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Modeling of fluvial episodic events at a channel in Nepenthes Mensae region of Mars

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1.Introduction

A straight V-shaped channel with two overlapped fan-shaped deposits at the mouth, close to a possible fissure volcano (121.43°N,2.16°E) in Nepenthes Mensae region of Mars (Fig.1) has previously attracted our attention [1]. The MOC-NA and the first HRSC images in the area allowed us to propose a hydrological evolution for the area, including water level variations over time [2]. Now, we revisited the site with higher resolution images and topography to model [3] the mechanisms that created the fan-shaped deposits with a recent methodology [4]. This will expand our understanding of the area's fluvial processes by adding to the debate over variations in water levels at long-standing water bodies. Here we present the preliminary geological observations that will constrain the forward topographic deconstruction and the numerical modeling.

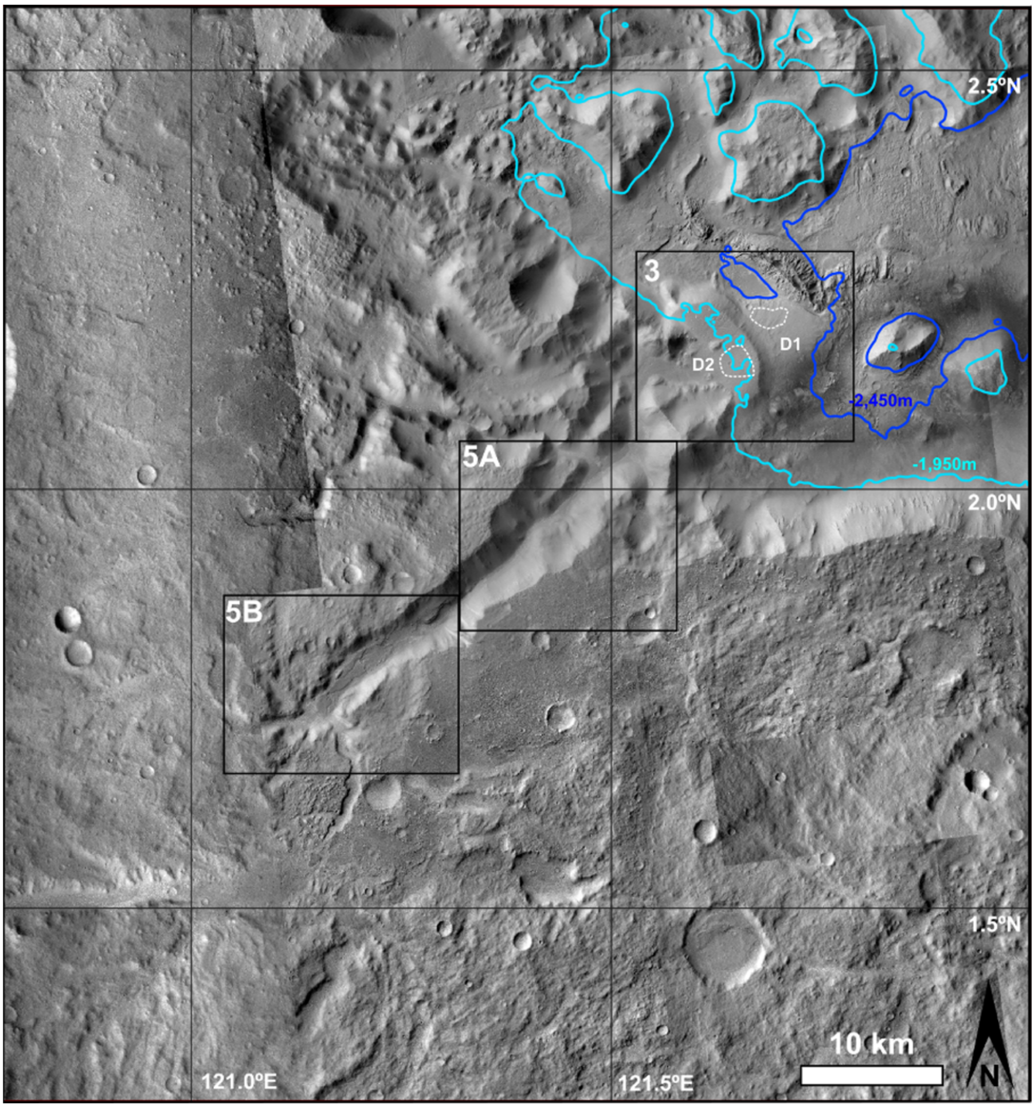


Figure 1: Study area in the Martian highlands-lowlands boundary in Nepenthes Mensae, Mars, where 2 deltas (D1 and D2) were described at the mouth of a V-Shaped channelbetween elevations of -1950 and -2,450 m. Inboxes show detailed views of Figures 3 and 4. White dotted polygons represent the crater counting areas for CSFD analysis and age modeling shown in Figure 5.

