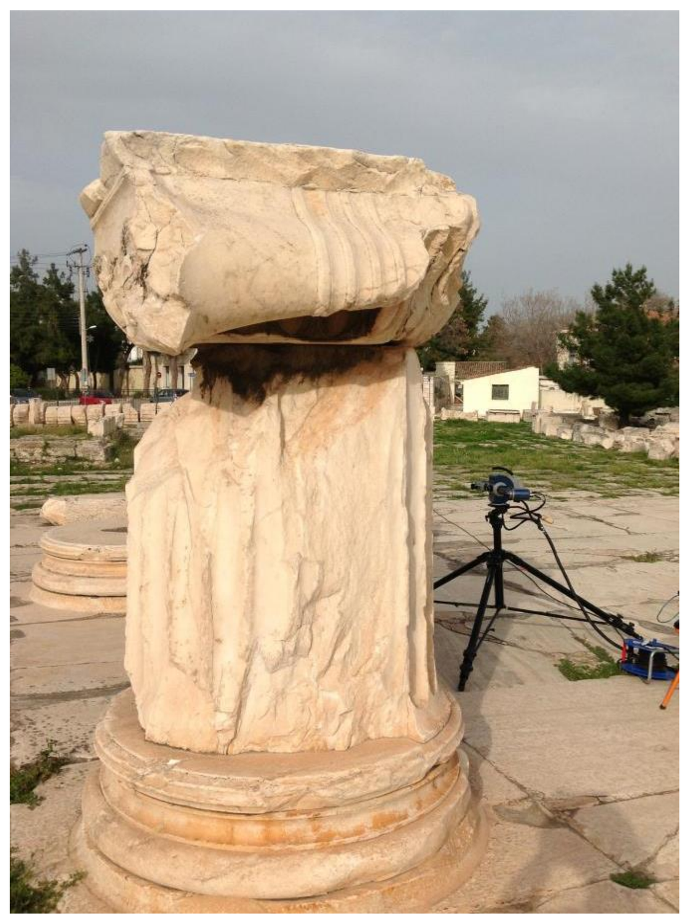


BSE image of non-weathered soapstone sample weathered in the chamber for one month (a). The corresponding elemental mapping for the BSE image. The elongated tabular crystals of actinolite-tremolite can be seen along with chlorite and talc (b).

