SCENARIOS TO EXPLAIN THE FORMATION OF GULLIES ON MARS : NUMERICAL SIMULATION WITH A CLIMATE MODEL. F. Forget[1] N. Mangold[2] and F. Costard[2], [1]LMD, CNRS, Université Paris 6 BP99, 4, place Jussieu, 75252 Paris cedex 05, France (forget@lmd.jussieu.fr) [2]Orsay-Terre, FRE2566, CNRS et Université Paris-Sud, Bat. 509, 91405 ORSAY Cedex, France

Introduction: The observations of geologically young gullies [1] in the middle and high latitude on Mars are among the most debated topics in Martian science. Most scientists believe that their formation involved liquid water, but current temperature and pressure conditions on Mars are too low to allow liquid water or debris mixed with liquid water to freely flow on the surface.

Possible Scenarios

Gullies have been proposed to result of subsurface seepage of water [1] by geothermal activity [2] or brines [3], near-surface ice melting at recent periods of high obliquity [4], snowmelt in more recent periods [5] One of the best constrain to test the various possible scenarios are the spatial distribution and the orientation of the slope on which gullies can be observed (Figure 1). The first two scenarios are somewhat difficult to reconcile with observed distribution. There is no clear association between the location of debris flows and the general distribution of recent geothermal activity [1]. Furthermore, gullies originating from the top of isolated peak and from the crest of large dark dunes [6] have been observed. In these cases, the involvement of a subsurface aquifer is unlikely.

Formation of Gullies at high obliquity

The formation of the observed gullies can be several hundred thousand or even several million years old. Therefore, when considering the possible origin of the Martian Gullies, one has to consider how Mars could have been at other obliquities.

In a previous work [4] we have explored the possibility that the gullies could be formed by the melting of the near-surface when the obliquity was different than today. Using the climate model developed at LMD, we calculated the temperature of the surface and subsurface on various locations on Mars and for various obliquities. We also included the ability to compute the climate on various slopes with various orientation, which is of key importance here.

Our calculations revealed that the only places on Mars where the daily mean temperature has been above the melting point of water during the past obliquity cycles are the mid and high latitudes above 30°, especially on poleward-facing slopes, except in the polar region where warm temperatures are found on both southward and northward facing slopes. The corresponding thermal wave could have melted the ground ice over several tens of centimeters. The fact that poleward-facing slopes receive more sunlight and get warmer at high obliquity in the summer is due to the pole being tilted toward the sun (In the southern hemisphere around summer solstice, the sun appears most of the time in the southern sky).

This preferential orientation and the latitudinal distribution of the warmest near-surface temperature coincide with the location of the observed Martian gullies, suggesting a link between near-surface warming and debris flows. We have performed a detailed statistical analysis of the gullies orientations as observed in the most recent MOC pictures (M01 to E06, Fig. 1) We found a very good agreement between the variations of the orientation of the gullies with latitude observed on mars and those predicted by the model.

It must be noted that, even though the poleward facing slopes can get very warm around summer solstice at high obliquity, they remain colder on a yearly average than any other exposition. For instance, at 35° obliquity, a 30° poleward slope receives about 100 W m^{-2} along the year, compared to almost 150 W m^{-2} on a flat surface. When studying other aspect of the climate system like the CO2 cycle and the water ice cycle, this means that both CO2 ice and water ice tends to be more stable on such slopes. This strongly favours the formation of gullies.

For instance, around summer solstice, any near-surface ground (or ice layer) which is progressively warmed toward 0°C tends to sublime or lose its water trapped in its pores through the diffusion of H2O molecules into the atmosphere. However, on poleward-facing slopes, the seasonal CO2 ice layer accumulated during fall and winter maintains the surface at the low CO2 frost point temperature until late spring (see Fig. 3 in [4]). These slopes are covered by seasonal CO2 ice later in the season than other slopes, and get free of ice only in summer when the solar flux is already strong. The disappearance of CO2 ice allows a sudden warming of the surface and of the near sub-surface which reach 0°C in a few days. If any water ice is present on the surface or in the soil, it have less time to completely sublime or diffuse out of the ground, especially since the atmosphere water content is then near its peak (diffusion primarily depends on the ground – atmosphere water density gradient). In addition, poleward slopes act as cold trap for the water ice sublimed for nearby area, and this also favour the accumulation of ice before they get warm.

