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A DTM-based volume extraction approach: from micro-scale weathering forms to planetary lava tubes

Riccardo Pozzobon (1), Silvia Salvini (1), Claudio Mazzoli (1), Matteo Massironi (1), and Francesco Sauro (2)

(1) Department of Geosciences, University of Padova, Via Gradenigo 6, 35131, Padova Italy (riccardo.pozzobon@unipd.it), (2) Italian Institute of Speleology Dipartimento di Scienze Biologiche, Geologiche ed Ambientali - BIGEA Sezione di Geologia - Geology Division Università di Bologna Alma Mater Studiorum Via Zamboni 67 - 40126 Bologna

In this work we show how a GIS-based approach on 3D terrains can be useful to analyze volume variations from the microscopic scale on rock samples to large geomorphological features of collapse pits on Earth, Moon and Mars.

The microscale surface analyses were performed on carbonate rock plates dissolved by immersion in slightly acidic solutions: each studied sample underwent an increasing number of immersions aiming to calculate the recession rate of such stones commonly used in the cultural heritage when exposed to acidic rain.

A confocal laser scanning microscope was used to obtain a surface model of the stone surface, whose total size was about 2550 x 2550 microns with a sampling step of 0.6 microns and a vertical resolution of 0.01 microns. This instrument outputs a matrix of pixels whose values corresponded to the height in microns of the actual features on the sample surface, which was treated as a DTM in a GIS environment. Several scans were repeated on each sample after an increasing number of immersion cycles, and progressive recession evaluated.

However, multi-temporal comparisons were not straightforward: the scanning technique suffers of reference system shifts in x, y and z. Indeed, variation of distance and tilting among subsequent acquisitions on the same sample are not constrainable due to hand positioning: the obtained height values are indeed internally consistent within the output, but not fixed to a common reference system.

We overcame this problem by referring all the heights to a “zero reference surface” laid parallel to the sample surface in contact with a flat metal plate, which was previously anchored to the sample and never removed during subsequent attacks. This plate, slightly higher than the sample surface, served as a base to interpolate a synthetic surface covering the entire sample that was common between all the scans. This technique allowed evaluating and correct any shift in x, y and z and obtain absolute height recession and volume loss among subsequent scans after increasing number of immersion cycles, both on the whole sample and specific areas.

The same approach was adopted in planetary remote sensing to evaluate the actual volume of collapsed conduit sections of Earth and Martian lava tubes. Mars and Moon remote sensing surveys highlighted the presence of elongated aligned pits on volcanic areas that closely resemble Earth lava tubes collapsed roof sections. These conduits can be up to tens of kilometers long on Earth and up to hundreds on Mars and Moon. However, a numerical estimate of the possible volumes of the collapses (and thus, of the voids) was never attempted on actual data. The collapse pits were mapped onto stereo-derived DTM and the nodes of the edge of the resulting polygons were then triangulated and rasterized in a new DTM in the same reference system, filling the holes and approximating the pre-existing topography. Surface differences between the reference DTM and the synthetic surfaces was performed to calculate the total volume of the collapsed sections to be compared on distinct planetary bodies.