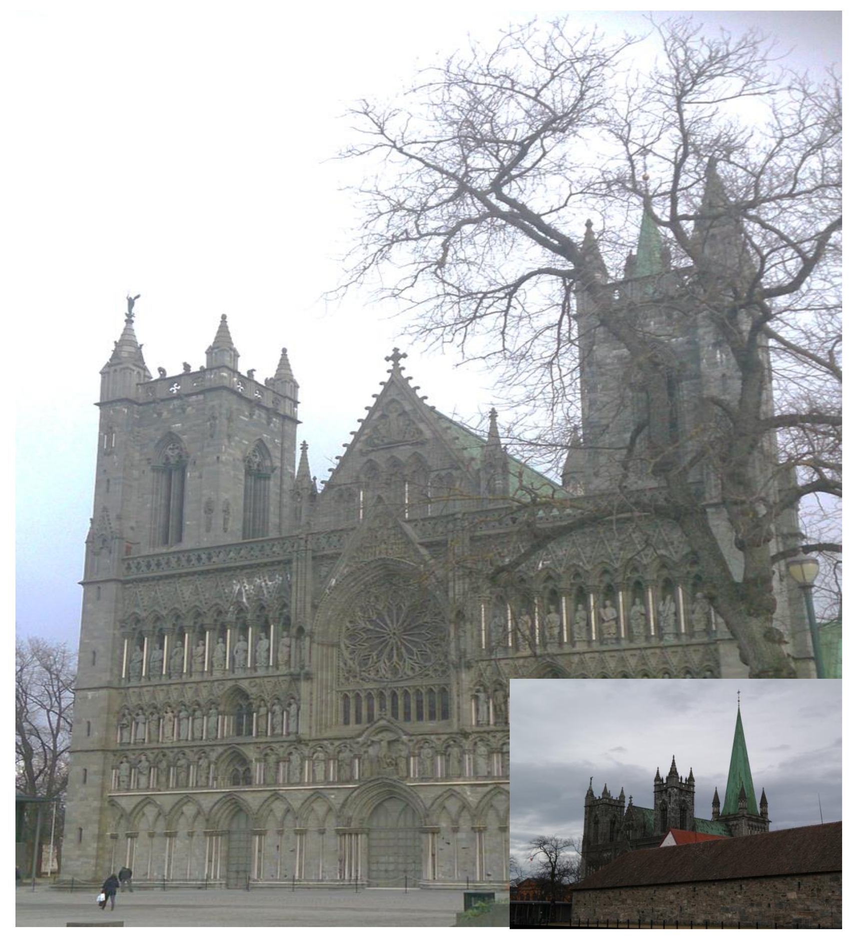


High precision 3D optical imaging of already weathered soapstone and non-weathered marble after one month weathering. Breukmann scanner was used for the 3D imaging.

In which monuments are the stones used?

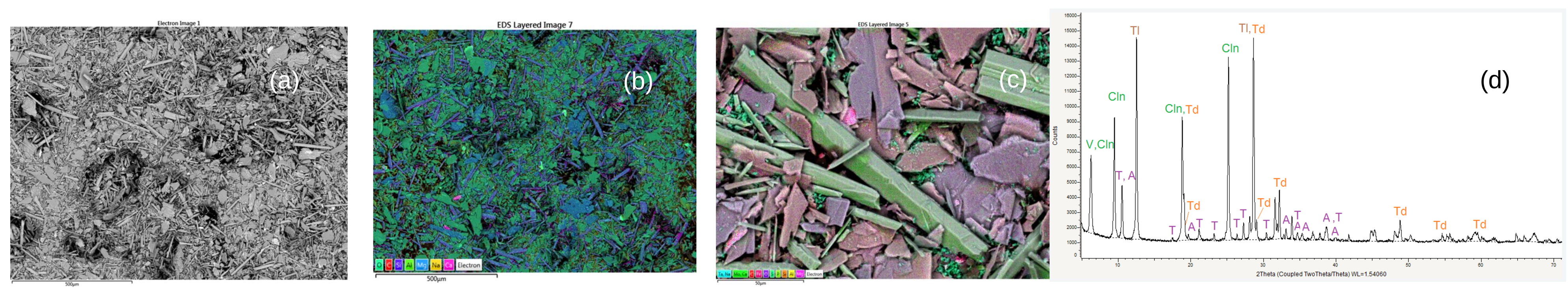


Elefsis archeological site in Greece during the high resolution 3D scanning. The patelikon marble stones are subjects of the accelerated weathering study

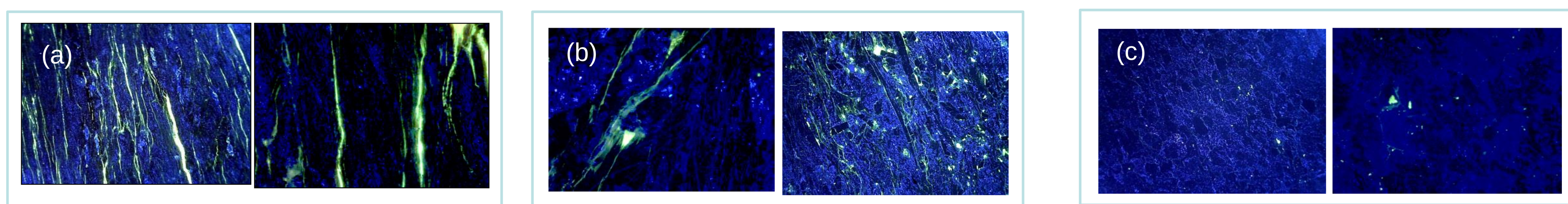


Nidaros Cathedral Church in Trondheim, Norway. Part of the church stones are soapstones under the accelerated weathering investigation.