On this basis, and since Mars at high obliquity is thought to have had a water-rich atmosphere thicker than today (so that liquid water could sometime flow on the surface), we believe that the Mars gullies result from the melting of the ground ice at high obliquity Figure 2 presents a summary of the environmental conditions.on poleward facing slope at high obliquity that may have enable the formation of gullies.

Ultimately, the key question that remains to be solved is how much water can be available on the surface or in the subsurface at high obliquity, and whether the ice layer can actually accumulate in the relevant locations. On the one hand, the Mars Odyssey GRS records suggest that significant amount of water ice is currently accumulated in the high latitude subsurface. On the other hand, recent Global Climate Model simulations performed by several major GCM team (NASA Ames : Bob Haberle, GFDL-Caltech : M. Mischna, M. Richardson and R. J.Wilson, we at LMD) shows that at high obliquity the Martian climate was extremely "wet", and that, for instance; water ice or snow may have accumulated in the mid-latitudes. This should be especially true on poleward facing slopes.

Formation of Gullies under snowpack

Recently, Christensen [5] suggested that the gullies could form presently below snow-covered slopes through erosion by water melt beneath the dusty snow. The main motivation for this scenario was the observations of smooth mantle (thought to be a water ice snow pack covered by sediment) immediately next to gullies. According to P. Christensen, the water was transported from the poles to mid-latitudes during period of high obliquity. Patches of snow remain today on the cold poleward facing slope where they form gullies, thus explaining why gullies would be preferentially found on poleward-facing slopes.

However, this model does not fully address how liquid water can form beneath the snow, reach the surface and erode the substrate. Christensen based his scenario on calculations performed by Clow [7] using an optical-thermal model developped for dusty snow at 38° south latitude. However, in this paper, it is shown that it is relatively difficult to melt snow on current Mars (with a pressure of 7 mbar, this requires a very specific type of snow) and that liquid water would be available for run off at atmospheric pressures well above 7 mbars. Moreover, the calculations are performed on a flat surface. On a poleward facing slope on present Mars, melting the ice would be even less likely. For instance, the maximum clear sky solar flux reaching -38° latitude on present Mars is about 700 W.m-2 on a flat surface compared to only 525 W m-2 on a 30° poleward slope (and only 420 W m-2 at 50 deg latitude, where many gullies are observed).

If the smooth deposit discovered near some gullies are indeed the remnant of a snow pack that accumulated there during high obliquity period, it is more than likely that in some location the same snow could quite easily melt, but, as explained above, at obliquity higher than today. The melted snow would have then impregnate the debris observed on the surface, and form debris flows as described in [4]. Such a process would be very close to what is observed for Earth periglacial debris flows. It must be reminded here that the geomorphological characteristics of most Martian gullies, with levees and accumulations of debris at their base, do suggest that they are formed by debris flows rather than a slow erosion by little water flowing beneath a snow pack. At high obliquity, water do not need to be sheltered from rapid evaporation because the pressure is expected to have been higher than today and probably above the triple point of water thanks to the desorption of CO2 from the regolith [5].

Conclusion

During our talk, we will review the different clues that are now available to constrain the possible scenarios that explain the formation of Gullies, and in particular present new calculations of the environmental conditions (temperature, water ice accumulation and sublimation) on various slopes and at various obliquity

References:

