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Geomorphological analysis of Ares Vallis (Mars) by using HRSC (MEX) data: catastrophic floods and glacial morphologies

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Abstract. Ares Vallis is one of the largest outflow channels of Mars. Aim of our work is a geomorphological analysis of the trough by using high-resolution images. We utilise principally the High Resolution Stereo Camera (HRSC) images, onboard Mars Express (ESA). Images have been processed in order to obtain stereo-derived Digital Terrain Models (DEMs). HRSC images and DEMs, together with high-resolution images of different Martian missions (MGS, and 2001 Odyssey) are successively visualised by using a GIS software, and a three-dimensional analysis have been performed.We analysed morphologies indicating catastrophic flood processes and others indicating glacial and periglacial processes. Geological properties and geometrical relationships of these features are here presented. Geomorphological analyses provide new constrains about Martian catastrophic flood processes and their possible minimum and maximum depths, and allow us to present more detailed hypotheses about the geological evolution of the investigated area.
Catastrophic floods sculpting Ares Vallis appear to have been multiple and scattered in time: periods of time separating different floods could have been hundreds to thousands of years. Geomorphological evidences show that ice masses formed on top of catastrophic floods, and that successively grounded, forming dead-ice masses. Such dead-ice masses played a foundamental role on the evolution of the Ares Valls landscape, leading to the formation of prominent kame-like features.
A few portions of the ice masses infilling Ares Vallis could have been buried and therefore preserved for long time (maybe until the present time).

Key words. Mars – Ares Vallis – outflow channel – catastrophic flood – ice – kame – climatic variation

1. Introduction

The Martian outflow channels are large complexes of fluid-eroded troughs, as wide as 100 km and as long as 2000 km. One of the greatest among these is Ares Vallis (figure 1): this outflow channel has been well investigated in the past, as well to support the landing site analysis of the NASA Pathfinder Missions, which landed near the present termination of Ares Vallis, on 1997. The flows forming Ares Vallis and its channel arms appear to have emanated from distinct collapse zones or chaotic terrains, which are Iani Chaos, Hydaspis Chaos

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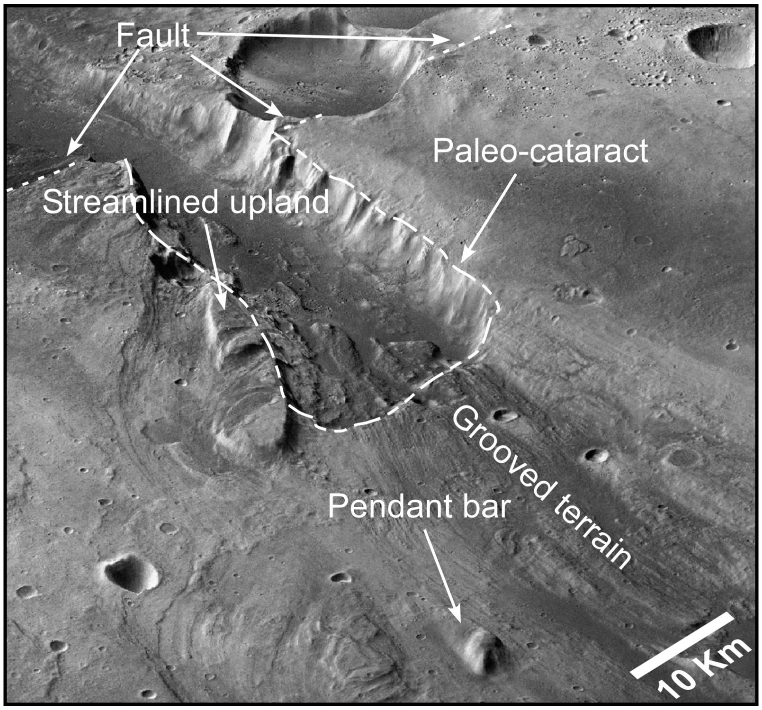

