LIQUID WATER IN A RECENT DEBRIS AVALANCHE ON MARS : EVIDENCES FROM VIKING DEM AND MOLA DATA

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Abstract. In the region of Reull Vallis, near Hellas basin on Mars, lobate debris aprons are recent landforms (Amazonian) due to the creep of water ice mixed with rocks. Amongst these landforms, one unusually long debris apron has a tongue-shape that suggests a different origin. A high-resolution Digital Elevation Model of the area is computed from Viking images and MOLA data. The analysis of these new topographic data demonstrates the role of liquid water during the flow. The late Amazonian age of this landform question the presence of near-surface water in the recent geological past.

Introduction

Recent data from the Mars Glover Surveyor (MGS) spacecraft has renewed usual conceptions about liquid water on Mars. Indeed, several high-resolution pictures of Mars Observer Camera (MOC) show debris flows probably created by liquid water on hill slopes.

On Earth catastrophic mass wasting like debris aprons avalanches exist also at the ten kilometers scale [2]. These landforms are often correlated with the presence of interstitial liquid water [3]. On Mars, huge landslides are especially developed along Valles Marineris scarps, but the role of liquid water is not obvious and remains debated [4, 5]. The landform we focus here (see figure 1) is equivalent in size but younger than the landslides of Valles Marineris. We present a topographic analysis of this landform that demonstrates the presence of liquid water during its emplacement.

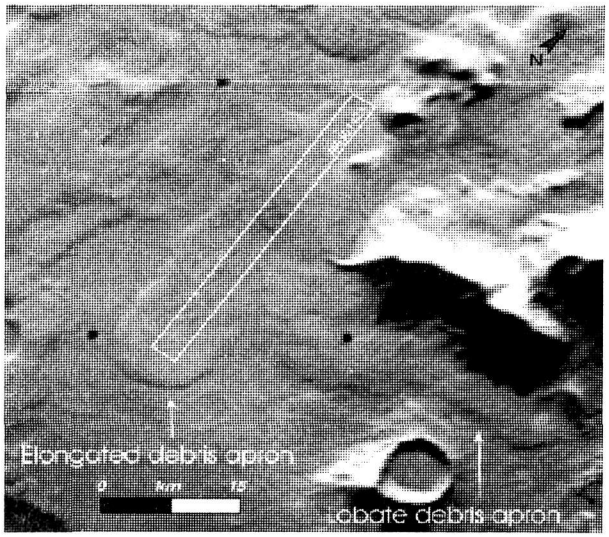

Fig. 1. Part of Viking image 329s25 of Reull Vallis with footprint of one MOC image and MOLA profile 1590. The elongated debris apron located (263.4°0W 40.1°S) is different from usual lobate debris aprons by its length and constant width (from [1]).

Geological Setting

The region of Reull Vallis is located at the north-west of the Hellas basin in the southern hemisphere of Mars. Lobate debris aprons developed at the foot of remnant hills and lineated valleys fills of Reull Vallis are the youngest features (middle to Late Amazonian epoch, few hundred millions years [6]) dated by Mest and Crown[7]. These debris aprons are produced by the creep of interstitial ice. This interpretation relies on longitudinal and transversal ridges and the convex shape of their topography [8]. However, the tongue-shape of the elongated debris aprons (figure 1) and absence of transverse ridges noted on MOC images suggest a process other than viscous creep.

High-Resolution topographic data

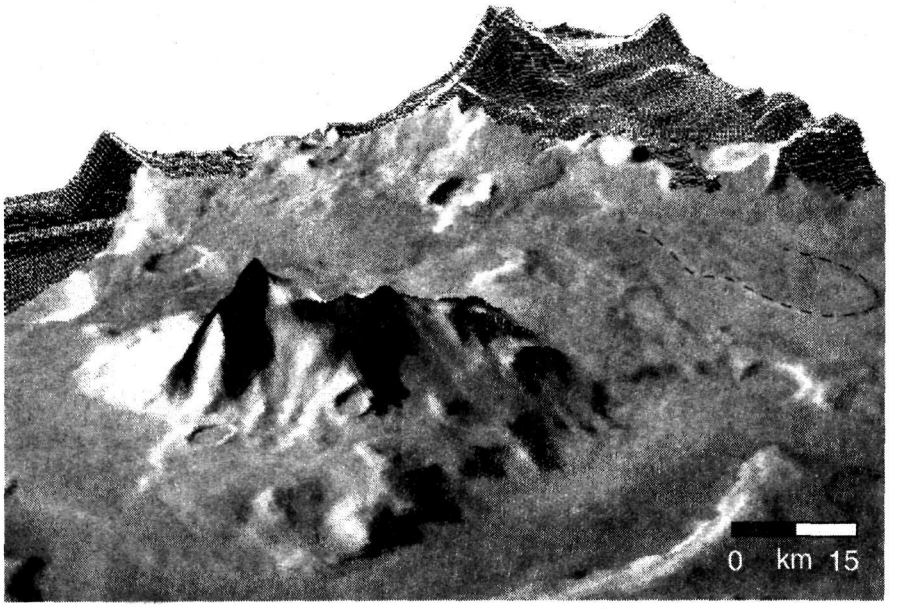

Fig. 2. Ortho-rectified Viking image 329s25 overlaid on our Digital Elevation Model. Vertical Exaggeration : 20X, view angle : 40°.

