Geomorphologic evidence for the presence of massive ground ice in the northern plains of Mars. M. Petitjean[1], S.M. Clifford[2], and F. Costard[3]; [1]Department of Geography, Université Paris 7, France, [2]Lunar and Planetary Institute, Houston, USA.,[3]IDES, UMR 8148, Université Paris –Sud 11, . 2014

The existence of a global ice-rich permafrost on Mars is supported by the identification of a variety of cold climatic landforms, the interpretation of various remote sensing data sets (including the Gamma Ray Neutron Spectrometer and the orbital radar sounders MARSIS and SHARAD), and direct investigations of the Martian surface by landed and roving spacecraft. But the origin, quantity and distribution of subsurface ice are still unclear. There are *in situ* drilling and geophysical investigations which are capable of resolving these questions, but they are expensive, technologically challenging, and spatially limited in their extent. Thus, mapping the geographic distribution of ice-related landforms remains the most expedient and cost effective ways of investigating the occurrence of ice in the Martian subsurface.

Our study investigates the possible correlation of MARSIS-derived radar surface permittivities [1] with Martian crater ejecta morphology, focusing primarily on those craters with fluidized ejecta — which are thought to result from an impact into ice-rich ground. We are particularly interested in the potential correlations that may exist in the northern plains, where such evidence may be indicative of the presence of a frozen relic of an early northern ocean or the ponded, frozen discharge of the outflow channels.

Based, in part, on the tentative identification of potential nested paleoshorelines along the global dichotomy boundary, Parker et al. [2, 3] and Clifford and Parker [4] have proposed that Mars may have once hosted a large early ocean or ice sheet in the northern plains, covering as much as a third of the planet. Hydrologic arguments suggest that such an ocean or ice sheet was almost certainly an initial condition – condensing shortly after the planet formed and persisting until the end of the Noachian (~3.7 Ga). With the loss of the planet's early atmosphere by atmospheric erosion, exospheric escape, and the formation of hydrated minerals, in addition to the long-term decline in the planet's geothermal heat flow, any early ocean is expected to have rapidly frozen. With the transition to global climatic conditions similar to those on Mars today, any ice, exposed on the surface at mid- to low-latitudes, would have been thermodynamically unstable – leading to its eventual sublimation and cold-trapping at higher latitudes. However, before it was lost, some of this ice may have been preserved by its burial beneath mantles of volcanic, eolian and fluvial sediments, reducing its sublimative loss sufficiently to allow its survival over much of Martian geologic time.

Major episodes of outflow channel activity during the middle of Martian geologic history may have resulted in the occurrence of transient lakes and seas in the northern plains which, like an early ocean, would have rapidly frozen and been subject to both sublimative loss and potential burial by sediments and volcanics.

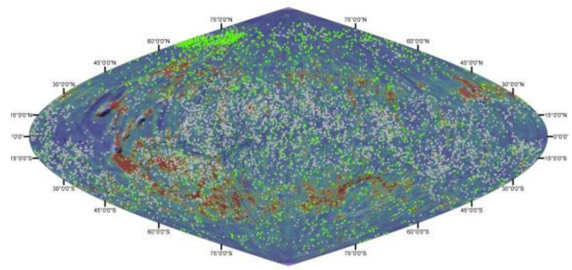

Fig.1: Rampart crater distribution in the Martian northern plains (Robbins crater database, http://craters.sjrdesign.net/). Craters with high ejecta mobility (>2) are in green, and craters with low mobility in grey. The occurrence of high-mobility craters is much higher at mid- to high latitudes, particularly in the northern plains – a distribution which is consistent with the low surface permittivities observed in this region by MARSIS [1].

One of the main requirements for our study was to find the most complete database of Martian crater characteristics, including: location, morphometry, and ejecta morphology. For our study, we chose the Robbins database, because it is the most recent, precise and complete (http://craters.sjrdesign.net/). The Robbins database also includes information about the ejecta mobility of craters, where ejecta mobility is defined as the ratio of the mean radius of the ejecta (R_{ejecta}) to the mean radius of the crater cavity (R_{crater}). High mobility (>2) is widely interpreted as evidence of the presence of subsurface volatiles [5]. This yielded a final database of 384343 craters, consisting of five crater ejecta morphologies (as defined by Robbins), and a mathematic approximation of their mobility.

