IMPACT CRATERS IN UTOPIA PLANITIA, MARS: WINDOWS INTO AN ICE-RICH SUBSURFACE.

G. R. Osinski[1,2], R. J. Soare[1,3,4], and G. Pearce[1], [1]Dept. of Earth Sciences, University of Western Ontario, London, ON, Canada N6A 5B7 (gosinski@uwo.ca), [2]Dept. of Physics and Astronomy, University of Western Ontario, London, ON, Canada N6A 5B7, [3]Dept. of Geography, Planning and Environment, Concordia University, Montreal, QC, Canada H3A 1M8, [4]Dept. of Geography, Dawson College, Montreal, QC, Canada H3Z 1A4

Introduction: The Martian impact cratering record is notably more diverse than for Earth and the other terrestrial planets [1]. Various factors govern the products of the impact cratering process, from the size, velocity and composition of the projectile – factors that are largely independent of the target – to the gravity and near-surface properties of the target [2]. Gravity is a known and measurable entity but for most planetary bodies, the sub-surface geology remains uncertain. As such, the morphology and morphometry of impact craters offers a unique tool for investigating the subsurface structure and composition of planetary bodies.

In this study, we explore the relationship between impact crater ejecta morphologies and target properties in Utopia Planitia using Mars Orbiter Camera (MOC), Thermal Emission Imaging System (THEMIS), and High Resolution Imaging Science Experiment (HiRISE) imagery. This study forms part of a larger ongoing collaborative investigation of impact and periglacial landforms in Utopia Planitia, Mars, and investigation of terrestrial analogues in the Canadian Arctic [3]. Combining studies of periglacial landforms – which provide information to a few metres depth – with studies of impact craters – which provide information to several km depth – provides a powerful tool to explore the geological history of this region of Mars.

Utopia Planitia – A landscape of impacts and ice: Utopia Planitia is a major topographic depression situated in the northern plains of Mars. Several previous workers have noted the relative abundance of layered ejecta structures, in particular so-called double layer ejecta (DLE) craters, in Utopia and Chryse Planitae (reviewed by [4]). The presence of periglacial landforms, such as small-size polygonal terrain and thermokarst-like depressions, in Utopia Planitia has led to the suggestion that these regions of Mars contain, or previously contained, large volumes and possible excess ground-ice in the near-subsurface to dozens of metres depth [5-7] and that fluidized ejecta blankets, therefore, are the result of impact into ice-rich terrains [8]; however, exactly how and in what state H_2O is incorporated into the ejecta is unclear. In addition, a competing theory is that such ejecta morphologies require no volatiles and instead are formed due to interactions between the ejecta and the atmosphere[9].

It is also important to note that while layered ejecta structures and periglacial landforms have been documented in Utopia Planitia on a regional scale, to the knowledge of the authors, the unequivocal close spatial (i.e., sub-km scale) and temporal association of these geological features has not yet been recognized. It could be argued, therefore, that the periglacial landforms are vastly younger than the impact craters and that the close spatial association is nothing more than a coincidence. Here, we demonstrate that impacts have occurred into ice-rich periglacial terrains in Utopia Planitia and show that the impact stratigraphy can be used to build up a clearer picture of the geological history of this region of Mars.

Results and interpretations – Ground-ice: We have been systematically mapping periglacial landforms – polygons, scalloped depressions, and possible pingos – in all available MOC and THEMIS images in the region 240–285° W, 15–60° N. The first results of this study, relating to the distribution of scalloped depressions, were presented in Soare et al. [3]. It is widely acknowledged that these depressions are thermokarst features and are indicative of substantial deposits of ground-ice in the near-subsurface [3, 5]. Our mapping shows that the thermokarst depressions are ubiquitous in an area of ~2 x 10^6 km^2 between longitudes 240–280° W and latitudes of 40–55° N (Fig. 1).

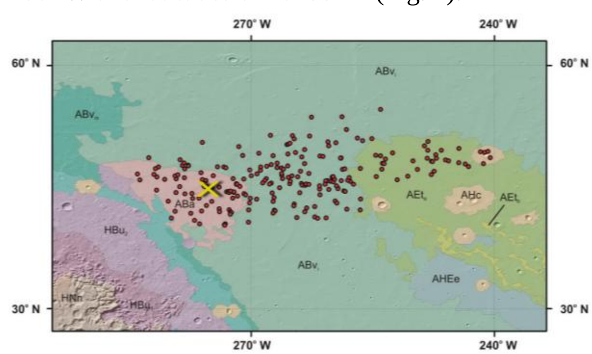

Fig. 1. Distribution of thermokarst depressions within Utopia Planitia superposed on a MOLA hillshade image (modified from [3]), with geology from [10]. One degree of latitude = 59 km. The location of Figure 2 is marked by a yellow "X".

It is notable that impact craters within this zone of thermokarst depressions are notably different, in terms of morphology and morphometry, from their counterparts to the north and south. In this zone, there is a complex history and a unique relationship(s) between impact and periglacial landforms.

Figure 2 shows an impact crater in this zone of thermokarst. There are several points to note. It is clear that the ejecta from this crater overlies and infill's a prexisting periglacial landscape modified by polygons and thermokarst depressions (Figs. 2a–c), providing a clear age relationship. Polygons and thermokarst depressions are also present in the sedimentary (and, therefore, ice-rich) crater-fill and must postdate the impact event (Fig. 2a). The ejecta blanket is pristine as evidenced by the blocky nature of the ejecta seen in HiRISE images (rocks and boulders <1 m across comprise the upper surface of the ejecta blanket but do not cover the plains; Fig. 2c). Thus, this infill is unlikely to be Vastitas Borealis Formation as has been suggested.