The dimensions and thickness of the deposit estimated from the resolution of Viking images and shadows lengths are respectively a few tens of kilometers and a few tens of meters. So, high-resolution topographic data are required for an accurate analysis : a resolution that ranges from 100 to 500 meters and a vertical precision that ranges from 10 to 50 meters. The topographic data from the MOLA instrument have a vertical accuracy of 1-2 meters and the distance between MOLA ground spots along the tracks are about 300 meters. However, the average distance between topographic profiles at this latitude is 1 km, and might increase to a few kilometers in some places. Thus, additional topographic data have been computed from the method described in [9] using two Viking images. This method have three main advantages. The algorithm of correlation is based on Fourier transform and improves the accuracy and efficiency of the automatic correlation of stereo pairs. The camera angles and position are re-estimated through the process by a relative orientation method. Finally, the absolute orientation is achieved using MOLA data. Since this last step was not possible before the availability of MOLA data, the advantage of this orientation method in two steps (relative orientation followed by absolute orientation), had not yet been explored with the Viking images. This method allows us to derive resolution and precision maps. The resolution of our DEM is about 300 meters, with a vertical precision better than 50 meters. The achievement of absolute orientation from MOLA data implies that the offset between the two data set can be estimated. Therefore, ortho-rectified Viking images have been produced and found very useful to define the limit of features directly on the images while volume or area are estimated from the corresponding topographic data in the same frame.

Topographic analysis

The presence of liquid water during the flow is demonstrated from the tri-dimensional geometry of the deposits, and from the analysis of energy balance. The topography along the elongated debris apron does not display the convex shape as other debris aprons. The topography of the deposit area is characterized by a zone of thin material (10-50 meters) at the bottom of one of the rock glaciers and a zone of increasingly thick material (150 meters). The thick head of the debris apron lies on a flat area. This topographic signature is not consistent with a slow viscous flow. However, during the deposition phase, coarser debris that collects at the debris flow head form a dam that can stop the movement and produce such a topographic signature. Furthermore, the constant width of the deposit is consistent with an emplacement mechanism where inertial forces play a role, while other rock glaciers tend to spread laterally.

The direction of the maximum slope and the local topography have been used to estimated a source area. So, we proposed that the debris flow should have been triggered in the area inside the dotted circle, where one of the two hills should be the source of the avalanche (figure 3). The energy balance is performed using the net coefficient of efficiency (R), equal the ratio of the difference in elevation and run-out distance, measured at the center of mass of the flowing material [3]. The following estimates from our topographic and MOLA data allows us to estimate the value of R :

Area of the deposit	325 km2
Area of the head of the debris flow (figure3)	170 km2
Average thickness of the deposit	60 m
Run-out distance	30 ± 5 km
Elevation difference	0.8 ± 0.100 km
Net coefficient of efficiency	35 ± 5
Volume of the knob (a) (figure3)	39 km3

R has been measured for wet and dry landslides on Earth. For debris flows that contain a fraction of water, the net efficiency coefficient is proportional to the logarithm of volume removed (figure 4), at least for volume greater that 100 km3 [3]. However, dry landslides have a smaller run-out distance. This is consistent with the fact that dissipation of the potential energy is more efficient in dry flowing material.

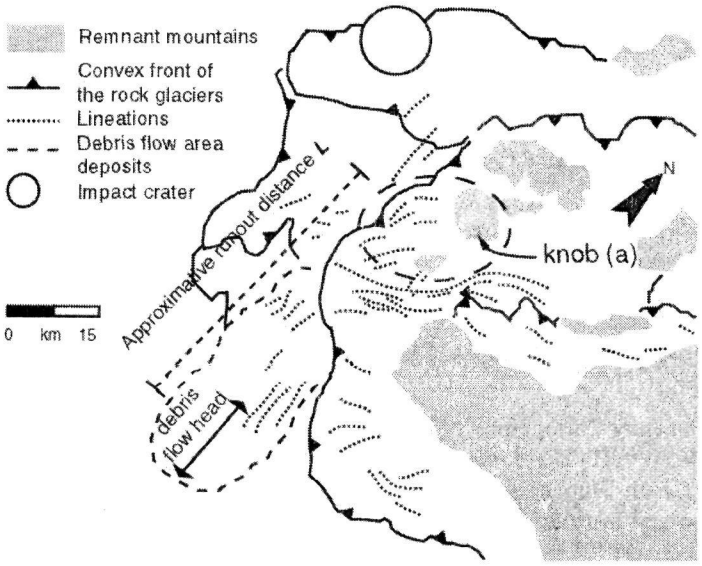

Fig. 3. Morphologic map of the Reull Vallis area. Lobate debris aprons are rock glaciers that are associated to hills and topographic highs. Lineation and crevasses are usually concentric or radial to the creep that extends around hills. The elongated debris apron defines a debris avalanche which is distinguishable from rock glaciers. Lineation over the debris avalanche extend only in the direction of the flow.[1]