2.Methodology

We plan to reconstruct the hydrogeological evolution of the area using a three-step iterative model (Fig.2,[4]). Starting with the geological study of the area (Fig.2,O1), we used a GIS (QGIS 3.16) with recent imagery (CTX,HiRISE) and topography (HRSC). We refined the previous geomorphological description of the features and dated the two hydrologic events through CSFD analysis using the CraterStats2 software [5]. After identifying topographical constraints for the modeling process [3] we performed a series of topographic deconstructions (Fig.2,O2) that would be the input for the numerical modeling (Fig.2,O3).

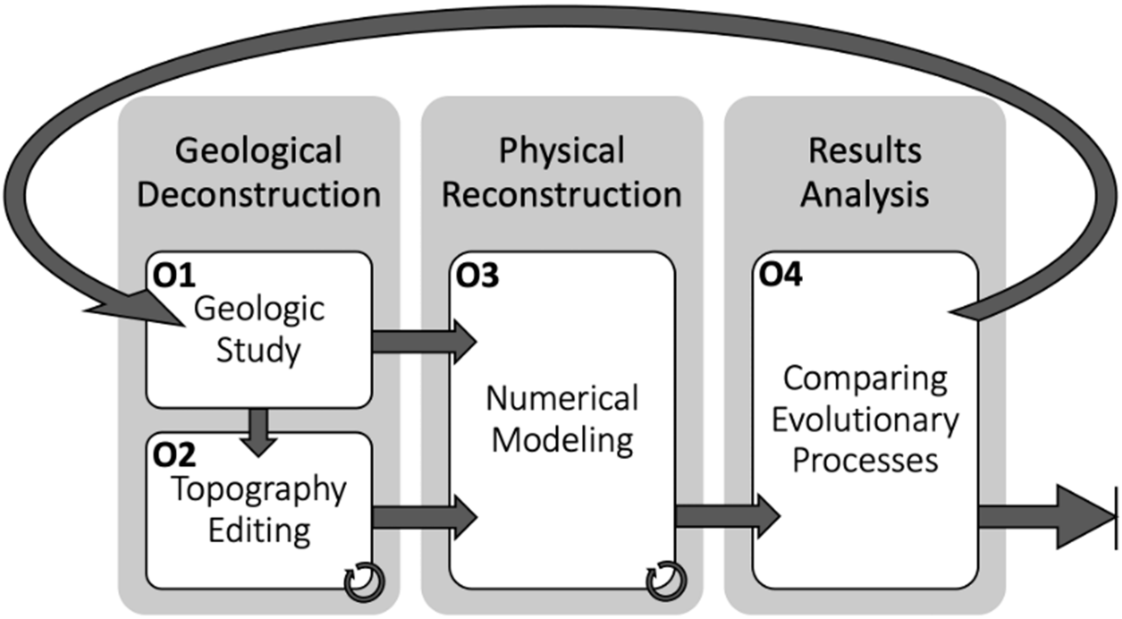


Figure 2: Schematic diagram summarizing the methodology to reconstruct a channel-fan formation iteratively with mapping and mechanical modeling [4].

2.1.Geological Deconstruction

2.1.1.Geologic study

Two major fluvial phases were proposed at first based on the appearance of two overlapped deltas [2]. The first, resulting in the formation of an alluvial fan at the bottom (D1), could have formed in the absence of a standing water table; the second, a pristine Gilbert-type delta (D2), could have formed at roughly -1,990 to -1,950m elevation water table [2,6]. According to HRSC-derived topography, the base of D1 is at around -2,540m elevation (Fig.1), and Contact 1 of Oceanus Borealis is at about -2,499m elevation [7,8]. This could support the hypothesis that D1 originated as an alluvial fan near the water's edge.

