THE RECENT MARS GLOBAL WARMING (MGW) AND/OR SOUTH POLE ADVANCE (SPA) HYPOTHESIS: GLOBAL GEOLOGICAL EVIDENCE AND REASONS WHY GULLIES COULD STILL BE FORMING TODAY. Nathalie A. Cabrol, and Edmond A. Grin. NASA Ames Research Center. Space Science Division. MS 245-3. Moffett Field, CA 94035-1000. Email: ncabrol@mail.arc.nasa.gov and egrin@mail.arc.nasa.gov.

Rationale: A global survey of the MOC images shows that gullies are far from being the only evidence supporting a significant climate change in recent Mars history. With several thousands images already examined and our global survey still ongoing, we have catalogued so far nearly 500 recent landforms which morphology is similar to terrestrial mudflows, striped valleys, rock glaciers, debris-covered glaciers, and cryokarstic features. They are localized in a strict latitudinal and altitudinal domain and show a clear morphological and environmental continuum best explained by a recent climate change. This climate change could have involved a global warming with snow precipitation and/or a massive South Pole advance to the mid-latitudes. Our hypothesis is geology-based but provides clues for climate modelers (e.g., altitudes, latitudes, slopes) to reconstruct the climate conditions necessary to generate the specific environment required by these landforms.

The Significance of Martian Gullies: After their discovery [1], a debate was engaged about the climatic and geologic significance of the gullies. Their pristine morphology supports a recent setting. The possibility that they are formed in present days is being scrutinized from the climate standpoint but no correlation between their location and the current regions of water metastability is found [2, 3]. Because of their location, it has been suggested that, if current, water could not be involved in their formation [4]. So far, MOC did not reveal any proof that the morphology of a gully has changed in the past four years of the mission. As Mars Odyssey successfully entered orbit in October 2001, the spacecraft might be able to detect water activity if it is indeed still going on. At the present stage, although the current formation of gullies cannot be proved, it cannot be deterred either. Showing that they are recent seems easier: they display little erosion and no superimposed impact craters [1]. The zonality of their distribution could indicate the role of a past climate change [5, 6] and mostly rules out random accidental releases, although local geological factors may have locally influenced their formation [7].

Despite the controversy, gullies are a pointer to a Mars more active recently than previously thought after Viking. However, how much activity, when in time this activity took place, and what it implies in terms of climate and geology are difficult questions to resolve with the gullies only. While searching the MOC archive for the characterization of recent aqueous environments in impact craters [7], we stumbled into an overwhelming volume of new evidence hereafter described. This evidence provides information that helps in constraining the extent and nature of the changes that affected Mars recently and, we believe as a result of this study, might still be affecting it today.

Category and Distribution of New Evidence: The volume of evidence required that a global survey of the MOC image archive be undertaken to understand its context and implications. We started compiling a catalog that includes the coordinates of the features and characteristics. At the time this abstractsubmission, with the exception of the most recent image releases (M18-M23) that were accessible only recently, we have completed the survey of the Southern Hemisphere between 20°S and 60° S and initiated in parallel the survey of the Northern Hemisphere. The categories of evidence we found encompasses:

(1) Pristine Mass Flows (PMFs). We utilize the generic name of *mass flow* to designate landforms and features including: mudflows, striped valleys, debris-covered glaciers or glaciers [8-10], folded volatile-rich sediments, creep features (terracettes, ridges), and relic material located in depressions and topographic lows in elevated regions;
(2) Cryokarstic Features (CKFs) that clearly show the effects of a near surface ground saturated by water and/or ice between 35°S and 50°S;
(3) Material Root Zones (MRZs) that are the source areas for the observed PMFs and located in cirque-like regions, high-energy slopes and summit of topography.

A Specific Environmental Domain: From the results of our survey, we were able to establish specific environmental characteristics of latitude, altitude, and slope for the PMFs, CKFs, and MRZs. The observations recorded so far in the Southern Hemisphere strongly support a recent and widely spread activity of glaciers, rock glaciers, striped valleys, creep, and mudflows between 30°S and 55°S latitude, activity which traces are not detected above and beyond those latitudinal boundaries. The root zones of the PMFs are often located at the summit of topography, on impact crater, valley, and depression walls, and in mountainous regions. They do not appear to a have preferred orientation. Their starting slopes average 30%, which is comparable to terrestrial analogues. This value is preliminary and was established from the survey of MOLA data for a representative sub-sample. The task is still in progress and is complicated by the fact that only a small percentage of MOLA profiles follow completely or enough of the longitudinal profiles of the PMFs. Although more sampling needs to be performed to increase the significance of the result, we are confident from repeated observations that this slope value is a representative result. A

larger sample will allow us to define the lower slope limit on which the flows can be initiated. The root zone of the PMFs seems to be confined very specifically between 1300 and 2300 m elevation.

