MORPHOMETRY OF TERRESTRIAL, LUNAR AND MARTIAN LAVA TUBE CANDIDATES

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Introduction: In the last years pit crater chains, skylights and sinous rills, on Lunar and Martian volcanic fields have been interpreted as collapsed sections of lava tubes [1], although a clear understanding of their dimension, depth and formation processes in comparison to the Earth analogues remains elusive. In addition, as demonstrated by previous authors, several pit crater chains can also be related to tectonic or volcano-tectonic processes [2] and sinous rills to lava channels [3]. In order to identify the most promising lava tube candidates on Mars and the Moon we have adopted some criteria that allow to distinguish lava tube pit chains on Earth not only among other pit features, but also between overcrusted and inflated tubes [4]. Following this latter distinction, we present a morphometric comparison between lava tubes on Earth and the most prominent lava tube candidates on Mars and the Moon.

Methods: Pit chains related to lava tubes on Earth present peculiar characteristics: 1) collapses are elongated ellipses with the minor axis approximating the width of the tube; 2) their alignment is sinuous and can be braided; 3) the depth/width of the collapses represents the asymmetry ratio (ellipticity of the conduit), which is different between inflated and overcrusted tubes. Taking these characteristics into account, we have performed morphometric analysis of terrestrial collapses and tube dimensions, focusing on Hawaiian systems (Kazumura, and Ambigua), La Corona system of Lanzarote and the Undara System in Queensland, representing the most voluminous lava tubes known on Earth. On Mars, potential lava tube candidates have been proposed and measured on Hadriaca Patera, Arsia and Olympus Mons. On the Moon, we performed morphometric analysis in the area of Marius Hills, and specifically along the sinous rills related to the Marius Hill skylight [5] and along a pit chain in a parallel rill. Other measurements were done on pit chains in the Gruithuisen area. In total we have measured 112 collapses on Earth, 81 on Mars, 26 on the Moon. The lunar lava tube candidates have been measured on the Selene-Kaguya/LRO-LOLA merged global DTM at ~59.22 meters/pixel, which is the result of coregistration and merging of stereo images from JAXA Selene-Kaguya mission with Lunar Reconnaissance Orbiter Laser Altimeter [6]. Martian DTMs were obtained by the stereo matching overlapping CTX (Context Camera, Mars Reconnaissane Orbiter) images at ~6 meters/pixel with Ames Stereo Pipeline software [7]. The resulting DTMs at ~18 meters post spacing, were successively co-registered on validated HRSC DTMs provided by Mars Express mission and adjusted to the MOLA areoid. The collapses of La Corona Volcano lava tube, were measured on a 5 meters resolution DTM obtained from the interpolation of LIDAR shots provided by the Spanish Geological Service, validated on existing topographic maps of the cave. Data form literature and topographic maps (plan maps and profiles) have been used for measuring lava tubes in Hawaii and Undara.

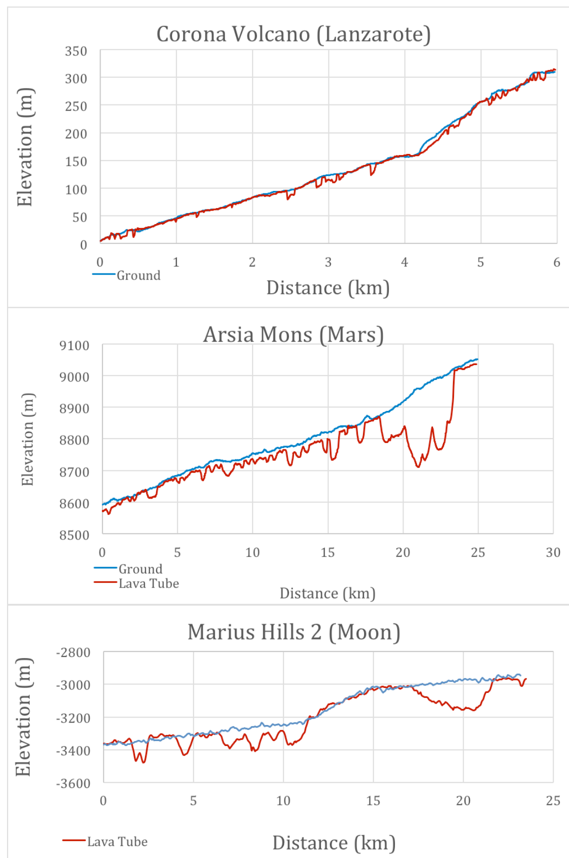

Figure 1: Examples of topographic profiles extracted along the tubes highlighting the collapse alignments and depths. In a) Marius Hills tubes b) Arsia Mons and c) Corona

Results and discussion The data obtained are in agreement with recent modeling of lava tube stability on Mars and the Moon [8] and sheds light on their formation processes and depth of emplacement. The depths of the collapses in each chain show a typical value which corresponds to the level of emplacement of the collapsed tube. While on Earth this is between 10 to a maximum of 30 meters, on Mars this value is between 20 and 80 in Hardiaca Patera and Arsia Mons, reaching a maximum of 130 meters in Olympus. On the Moon the depth of the pit chain of Marius Hill ad Gruithuisen shows a homogeneous value around 200 m.