Other deposits at the base of both deltas are visible on high-resolution images, which could result from prior fluvial processes (Fig.3). The images demonstrate the presence of other distal deposits between the two deltas (Fig.3), most likely due to the gradual rise of the water table, resulting in a reduction in the areal extension of the deposits while they increase in thickness. The presence of benches at elevations ranging from -1,400 to -2,400m [2,6] may indicate a progressive change in the water table level.

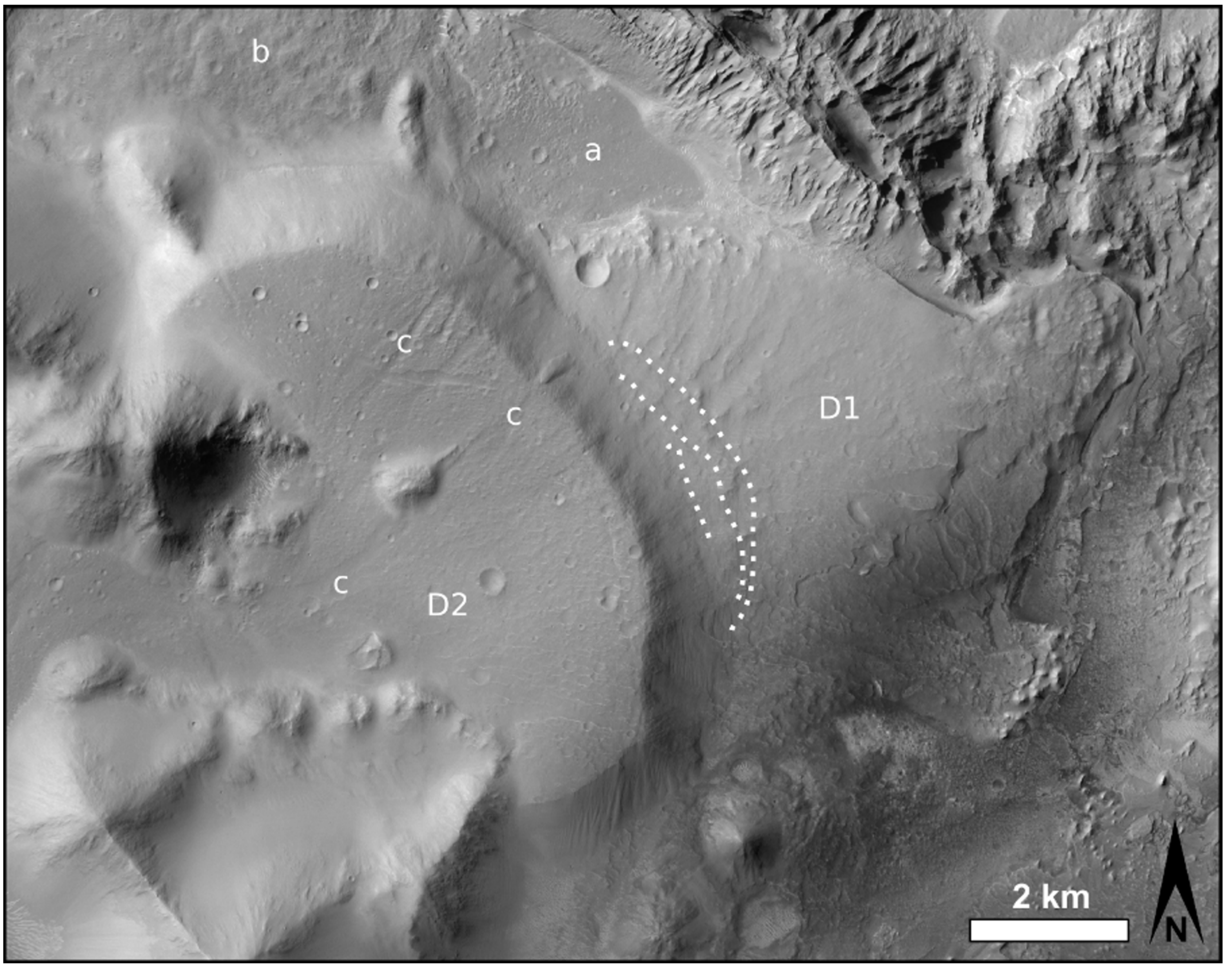


Figure 3: CTX image of the deltas (D1 and D2) formed at the mouth of the channel. Images show the presence of distal deposits of intermediate sedimentary structures (white dotted lines) formed between D1 and D2, as well as possible older fluvial deposits (and and b). Recent fluvial resurfacing is visible by channels (c) dissecting the surface of D2 deposit.