A Morphological and Climatic Continuum: Although all categories of evidence show occurrences between 30°S and 50°S latitude, their specific *maximum* distribution peak given below may vary slightly and reveals a morphological continuum from periglacial to glacial features: Creep: [35°S-45°S]; Striped valleys and striped deposits: [35°S-45°S]; Rock glaciers, and debris-covered glaciers: [42°S-48°S]; Cryokarstic terrain: [45°S-50°S]; Polygonal terrain: ≥ 55°S. When their latitudinal distribution peak is compared with the processes necessary to generate them, a possible climate-related trend appears. Creep and striped material require freeze and thaw cycles, as well as some types of rock glaciers based on cryogenic gelifluction and debris mantle flow. Glaciogenic rock glaciers (debris-covered glaciers, morainal material flow) and glaciers require a supply of ice from the surface. The degradation of vast surfaces of terrain through cryokarstic processes requires a near-surface water/ice-saturated ground and an intense evaporation/sublimation process showing a desequilibrium between the time the ground was saturated and the time the cryokarstic regions were formed. The vast expanse of polygonal terrain beyond 55°S indicates heaves in ice-rich subsurface in regions and at depths where ice is in equilibrium with the current conditions.

Geology-Based Climate Hypotheses: The collection of geological evidence is consistent with two, non-exclusive, climate scenarios. The time-scale proposed is based on an average terrestrial glacier lifetime (10^4 years) and on the observation of material we interpret as being glacier remnants and debris-covered glaciers. If it is demonstrated that glaciers can survive longer on Mars (e.g., protected by a debris cover), the time-scale will need to be adjusted.

Mars Global Warming (MGW): In this model, ice accumulates in two ways ~10^4 years ago. The water saturation of near surface ground is acquired by basal melting of the South polar cap advanced at latitudes that are slightly North from those of today (~50° S latitude). Warming generates precipitation of snow that accumulates at mid-latitudes and forms glaciers. After the polar cap recession, ice remain locally trapped in depressions and alcoves. Warmer temperatures affect the upper permafrost layer and rock glaciers, gullies, and striped valleys are generated through destabilization in the active layer.

South Pole Advance (SPA): This model does not requires snow precipitation but does not preclude them. However, it demands the advance of the South Polar cap up to the mid-latitudes (42°S-48°S) where glaciers are observed, and possibly up to 35°S to explain the extent of creep and striped valleys at these latitudes. Ground saturation of water results from basal melting of the polar cap. As the polar cap retreats South, masses of ice left behind start flowing on steep slopes. Rock glaciers, gullies, striped valleys, and creep are formed through the same process as in the MGW model.

Current Activity as a Lag Response to Climate Change? Glaciers and glaciogenic rock glaciers cannot form in present-day Mars as they require precipitation but some might still be passively flowing by gravity. However, considering the time frame proposed, it is possible to envision that a lag response of the permafrost to the proposed recent climate change might still be triggering the activity of gullies, rock glaciers, creep, and striped valleys *today*. In some regions of Mars, and similarly to cases on Earth, the permafrost could still be in desequilibrium with the current climate setting. Depending on the permafrost thickness, likely to be significant on Mars, adjustment to climate changes can take millennia. Terrestrial examples of such phenomenon include the Siberian permafrost, which distribution is related to the Last Glacial Maximum (LGM) 21,000 years ago and could date back to Pleistocene variations (2 Myr ago). The lag time in the response of rock glaciers was modeled by Olyphant [11]. His model suggests that a 500-m long rock glacier may take 425 years to react to an increase of debris supply and a further 1225 years to reach equilibrium. For longer rock glaciers, as observed in MOC images, the lag time can reach 10^3 to 10^4 years. Current activity of Martian rock glaciers and gullies could be expressions of such desequilibrium.

Implications: The locations identified by this work could be used as targets by Mars Odyssey in search for water activity. They also have a high astrobiological potential. Debris-covered glaciers could still contain significant proportion of ice in their core that constitutes a possible resource for future missions and for life. Geological materials pertaining to ancient periods were brought recently to the surface by the PMFs. They may contain fossils and/or traces of extant micro-organic communities normally sheltered in the subsurface and now within grasp. Accessing these sites requires precision landing and energy sources adequate to survive cold conditions at mid-latitudes.

Reference: [1] Malin and Edgett, 2001. *Science* **288**, 2330-2335. [2] Haberle et al., 2000. *32th LPSC*, 1509; [3] Haberle et al., 2001. *JGR*; **106**, E6, 23,317-23,326; [4] Hoffman, N. 2000. *Icarus,* **146**(2), 326-343; [5] Mustard J. et al., 2001. *Science* **293**. [6] Costard, F. 2001. *Science*.**297**, [7] Cabrol, N. et al., 2001. *Icarus*. In press. [8] Cabrol et al., 2001. 32th *LPSC*, 1251. [9] Kargel, J. 2001. 32th *LPSC*, 2079. [10] Baker et al., 2001. 32th *LPSC*, 1619. [11] Olyphant, G. 1987. *In* Rock Glaciers, 55-64.