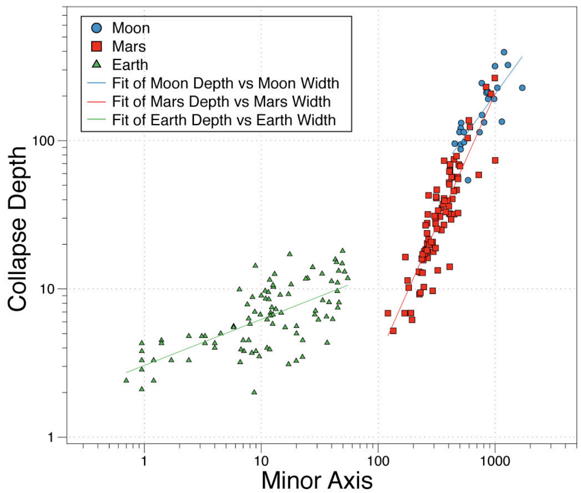

Figure 2*:* Power laws of collapses minor axis versus depths on Earth, Moon and Mars in a Log-Log plot.

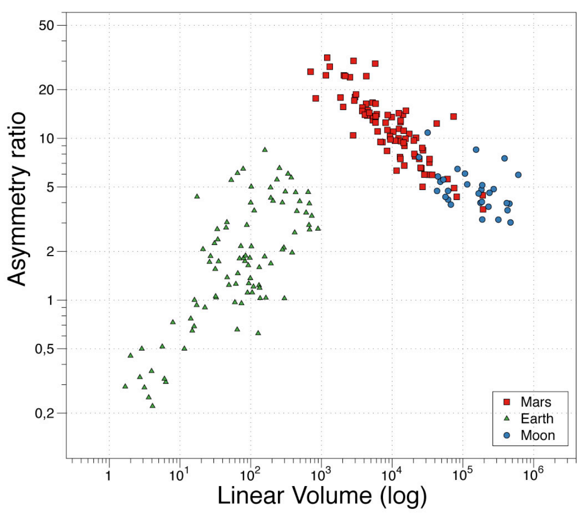

Figure 3*:* Relationship between linear volume and asymmetry ratio on Earth, Moon and Mars.

The minor axis analysis of the pits (which represents the width of the collapsed tube) shows a relevant increasing trend from Earth (10-30 m), to Mars (250-400 m), and to the Moon (500-1100 m). Linear volumes (for 1 meter long tube sections) of the original conduits before the collapse can be estimated, showing also an increase from 1-470*10 m^3 on Earth, one order of magnitude higher on Mars (79-240*10^2 m^3), to two orders of magnitude greater on the Moon (140-170*10^3 m^3).

These data clearly suggest that the dimension increase of the conduits depends mainly on gravity controls on effusion rates. Nonetheless, on the Moon pit chains are not so common suggesting that most of the tubes are not collapsed due to the higher stability of the ceilings, which are probably lying below shallow sinuous rills like where the Marius Skylight is located. Indeed the collapses of the two pit chains analyzed on the Moon seem to be triggered by impact cratering or potential tectonic activity along nearby wrinkle ridges.

Another interesting parameter is the asymmetry ratio of the collapses (AR: depth versus minor axis), which represents the expected ellipticity of the conduit. AR is much higher on Mars (10-15) than on Earth (0,5-4), while it shows intermediate values (5-7) on the Moon. This trend suggests that conduit genesis through deep inflation along inception horizons are much more common and crucial on Mars than on Earth where most of the conduits are due to overcrusting. The intermediate case of the Moon is probably due to higher effusion rates, lower gravitational load and higher thermal erosion capacity of the flows.

Conclusions: This study for the first time infers the dimension and morphology of lunar and martian lava tubes compared to terrestrial ones, on the basis of direct measurements of collapses on the surface of these planetary bodies, with implications on the study of planetary vulcanology, habitability and astrobiology.

References:

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