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## Gullies on Mars sculpted by dry ice rather than liquid water.

Mars's gullies may be formed by dry ice processes rather than flowing liquid water, as previously thought. This is the conclusion of a study conducted by two French scientists published online on December 21st in Nature Geoscience. They show that, during late winter and spring, underneath the seasonal CO2 ice layer heated by the sun, intense gas fluxes can destabilize the regolith material and induce gas-lubricated debris flows which look like water-sculpted gullies on Earth.

Since 2000, the cameras in orbit around Mars have transmitted numerous images of small valleys cut into slopes, similar in shape to gullies formed by flowing water on Earth. The gullies seem less than a few million years old—and sometimes less than a few years old. This suggested that significant volumes of liquid water may form on Mars today.

This scenario has recently been questioned by frequent monitoring of the Martian surface by the HiRISE camera aboard NASA Mars Reconnaissance Orbiter. This revealed that gully formation is ongoing on present-day Mars, at seasons when the surface environment of Mars is much too cold for liquid water to flow. However, the observed gully activity seems to occur when CO2 ice (condensed from the atmosphere during winter) is defrosting on the Martian surface. Can the two phenomena be related? If so, how could a thin seasonal dry ice layer deposited above the regolith trigger the formation of decametre-scale debris flows behaving as if they were lubricated by liquid?

To better understand the interaction between the CO2 frost and the surface materials, Cédric Pilorget, researcher<sup>1</sup> at the Institut d'Astrophysique Spatiale (CNRS/Université Paris-Sud) and François Forget, CNRS scientist at the Laboratoire de météorologie dynamique<sup>2</sup> ((UPMC/ ENS Paris /CNRS/Ecole polytechnique)) have developed a numerical model to simulate the environment on a slope. From the underlying regolith to the atmosphere above, the model takes into account the energy exchanges due to radiations, thermal conduction or induced by  $CO_2$  phases changes.

<sup>&</sup>lt;sup>1</sup> Cedric Pilorget was a post-doctoral scientist at the California Institute of Technology (Caltech, Pasadena, USA) when this study was conducted, and is now a CNES postdoctoral fellow at IAS

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A key characteristic of the locations where CO<sub>2</sub> ice condenses is that there is always a permafrost layer composed of water ice-cemented grains a few centimeters below the surface. Thus, when CO2 condenses on the surface in winter, the air present in the porous near-subsurface is trapped between the impermeable permafrost layer below and the CO2 ice layer above.

In such conditions, the numerical simulations carried out by Cedric Pilorget and François Forget have revealed a surprising behaviour. At the end of winter or in spring, the solar light penetrates into the translucent CO2 ice layer and heats it from below. The CO2 ice does not melt, but "sublimes" (it passes directly to the vapour state). This gas diffuses down through the near surface porous soil. A fraction can recondense there, while the rest of the gas accumulates in the porous volume. This can considerably increase the near-subsurface pressure, up to several times the atmospheric pressure value. The CO2 ice layer eventually ruptures, inducing a violent decompression. Within a few seconds and up to a few minutes, several cubic meters of gas (and possibly several tens of cubic meters around the vents) have then to flow up through the soil. Such fluxes are able to destabilize the soil grains to form granular flows. Moreover, they can also fluidize the avalanche which may behave like a viscous fluid.

Although this process has no exact analogue on Earth, it can be related to terrestrial pyroclastic flows, which are gas-particle mixtures generated during volcanic eruptions. Such flows can travel several kilometers even on very moderate slopes. They can transport meter-sized rocks, and have been found to exhibit side "levees" which are very similar in size to the ones observed on the side of Mars's gullies. As on Earth, where debris flows triggered by rain or melting snow are rare events, it is likely that an uncommon combination of conditions are required to destabilize the slopes.

The model created by the two French scientists can also explain why Mars's gullies are located mostly in the 30°–60° latitude range -with a few spots at higher latitudes- and why most gullies are found on poleward facing slopes between 30° and 45° latitude. The CO2 induced pressurization and fluidization is predicted to occur precisely where gullies are observed.

All these findings suggest that the solar heating of the seasonal dry ice deposited in winter on Martian slopes is at the origin of a fraction - and possibly all- of the gullies observed on planet Mars. This process has no terrestrial analogues and do not require liquid water. According to this study, the gullies area may not provide potential habitable environments in Mars's recent past.





Figure 1: Examples of Martian Gullies. Until recently they were thought to have been sculpted by flowing liquid water, but they may result from defrosting dry ice processes at the end of winter. On the right, gullies on dunes in Russel Crater (54.3°S-12.9°E) are partially covered by CO2 ice. On the left, sinous gullies in a Crater in Newton Basin (41°S-202°E) ©NASA/JPL/University of Arizona

High resolution images:

http://static.uahirise.org/images/wallpaper/2880/ESP\_034234\_1255.jpg http://hirise.lpl.arizona.edu/PSP\_003464\_1380

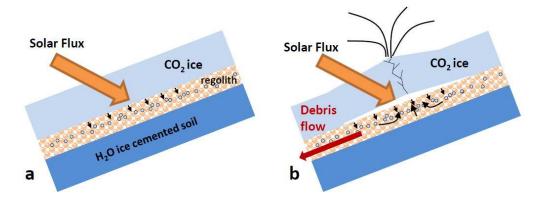


Figure 2: How debris-flows looking like water-sculpted gullies can be triggered by dry ice processes on Martian slopes (see text)

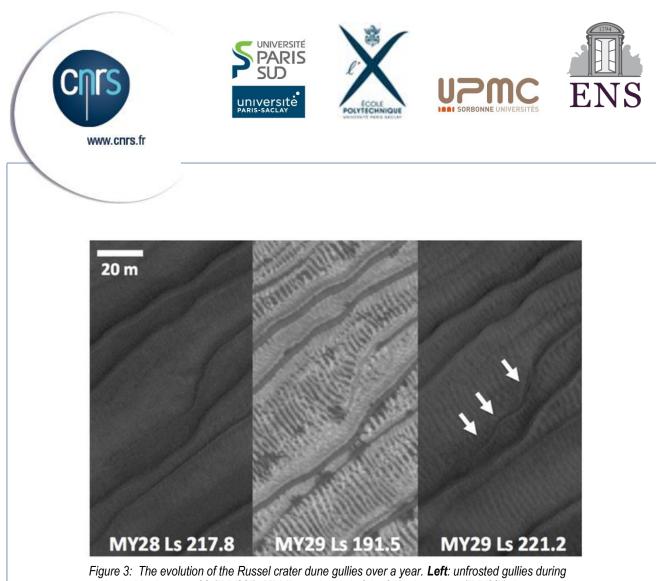


Figure 3: The evolution of the Russel crater dune gullies over a year. Left: untrosted gullies during spring in Martian year 28 ("MY28"). Middle: at the end of the following winter ("MY29") dunes are covered by CO2 ice. CO2 jets formed by sublimation beneath translucent CO2 ice have deposited sand grains on the ice where they form dark spots, confirming the intense subsurface activity predicted by the model **Right**: In the spring of the following year, a new channel has formed. © NASA/JPL/University of Arizona

## Bibliography

Pilorget C. and F. Forget. **"Formation of gullies on Mars by debris flows triggered by CO<sub>2</sub> sublimation".** *Nature Geoscience* (2015). DOI 10.1038/ngeo2619 http://dx.doi.org/10.1038/ngeo2619

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