Fig. 1. This picture shows the typical erosive features sculpted by a catastrophic flood. The paleo-cataract formed in correspondence of a 500 meters high scarp tectonic in origin. Upstream to the paleo-cataract a grooved terrain, a pendant bar, and a streamlined upland are recognizable. Flooding occurred from lower-right to upperleft. Three-dimensional view of an HRSC mosaic draped on an HRSC stereo derived DTMs mosaic; vertical exaggeration is five time.

and Aram Chaos. Ares Vallis extends for about 1500 km, and debouches in Chryse Planitia. Several geologic histories have been proposed for the evolution of Ares Vallis and other outflow channels(Baker and Milton (1974); Baker et al. (1992); Lucchitta (1982)). Each of these models of origin and evolution could imply different processes of formation of the trough, and different climatic evolutions of Mars. These models derive from observations conducted using Mariner and Viking data, which have low-medium spatial resolutions. Impact crater counting indicates that Ares Vallis developed through Martian Hesperian age. We investigated Ares Vallis with high spatial resolution images (HRSC, THEMIS VIS and MOC narrow angle) in order to hypothesize more detailed possible scenarios for the geologic history of Ares Vallis.

2. Methodology

In order to do this, we have used several datasets. The High Resolution Stereo Camera (HRSC), onboard the ESA mission Mars Express (MEX), provides orthorectified images and stereo-derived Digital Terrain Models (DTM). These data allow us to drape high-resolution images on HRSC stereo-derived DTMs, and to observe these in 3D view. We utilize also Viking, MGS MOC Wide angle, and Odyssey 2001 THEMIS (both Visible and IR) images. MOC na images were used to further characterize the observed morphologies with much more details. The Mars Odyssey THEMIS IR data were used in order to characterize (qualitatively) thermal properties of surfaces.

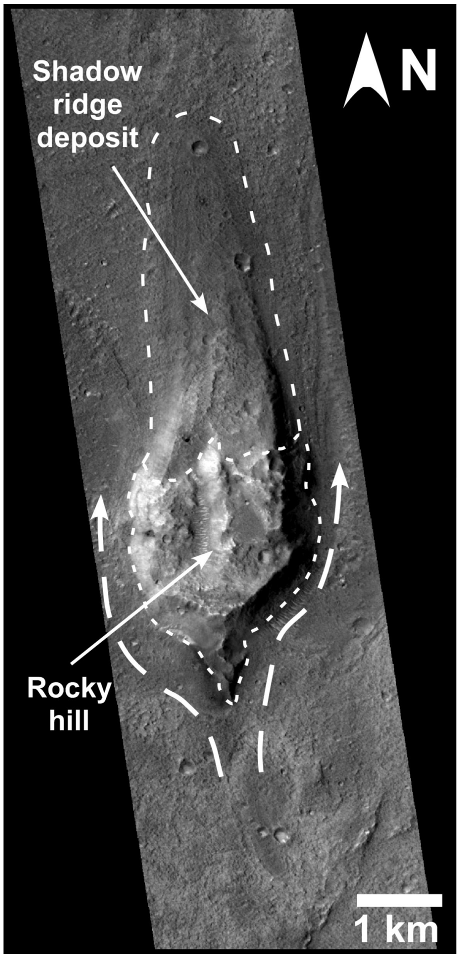

Fig. 2. High-resolution image of a pendant bar. The white arrows indicate the direction of the flow.

3. Catastrophic floods

Several of features characterize the Ares Vallis Complex, such as: erosive terraces, streamlined uplands, pendant bars, grooved terrains, and paleo-cataract features. Although different processes could explain the origin of each of such features, their association (figure 1) indicates that this outflow channel has been shaped by catastrophic flood processes. Upstream reach of Ares Vallis is characterised by several erosive terraces. These often show a grooved surface. The relationships occurring among different terraces indicate that Ares Vallis has been sculpted by several (at least four) catastrophic floods. The early flood event was characterized by a broad, shallow flow, while subsequent floods has been progressively channelized. During the processes of canalisation, the main tectonic structures of the area have played a fundamental role on determining the direction of floods. Pendant bars appear to have formed by a rocky hill on the upstream part, and by an obstacle shadow ridge deposit on the downstream part (figure 2).