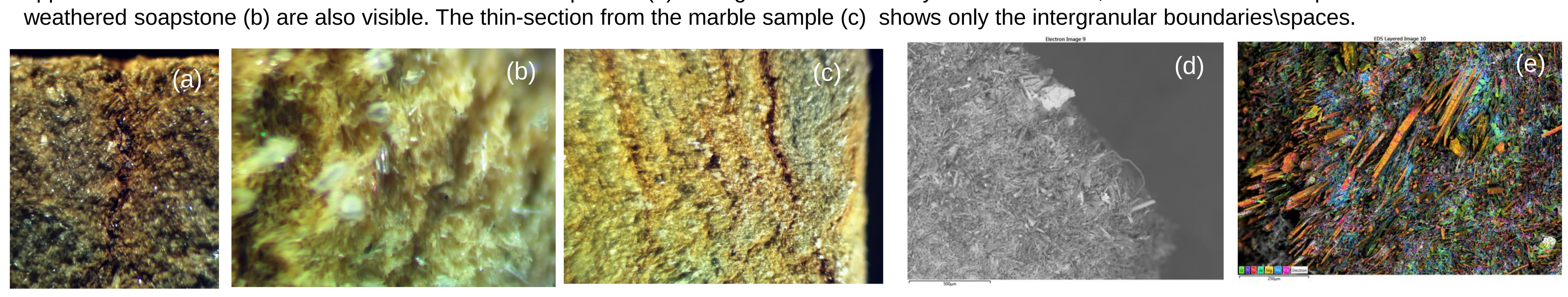
Some of the results continued



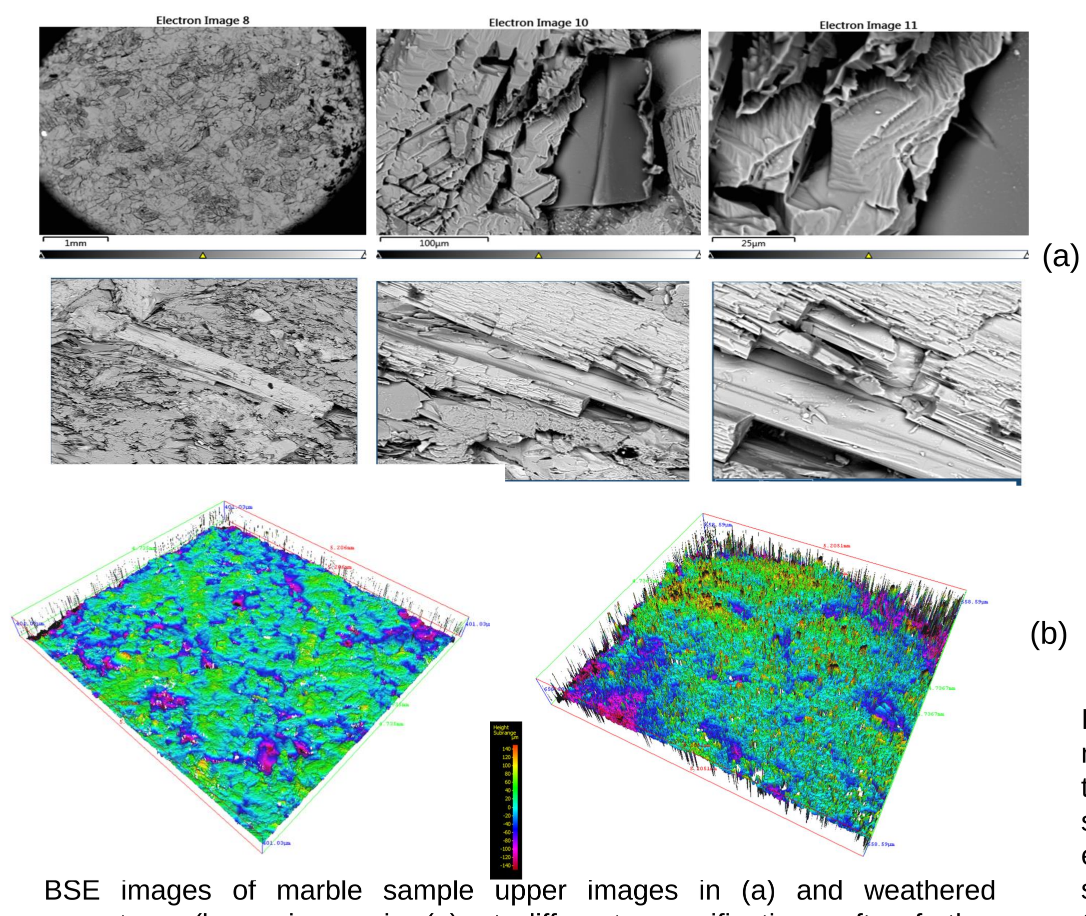
BSE Imaging (a), elemental mapping (b) on the residue obtained after one month weathering. Magnified image of the some of the crystals detached from the stone samples shown in (c). Actinolite-tremolite, talc, clinochlore, vermiculite are identified. The XRD analysis of the same residue (d) confirmed these mineral phases. V - Vermiculite, Cln - Clinochlore\Chlorite, Td -Thenardite, T - Tremolite, A - Actinolite, Tl - talc.