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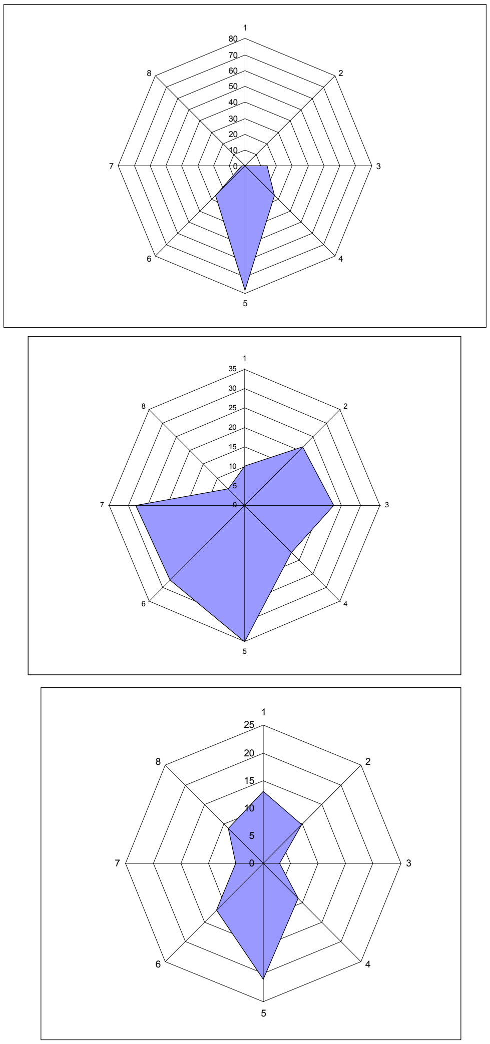

Figure 1 : Distribution of the orientation of martian gullies in three ranges of latitude in the southern hemisphere: None are observed equatorward of 28° of latitude. Statistics are made over all MOC images from data archives M01 to E06. The total number of gullies is 395, respectively 146, 167 and 82 in each latitude range. Orientations have been divided in 8 sectors of 45° large (S is centered at 180°, including directions from 157.5 to 202.5°). S means that gullies face the southern direction (the pole) on hillslopes oriented along the E-W direction. The number of octagons corresponds to the number of gullies in each of the eight sectors.

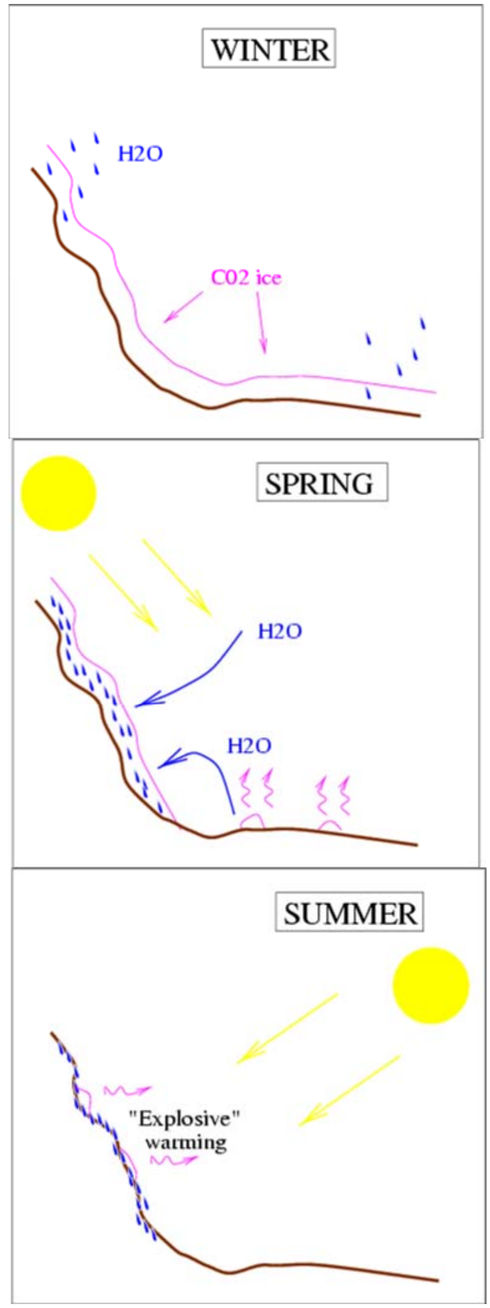

Figure 2: Schematic drawing of the environmental conditions on poleward facing slopes at mid latitude when Mars obliquity is higher than 30° which are thought to favour the formation of gullies.