The CSFD analysis allowed both deltas to be dated (Fig.4). Due to resurfacing events, D1 does not reveal ages older than 400Ma (400 and 84Ma). Since ages of 3.5 and 3Ga have been fitted, D2 was produced in Hesperian. Other ages of 820 and 63Ma are produced by resurfacing processes. Although we found younger resurfacing ages, the age of creation of D2 fits with the age of other deltas in the vicinity [6]. Resurfacing activities and aeolian events are aided by channels slicing the top surface of D2 (Fig.3).

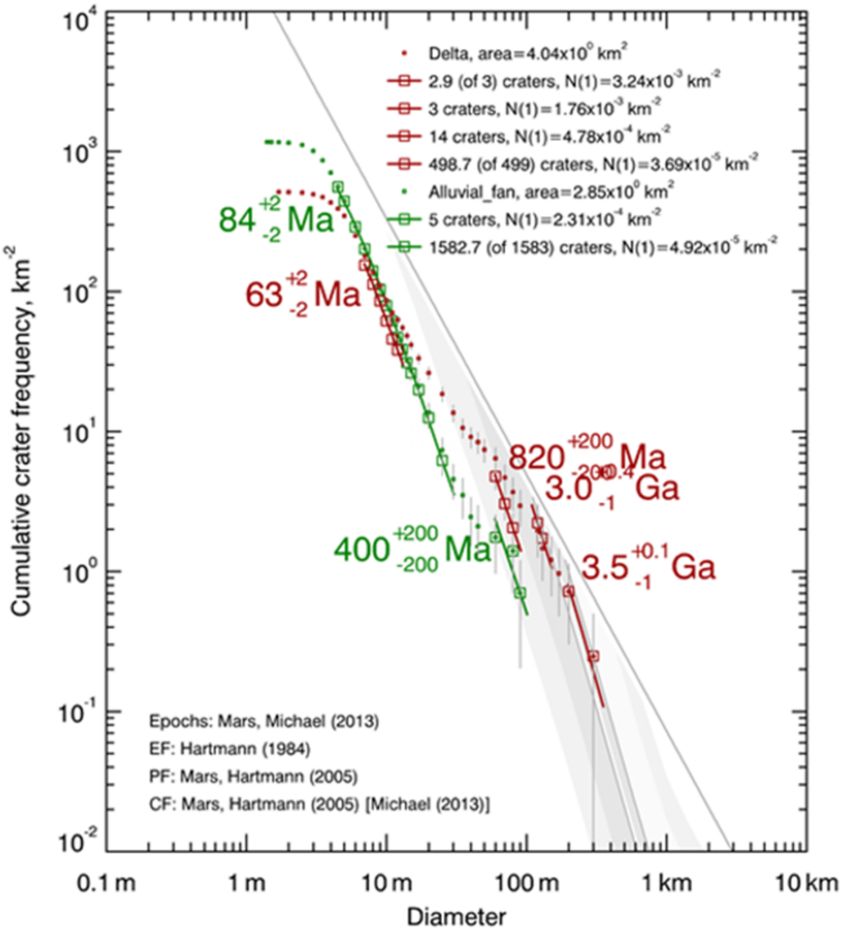
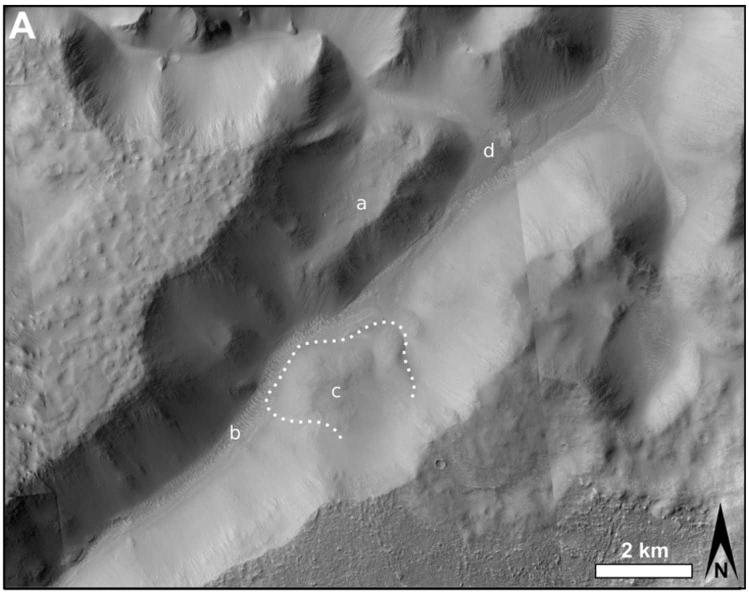