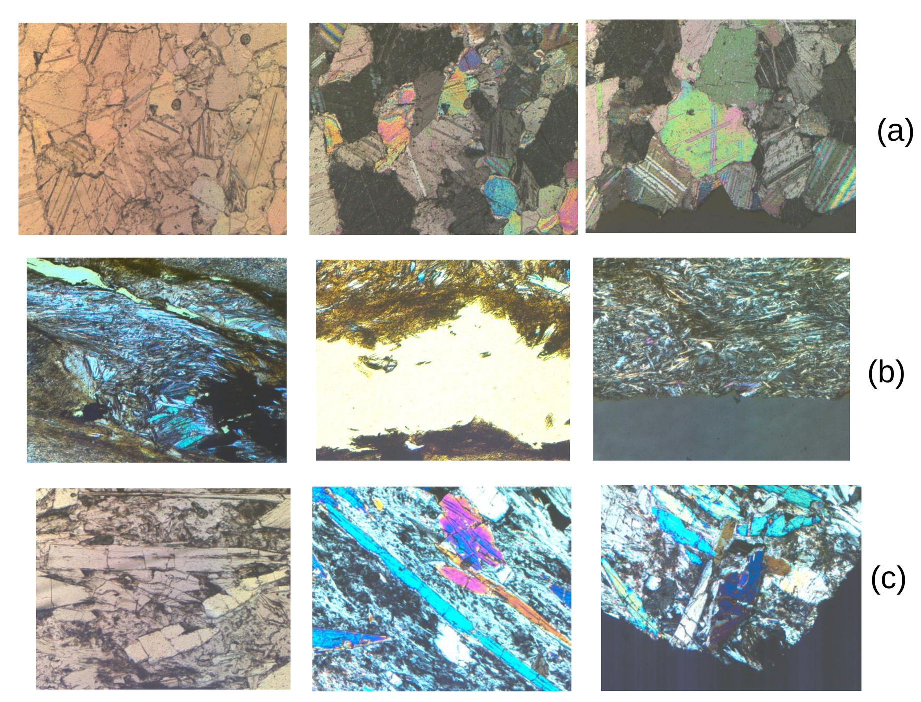
Fluorescence imaging of thin-section samples prepared by embedding in a resin containing fluorescent compound. The cracks and fissures are apparent much more enhanced in the weathered soapstone (a). Along with the relatively thinner fissures, the fluorescent components of the non-weathered soapstone (b) are also visible. The thin-section from the marble sample (c) shows only the intergranular boundaries\spaces.



