EVIDENCE FOR FLOW IN BURIED ICE IN THE MID-LATITUDES OF ARCADIA PLANITIA. S. M. Hibbard[1], N. R. Williams[2], M. P. Golombek[2], and G. R. Osinski[1,3], [1]Centre for Planetary Science and Exploration / Dept. Earth Sciences, University of Western Ontario, London, ON N6A 5B7, Canada, [2]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, United States 91109, [3]Dept. of Physics and Astronomy, University of Western Ontario, London, ON N6A 5B7, Canada (shibbard@uwo.ca).

Introduction: Evidence for ice in the upper tens of meters of the Martian crust has been observed poleward of 30° on Mars [1]. Arcadia Planitia is a relatively flat plain located around ~40°N, ~200°E, and has widespread near-surface water-ice based on gamma ray spectroscopy indicating 35 ± 15 wt% ice below the surface [2,3], the presence of lobate debris aprons (LDA), lineated valley fill (LVF) [4,5,12,13], exposed subsurface ice at recent small impacts [6,7], thermokarstic expansion of secondary craters [8], concentric terracing within the walls of simple craters [9], polygonal surface terrain [10], and dielectric constants similar to that of ice detected by ground-penetrating radar [5,9,11]. Here, we report on two major sinuous units, and one minor unit, between 38°–40°N and 156°–166°W that show surface morphologies and remote sensing properties indicative of massive buried ice but are different from previously reported LDA and LVF features elsewhere on Mars (Fig. 1).

Observations: Sinuous units 1, 2, and 3 found in eastern Arcadia (Fig. 1) have a knobby uneven polygonal surface mostly devoid of lineations or flow banding that is typically seen on LVF elsewhere on Mars (Fig. 2). Unit 1 is the largest sinuous unit with the most data coverage and contains a series of coaxially curved bands that appear to be flow bands resembling ogives indicating a southeast flow direction (Fig. 3). The surface morphology of the sinuous units differ from the surrounding crenulated, polygonal and pitted terrain (Figs. 1, 2) [10]. Knobs at the surface range up to 20 m in diameter and occur in clusters and can only be found on the sinuous units (Fig. 2). Semi-crescent-shaped ridges at the surface are found on the sinuous units and may indicate flow towards the southwest (Fig. 2). The sinuous units dissipate southward into weaker polygonal terrain where the knobs and ridges disappear. The lateral boundary between the sinuous units and surrounding terrain is sharp and is represented by a change in morphology from knobby and uneven polygons to smooth polygonal or crenulated terrain.

A blended digital elevation model (DTM) derived from the Mars Orbiter Laser Altimeter (MOLA) instrument aboard the Mars Global Surveyor (MGS), and the High Resolution Stereo Camera (HRSC) aboard the Mars Express indicates the sinuous units range from being topographic lows to being higher than the surrounding plains. Up to 80 m of excess ice has been detected beneath the surface at unit 1 with thinner ice in surrounding terrain (Fig. 4) [9]. Thermal inertias of the sinuous units (200-250 J m^{-2} K^{-1} $s^{-1/2}$) are higher than the surrounding terrain (100-200 J m^{-2} K^{-1} $s^{-1/2}$) [14]. Thermal Emission Spectrometer (TES) albedo and dust cover index data, and Viking rock abundance data are too coarse to identify differences between the sinuous units and their surrounding terrain. HiRISE images show the sinuous units have few rocks >1 m diameter. TES dust cover index shows optically thick dust overlies most of Arcadia [15].

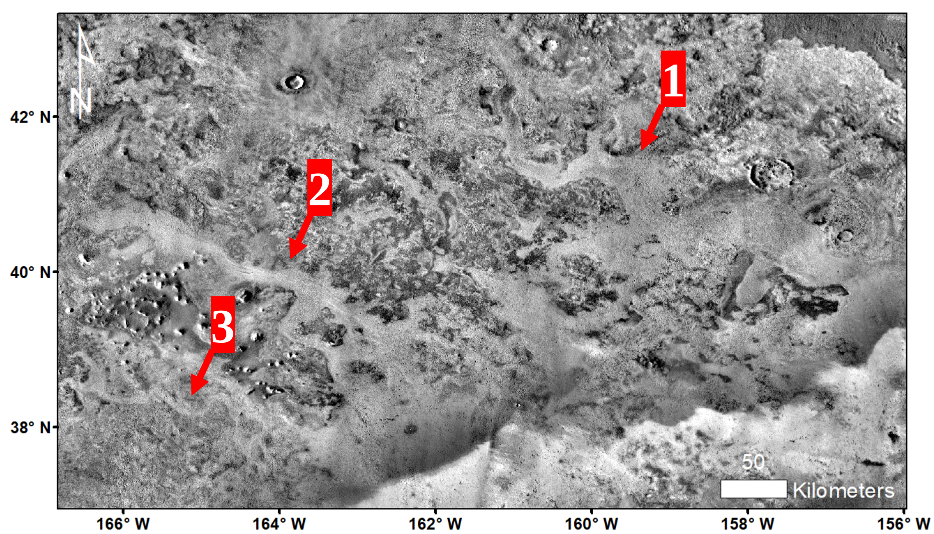

***Figure 1**: Thermal Infrared daytime mosaic of the study area at Arcadia Planitia. Numbers show sinuous units described in the text. These sinuous units run roughly parallel to one another in a northwest-southeast direction. The source and beginning of the sinuous units is unclear.*