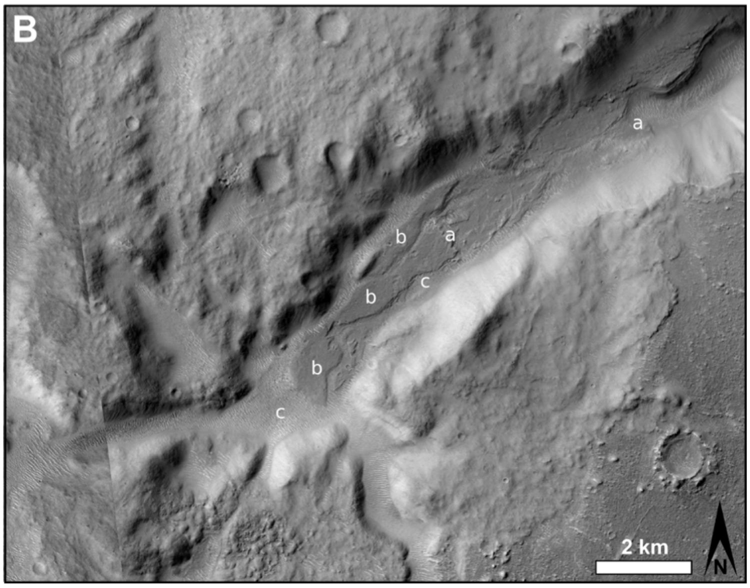
Figure 4: Ages model showing cumulative fitting of CSFD for alluvial fan (green) and Gilbert-type delta (red). Except for the first age for each deposit, the other ages were obtained by correction of resurfacing events.

These sedimentary deposits were made possible by materials carried by a river flow after excavating a V-shaped valley, which is now filled with fluvial, aeolian, and sediments from mass-wasting processes, such as a rotational landslide (Fig.5A). A probable fluvial terrace was presented [2]; however, it could not be now validated using high-resolution images. Other features, such as two knickpoints, are now visible (Fig.5B), indicating (1) the presence of resistant material acting as local base levels or (2) the decline of water table levels at the channel mouth [9]. Also evident are sedimentary deposits at the top section of the channel, as well as along the degraded channels, such as those coming from the tributary, which gives a key to reconstructing the sequence of fluvial events in this system.

Figure 5.



A. CTX image mosaic of the central sector of the channel where the putative terrace (a) requires further detailed studies. The channel is filled with sediments, including from eolian (b) and mas-wasting processes (c), as well as fluvial from tributary streams (d). White dotted line defines the landslide deposits not recognizable in other type of less-resolution images.



B. CTX image of the head sector of the channel showing 2 knickpoints (a) and ancient sedimentary deposits (b) later eroded by fluvial processes, leaving new sediments,covered by aeolian sediments on present day (c). These features point to a complex hydrological evolution in this channel.

2.1.2.Topography editing

Having differentiated the phases for the formation of hydric geomorphologies, their characteristics, and the extent of other subsequent processes altering the relief, we modified the topography to emulate the one prior to the hydrological process, also determining the position and volume of the mobilized material. We tested the different working hypotheses with different deconstructions that will be iteratively refined.

2.2.Physical reconstruction: Numerical Modeling

The initial conditions and topographies are extracted from the geological deconstruction, which must be interpolated in a computational mesh (Fig.6). Subsequently, a two-phase (i.e., soil and water) model based on the depth-integrated Navier-Stokes equations will be applied [10].