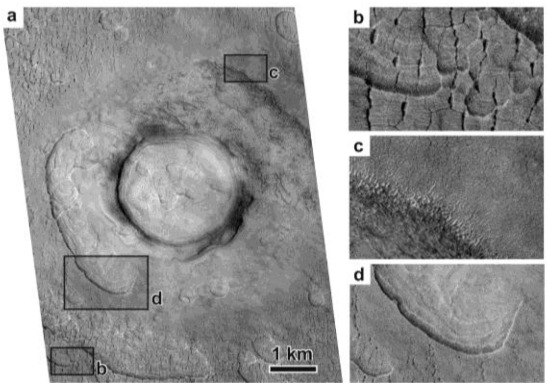

Fig. 2. This ~2.5 km diameter impact crater displays several attributes (a) A portion of HiRISE image PSP_007740_2250, centred at 44.8 °N, 84.8 °E. The regional surface before the impact (b) is has been pervasively modified by periglacial processes, including polygons and stepped thermokarst depressions (scarps seen in image running ~E–W). (c) The ejecta blanket of this crater clearly overlies the pre-existing periglacial landscape. (d) A later generation of large thermokarst collapse basins runs parallel to the edge of the ejecta blanket.

Also of note is that a generation of thermokarst collapse depressions can be seen to parallel the edge of the ejecta blanket and (Fig. 2a,d). These depressions step down towards the ejecta blanket (Fig. 2d) and extend into the ejecta deposits (e.g., trace the outline of the ejecta in Fig. 2a). We suggest that these observations can only be explained if the ejecta itself caused the thermokarst collapse. Thus, this crater shows that there were bodies of excess ground-ice before (Fig. 2b), during (Fig. 2d), and following impact (Fig. 2a). Many other craters in this zone of thermokarst (Fig. 1) display all, some, or additional relationships to the periglacial and glacial landforms seen in Figure 2.

Results and interpretations – Emplacement of ejecta: The properties of the impact crater in Figure 2 clearly show that ground-ice was present at the time of impact. This crater displays a well-developed fluidized, single layer ejecta (SLE) blanket. Thus, the simplest explanation for the formation of fluidized, layered ejecta structures, at least in this region of Mars, is that they formed due to the presence of sub-surface volatiles. But how and in what state is H_2O – the most likely volatile – incorporated into the ejecta?

Most workers have suggested that it is the interaction of the primary ejecta curtain with a volatile-rich vapour plume that is responsible for the formation of layered ejecta structures [8]; however, it has also been suggested that while subsurface volatiles do play a key role, the volatiles can either be entrained in the excavated material (primary ejecta) and/or as secondary ejecta incorporated from surficial sediments from outside the crater [11]. Given the evidence and close spatial and temporal association of periglacial and impact landforms from this study, we suggest that the latter model is more likely.

Regional implications: We will now step through, in chronological order, the sequence of events as evidenced by impact craters in Utopia Planitia and their relationship to glacial and periglacial features:

1) Deposition of an ice-rich “Unit 1”; this appears to overlie the VBF; its age is unclear at present.

2) Pervasive periglacial modification of Unit 1 (formation of polygons and thermokarst collapse pits). The presence of terraces and orthogonally oriented small-sized polygons is suggestive of ponding of water during this time [3].

3) Formation of the impact crater in Figure 2, and others; observations indicate that near-surface and deep ground-ice was still present at the time of impact.

4) Infilling of the crater with an ice-rich unit. We suggest this may be a combination of crater lake sediments, aeolian material, and a later ice-rich mantle.

5) Post-impact periglacial modification of the sedimentary infill.

In summary, the impact cratering record of Utopia Planitia is suggestive of an ice-rich sub-surface to considerable (km) depths. Properties of ejecta blankets are suggestive of the incorporation of volatiles as being responsible for fluidization.

Acknowledgements: We thank the HiRISE, MOC, and THEMIS instrument teams for access to the data, without which this study would not have been possible.

References: [1] R.G. Strom, et al., in: H.H. Kieffer et al. (Eds), Mars, U. of Arizona Press, 1992, pp. 383-423. [2] H.J. Melosh, Oxford U. Press, 1989, 245 pp. [3] R.J. Soare, et al. (2008) *EPSL, 271*, 382-393. [4] N.G. Barlow, in: T. Kenkmann et al. (Eds), GSA Spec. Pub. 384, GSA, Boulder, 2005, pp. 433-442. [5] F.M. Costard, J.S. Kargel (1995) *Icarus, 114*, 93-112. [6] B.K. Lucchitta (1981) *Icarus, 45*, 264-303. [7] R.J. Soare, et al. (2007) *Icarus, 191*, 95-112. [8] M.H. Carr et al., in: R.B. Merrill et al., (Eds), Impact and Explosion Cratering, Pergamon Press, 1977, pp. 593-602. [9] P.H. Schultz, D.E. Gault (1979) *JGR, 84*, 7669-7687. [10] K.L. Tanaka, et al., USGS, 2005, 27 pp. [11] G.R. Osinski (2006) *Meteor. Planet. Sci., 41*, 1571-1586.