In conclusion, the elongated shape of the landform, the topographic signature of the head of the deposit, and the considerations about energy dissipation implies the presence of water during the flow.

At the time of the event, few hundred millions years ago or less, the climate is thought to be similar to the present time and the subsurface was frozen down to 2-5 km [10]. Liquid water was not theoretically expected at the surface. The occurrence of a climate change at that time is unlikely. Any magmatic activity or geothermal heating could thus have melted the ground ice to produce liquid water at shallow depth. Indeed, the region shows a complex volcanic evolution. The presence of such feature during the Late Amazonian epoch is another evidence for youthful water-related feature such as those interpreted from new MGS data [11] .

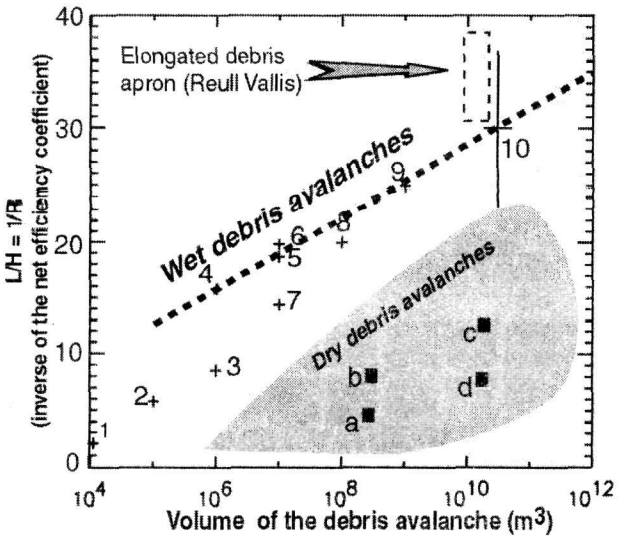

Fig. 4. Inverse of the net efficiency coefficient (L/H) versus volume of debris avalanches on Earth, and for the elongated debris apron of ReullVallis. (1) Pacifica, Califor., (2) Mount Thomas, NZ, (3) Three Sisters, Oreg. (4) Wrightwood, Califor. (5) Mount St Helens (South Fork toutle), (6) Nevado del Ruiz, Columbia, (7) Mount St Helens, Muddy River (8) Nevados Huscaran, Perou (9) Mount Rainer, (10) Mount Shasta Volcano, Calif. (a) Pamir, (b) Blackhawk, (c) Saidmarreh, Iran (d) Flims. Data from Iverson (1997)

References

1. Baratoux, D., et al., Evidence of liquid water in recent debris avalanche on Mars. Geophysical Research Letters, 2001(in press).
2. Crandell, D.R., et al., Catastrophic debris avalanche from ancestral Mount Shasta volcano, California. Geology, 1984. 12: p. 143-146.
3. Iverson, R.M., The physics of Debris Flows. Reviews of Geophysics, 1997. 35(3): p. 245-296.
4. Lucchitta, B.K., Valles Marineris, Mars : Wet debris flows and ground ice. Icarus, 1987(72): p. 411-429.
5. McEwen, A., Mobility of large rock avalanches: Evidence from Valles Marineris, Mars. Geology, 1989. 17: p. 1111-1114.
6. Hartman, W.K. and D.C. Berman, Elysium Planitia lava flows: Crater count chronology and geological implications. Journal of Geophysical Research, 2000. 105: p. 15,011-15,026.
7. Mest, S.S.C. and D. Crown, Geology of the Reull Vallis Region, Mars. Geology, 2001. 153: p. 89-110.

8. Mangold, N. and P. Allemand, Topographic analysis of features related to ice on Mars. Geophysical Research Letters, 2001. 28(3): p. 407-411.

9. Baratoux, D., C. Delacourt, and P. Allemand, Digital Elevation Models derived from Viking images : method and comparison to MOLA data. Journal of Geophysical Research, 2001. 106(12).

10. Clifford, S.M., A model for the hydrologic and climatic behaviour of water on Mars. Journal of Geophysical Research, 1993. 98: p. 10973-11016.

11. Malin, M.C. and K.S. Edgett, Evidence for Recent Groundwater Seepage and Surface Runoff on Mars. Science, 2000. 288(5475): p. 2330-2335.