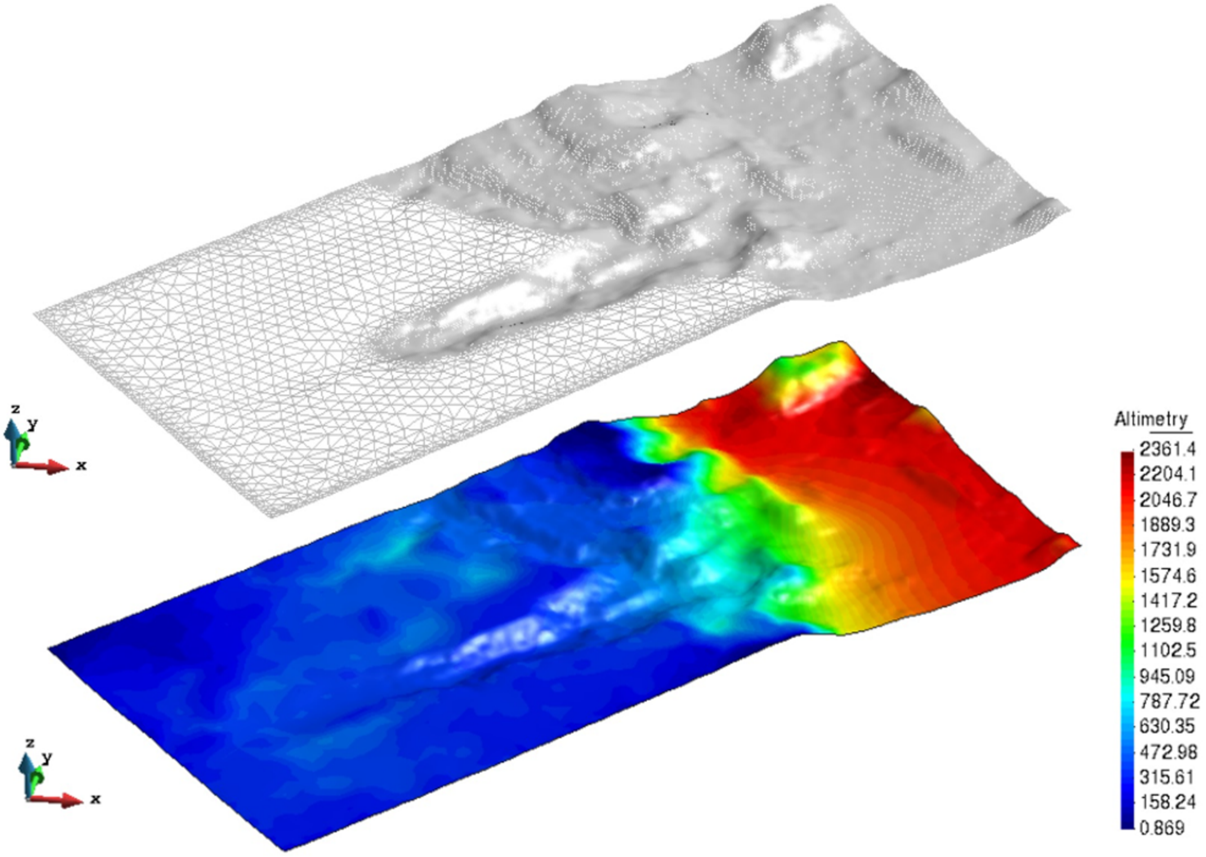


Figure 6: Computational mesh (43295 linear triangles) with variable resolution (top) and topographic deconstruction and mesh interpolation (bottom) with colorized altimetry (meters below Mars' datum).

The simulations will provide the volume of mobilized material, type of material (including its water content), a final topography, and the duration time of the event to be studied [3].

2.3.Results Analysis

A comparison of the evolutionary processes by evaluating the differences found between the simulation results and the studied morphologies in terms of volumes of mobilized material, flow directions, final slopes, and shape will be accomplished. Based on the discrepancies obtained, it will be decided whether the iterative process must be finalized or a new deconstruction/reconstruction process must be started.

3.Expected results

This methodology will provide a better understanding of the hydrogeological processes that lead to the formation of the deltas in Nepenthes. Information about the water content, duration of the processes, and the existence (or not) of a layer of water in the lowlands will be obtained.

Besides, the proposed technique can be applied elsewhere on the surface of Mars, being possible to extend it to the study of other geological processes and even other planetary bodies. In this way, this study will help shed light on how and when the geological and environmental evolution of Mars has taken place.

Acknowledgements

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