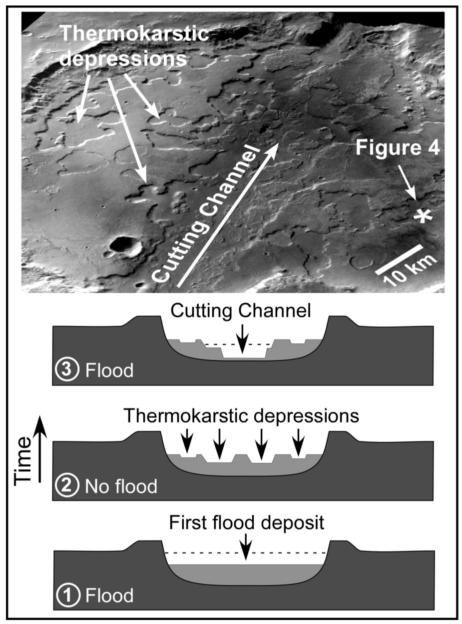

Fig. 3. Thermokarstic depressions characterize the flat, floor deposit of an impact crater crossed by a valley arm of the Ares Vallis Complex. The cutting channel reworked and postdated the thermokarstic depressions. HRSC mosaic draped over an HRSC stereo-derived DTMs mosaic. The vertical exaggeration is three time. The sketch illustrates a possible evolution model of the valley arm.

The heights of the downstream shadow ridges (about 300 meters) indicate the minimum depth of floods flowing through Ares Vallis at the time in which pendant bars formed. Pendant bars often show a parabolic scour on the upstream part, which form by acceleration of flow nearby the obstacle. The valley floor embaying pendant bars normally appear to be grooved. Erosive features, such as the grooved terrain and the upstream parabolic scour, are not observed nearby the pendant bars occurring in the inner part of the trough. This fact implies that during the waning stage of the floods, a smaller amount of water flowed just on the inner and deeper part of channel, and that the lower energy of flow caused depositional processes. In some areas, relationships among sedimentary and erosive features suggest that floods have been scattered in time. The figure 3 illustrates a possible evolutionary model of a portion of the Ares Vallis Complex. The thermokarstic depressions formed by melting and/or sublimating processes of an ice-rich deposit emplaced by first flood(s), appear etched and reworked by subsequent floods. The time elapsing among the two floods must have been enough extended to allow the shaping of thermokarstic features. It is difficult to determine the amount of time required to form so large thermokarstic features on Mars (we do no know the Martian climatic condition at this time, and properties of Martian ice-rich soil): nevertheless, just to make a rough comparison, similar thermokarstic features on our planet require hundreds to thousands of years to form.

4. Glacial morphologies

Several of features observed on Ares Vallis Complex indicate that ice-rich deposits or ice-masses formed at the end of each flood. The ice could have formed both in cold-dry climatic conditions similar to today (Wallace and Sagan (1974)) and in warm-wetter conditions (Lucchitta (1982)). On several areas of Ares Vallis we observe flat-topped mounds rising for about 100 to 500 meters varying in shape, dimension or orientation (figure 4).

Several characteristics of such features appear to be similar to terrestrial kame deposits, which form in ice-walled stream and lake, and become prominent flat-topped mounds once the ice is wasted. Martian kame-like structures overlie and postdate the features shaped by catastrophic floods, such as grooved terrains and streamlined features. (figure 4). Martian