The geographic distribution of these craters was then compared with the global surface permittivity values inferred from the radar surface reflectivities recorded by MARSIS [1]. Laboratory measurements of the permittivity of terrestrial basalt are typically in the range of ~9-12. However, the MARSIS-derived values for the northern plains averaged ~4.6±0.5 – a value that represents the volume-averaged permittivity of the top ~60-80 m [1]. The two most logical explanations for the low permittivity of the northern plains are either high porosity (35%) or high ice content (60%) [1]. Given this ambiguity, we sought to find a way to test the high porosity and high ice content hypotheses. As high porosity does not appear to play a role in the fuidization of crater ejecta, a comparison between the geographic occurrence of low surface permittivity and the occurrence of fluidized ejecta morphology appears to be a reasonable test of the ground ice hypothesis. Based on the surface permittivity data of Mouginot et al. [1] and the distribution of fluidized ejecta craters from Robbin's Martian crater database, we checked on possible correlations between the two datasets. Our initial observations were that there is no direct correlation between low permittivity areas and the concentration of rampart craters. We then extended our study to consider the ejecta mobility parameter (Fig.1), and obtained a clear correlation between high permittivity equatorial areas and the distribution of low mobility rampart craters, while in the northern plains we observed that low permittivities (potentiall indicative of the presence of subsurface ice) correlate well with the distribution of high mobility rampart craters (also indicative of the presence of ice).

One particular region in the northwest, corner of Fig. 1 (above Arcadia Planitia), has a very high concentration of small diameter (<2 km) fluidized ejecta craters with lobate morphology, which suggests the presence of significant amounts of ground ice within a few hundred of meters of the surface [5]. This area is part of the Vastitas Borealis Formation, which is believed to represent a mantle of fluvial sediments carried into the northern plains by Late Hesperian/Early Amazonian outflow channels [5]. This area also has a high concentration of high mobility rampart craters. Based on these observations, we completed our study by focusing on the northern plain, and this particular area – searching to find occurrences of overlapping craters whose ejecta morphologies might provide clues regarding the temporal evolution of subsurface volatiles in the area (e.g., the occurrence of a fluidized ejecta crater, superimposed on another fluidized ejecta crater might indicate little change in subsurface volatile content between the two impacts, while a lunar-style crater, superimposed on a fluidized crater, might indicate a depletion of local volatiles over time, Fig. 2). The distribution and superpositional relationship of such craters has been plotted with their mobility characteristics for the northern lowlands. The map was constructed using Google Mars and CTX imagery. Our method consisted of a systematic survey of the lowlands, noting the most interesting overlap relationships and characterizing the apparent degradation state of the craters. The Figure 2 presents a better idea of theses criterias.

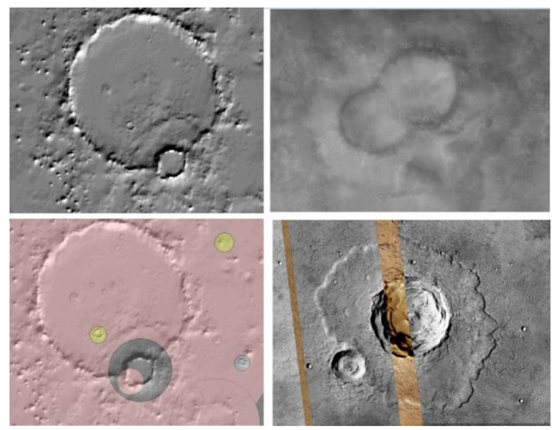

Fig.2: Here are some examples of overlapping relation we found. On the left, a good example of two rampart craters overlapping – suggesting in the preservation of the original ground ice inventory or local recharge, perhaps associated with the discharge of the outflow channels. On the right, are two examples of overlapping relationships that could not be interpreted, due to the degradation state of both craters in the upper right, and unclear nature of the superimposed crater on the lower right.

It is important to note that our study did reveal inconsistencies between the distribution of fluidized ejecta craters recorded by Robbins, other investigators, and our own observations. For this reason, we plan to follow up our present study with a more comprehensive analysis.

References: [1] Mouginot et al. (2012), GRL, 39, L02202. [2] Parker et al. (1989), Icarus, 82, 111–145. [3] Parker et al. (1993), JGR, 98, 11,061–11,078. [4] Clifford, S. M., and T. J. Parker (2001), Icarus, 154, 40–79. [5] Costard, F. M. (1989), Earth Moon Planets, 45(3), 265–290. [6] Journal of Geophysical research, Vol. 107. Kreslavsky, M.A., Head, J.W., 2002.