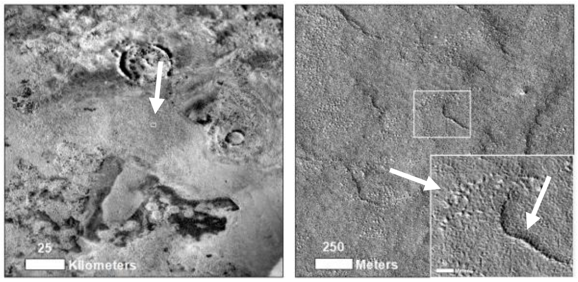

Figure 2: *Surface morphology of sinuous units is characterized by small clustered knobs and semi-crescent-shaped ridges. Left: THEMIS Day IR of Unit 1. White box shows location of image to the right (arrow). Right: HiRISE of unit 1. White box shows location of enlarged view of knobs and ridge (arrows).*

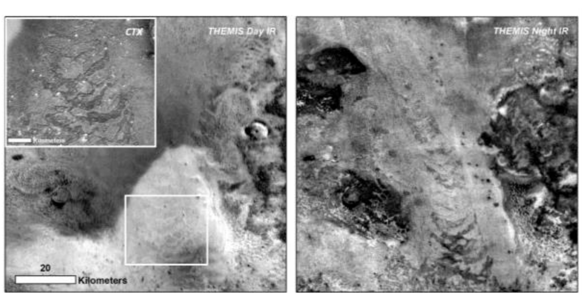

Figure 3: *Evidence of flow similar to ogives found on unit 1 at 39°N. Left: THEMIS Day IR. White box shows location of enlarged CTX view of flow bands. Right: THEMIS Night IR showing possible flow bands.*

Discussion: These sinuous units lie within a dusty, relatively flat plain surrounded by polygonal, crenulated, and pitted terrain consistent with desiccating near-surface ice [10]. Moderate thermal inertia of the units is too high to represent thermally thick (cm to tens of cm) loose dust and too low to represent pure ice. The low rock abundance and moderately low dust cover index, along with comparisons to surface materials at existing landing sites, argues that the surface is covered by common Martian soils composed dominantly of sand that is either cohesionless or with low cohesion [16]. Models of cryoturbation to form the polygonal terrain and observations at the Phoenix landing site suggest the soil is on the order of 10 cm thick [17]. The surrounding terrain has lower thermal inertia, higher albedo and lower dust cover index suggesting thicker deposits of loose, very fine grained dust.

Radar data and morphologies suggest the sinuous units are thick masses of ice. However, these units differ from LDA and LVF debris-covered glaciers in the following ways: (1) LDA and LVF tend to occur at mid-latitudes along the dichotomy boundary in regions of moderate or high relief; whereas, the sinuous units lie within a low-relief region of Mars. (2) LDA occur along valley walls, degraded crater walls, or around isolated massifs, none of which can be found in the sinuous units. (3) Unit 1 has evidence for flow banding, similar to ogives, that differ in morphology to the lineated flow bands seen on LVF. (4) The sinuous units have no obvious valley wall or divide, show little to no change in topography, and are slightly raised from the immediate surrounding.

Despite the differences to LVF and LDAs, the sinuous units' channel-like nature, sharp boundaries, evidence for flow banding similar to ogives, and indication of thick ice is consistent with being buried ice that has flowed in the past. As a result, the sinuous units may be buried glaciers or glacial remnants. If this is the case, then a mechanism to explain their current inverted stratigraphy with respect to the surrounding plains is needed and is the focus of ongoing work.

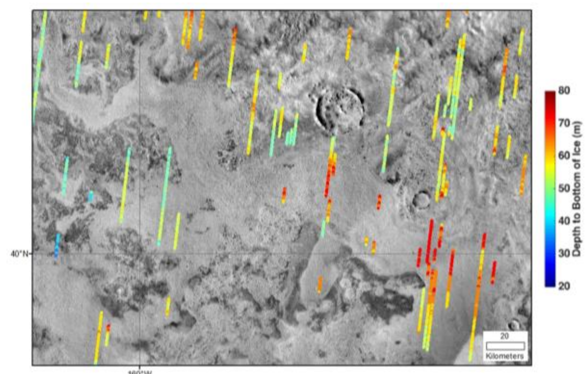

Figure 4: *Shallow Radar Data from [9] plotted at higher resolution on THEMIS Day IR of unit 1. Radar data detects dielectric constants similar to that of extensive excess ice across Arcadia Planitia.*

References: [1] Head J. W. et al. (2003) *Nature,* 797-802. [2] Boynton W. V. et al. (2002) *Science, 297,* 81-85. [3] Pathare A. V. et al. (2017) *LPS XLVIII,* Abstract #2543. [4] Mangold N. (2003) *JGR,* 108. [5] Plaut J. J. et al. (2009) *GRL, 36*. [6] Byrne S. et al. (2009) *Science, 325,* 1674-1676. [7] Dundas C. M. et al. (2014) *JGR, 119,* 109-127. [8] Viola D. et al. (2015) *Icarus, 248,* 58-61. [9] Bramson A. M. et al. (2015) *GRL, 34,* 6566-6574. [10] Williams N. R. et al. (2017) *LPS XLVIII,* Abstract #2852. [11] Holt J. W. et al. (2008) *Science, 322,* 1235-1238. [12] Head J. W. et al. (2010) *EPSL, 294,* 306-320. [13] Squyres S. (1978) *Icarus, 34,* 600-613. [14] Putzig N. E. and Mellon M. T. (2007) *Icarus, 191*, 68-94. [15] Ruff S. W. and Christensen P. R. (2002) *JGR,* 107. [16] Golombek M. et al (2008) Ch. 21 in, The Martian Surface, Cambridge U. Press. [17] Mellon M. et al. (2013) *Antarctica Science*.