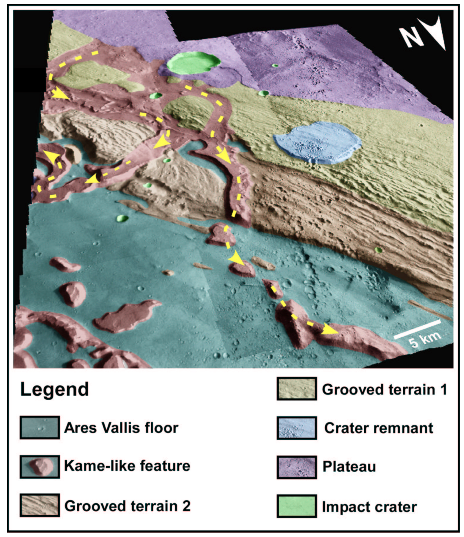

Fig. 4. Interpretative three-dimensional sketch illustrating relationships among grooved terrains, kame-like features and Ares Vallis floor. A scarp 200 meters high separates grooved terraces of different levels. A few channels, running toward the inner part of Ares Vallis, etch the uppermost terrace, and downstream becomes kame-like features. The kames-like features resulted by fluvial erosion of one or more ice-masses followed by topographic inversion processes, caused by ice wasting. the arrangement and the heights of kames-like features imply that an ice-mass up to one hundred of meters thick covered the Ares Vallis floor and lower grooved terrace. HRSC and THEMIS VIS images mosaic draped on HRSC stereo-derived DTM. The vertical exaggeration is three time.

kame-like deposits indicate that a large part of Ares Vallis has been filled by one or more stagnant ice masses. The arrangement and heights of Martian kame-like deposits allowed determining the minimum extension and thickness of the dead-ice masses infilling Ares Vallis in the past. In some areas of the Ares Vallis Complex, patterned terrains characteristically show high values of radiance on the IR night time images (figure 5). The typology of patterned terrains (pitted terrains and polygonal terrains) suggests that they form by periglacial processes: this implies the presence of permafrost or underground ice at the present day

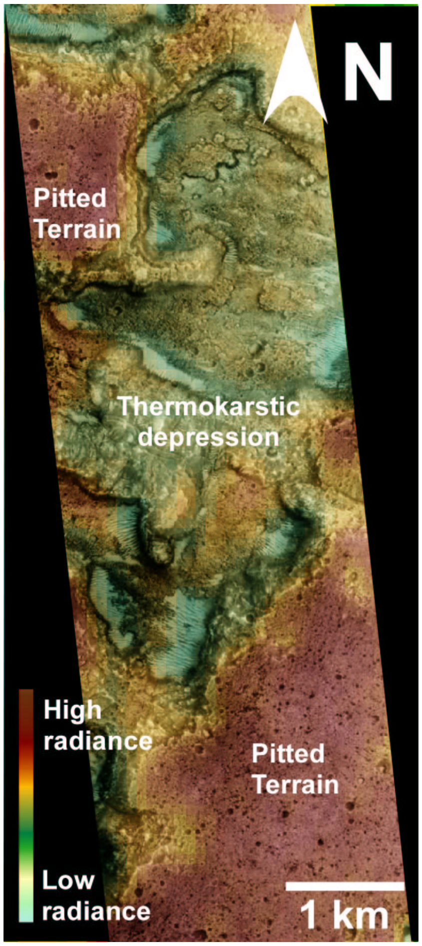

Fig. 5. data fusion among MOC E1700126 and THEMIS IR night time mosaic. The pitted terrain characteristically shows the highest values of emittance during the nigh. See figure 3 for location.

or in the past. The high values of radiance in IR nigh images could be due to ice cementing soil or duricrusts formed by ice sublimation or melting (Landis et al. (2004)).

5. Implications for climatic variations

All these glacial morphologies indicate variations of Martian climatic condition in the past. The thermokarstic depressions observed in the Ares Vallis Complex (figure 3) imply that ice-rich deposits form and wasted between two different floods. Kame-like features indicate that water-streams flowed on top of the ice masses: this implies that climatic condition of Mars, during the emplacement of such features, was warmer (and maybe wetter) than during the emplacement of ice masses. Finally, the patterned terrains indicate that permafrost or buried ice sublimates or melted. The overall pristine appearance of kame-like features suggests that ice masses infilling Ares Vallis wasted mainly by sublimation processes, indicating that after one or more brief periods of warmer-wetter conditions, climatic conditions changed to the ones similar to those of present day.

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