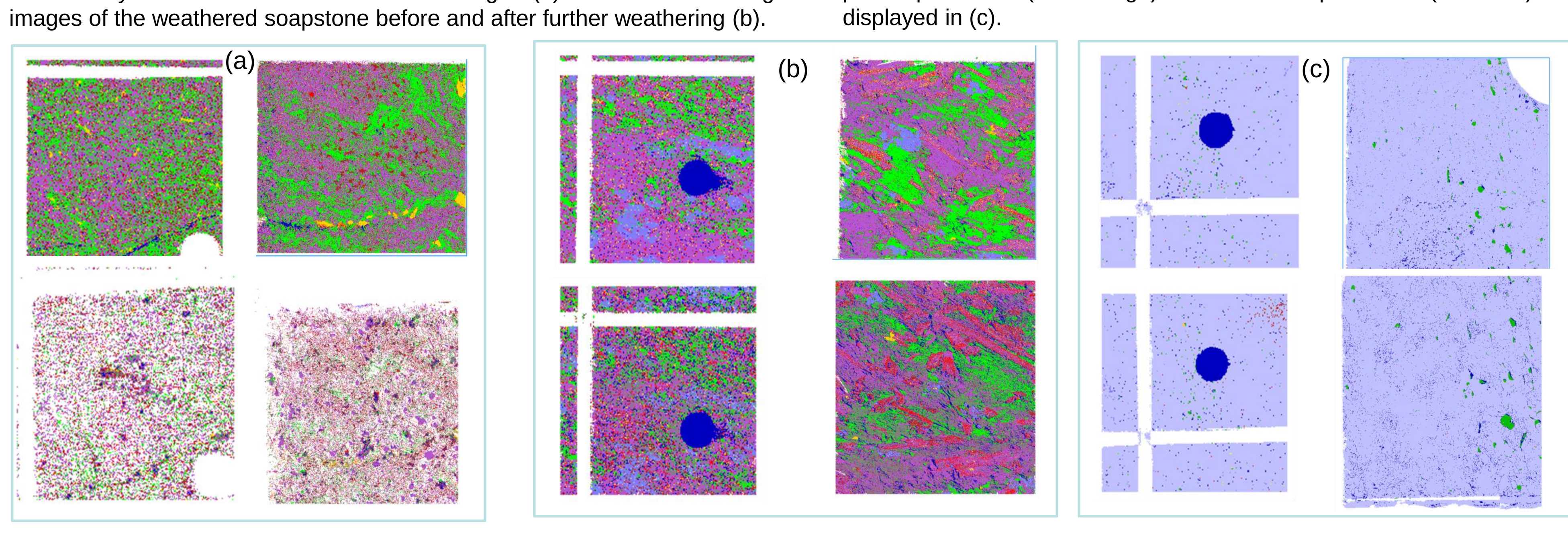
Microscopic close-up image of a weathered soapstone after further weathering (one month duration) at different magnifications and sites (a), (b) and (c). BSE of the same sample (d). Elemental mapping from the same sample (e). The columnar actinolite-tremolite crystals are more visible in (b), (d) and (e). These crystals appear as orange in the mapping image. The distribution of the weathering agent, sodium sulphate crystals are shown as light blue.



BSE images of marble sample upper images in (a) and weathered soapstone (lower image in (a) at different magnifications after further weathering (one month). An increase in the crystal grain boundaries is visible in last two upper images in (a). The deterioration of the actinolite-tremolite cystals is exhibited in the lower images (a). Laser 3D scanning images of the weathered soapstone before and after further weathering (b).



Images of thin sections from investigations using polarized light microscopy: Plane polarized (first image) and crossed polar images from the marble stones after weathering (one month) showing the calcite grain sizes, shapes, orientations and intercrystal grain boundaries(a). At the edge of the cross-section sample (corresponding to the salt weathered surface), breakage following the intercystal boundary is observed (a). Crossed polar images of the weathered soapstone before (first image) and after last two are shown in (b). Increase in the cracking\fissures dimensions is evident. Non-weathered soapstone after weathering in plane polarized (first image) and crossed-polarized (last two) are displayed in (c).



QEMSCAN phase mapping before (top row) and after one month weathering (bottom row) at low (100x100 µm area) and high magnifications (10x10 µm) area. The later is shown to the right in each pair. (a) Weathered soapstone (b) Non-weathered soapstone (c) Marble. Noticeable loss in chlorite (green) and dolomite (light blue) as well as increase in gypsum (red) concentration is indicated (b). The greater roughness after weathering the surface less suitable for the QEMSCAN scanning in (a).

Acknowledgement

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