THE DISTRIBUTION OF ICE EXPOSURES ON MARS. C. M. Dundas[1], K. E. Williams[1], A. S. McEwen[2], S. Byrne[2], M. T. Mellon[3], A. M. Bramson[2]. [1]U.S. Geological Survey, Astrogeology Science Center, 2255 N. Gemini Dr., Flagstaff, AZ 86001 (cdundas@usgs.gov), [2]University of Arizona, Lunar and Planetary Lab, [3]Cornell University.

Introduction: Steep scarps exposing cross-sections through Martian ice sheets were described in 2018 [1]. These scarps (Fig. 1) reveal ice with internal layering and a low dust content, shallowly buried beneath a thin regolith deposit. The ice is interpreted as accumulations of consolidated snow, which in some cases underwent some amount of glacial flow. The scarps provide the best information available on the vertical structure of mid-latitude subsurface ice and can serve as ground truth for lower-resolution remote-sensing methods.

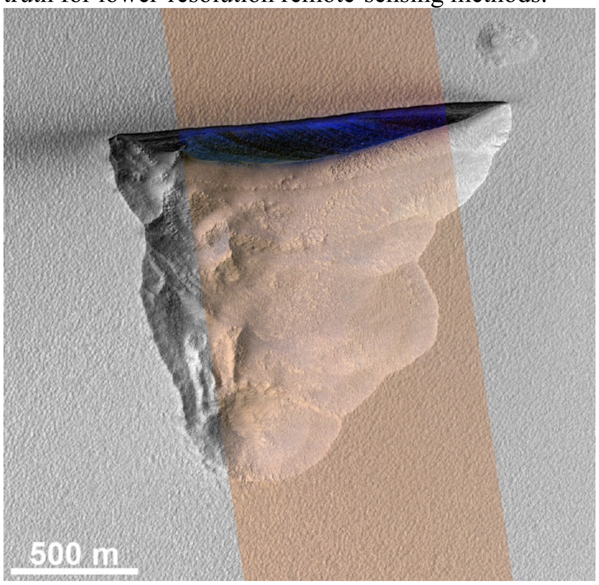

Figure 1: Ice-exposing scarp (blue) in the southern highlands (56.9°S, 96.3°E). Note scarp-parallel ridges indicating equatorward retreat and notches or kinks in the eastern wall. (HiRISE image ESP_057466_1230, MIRB enhanced-color composite; north is up, and illumination from the upper left.)

Survey: We conducted a search for ice-exposing scarps between 45–70°S and 45–65°N using mosaics of Thermal Emission Imaging –System (THEMIS) daytime infrared data [2–3]. Distinct pits several hundred meters across or larger were then inspected in Context Camera (CTX [4]) images to check for the distinctive morphology of known scarps: a sharp, nearly-straight, pole-facing scarp on the edge of a depression. Such scarps are considered probable ice exposures, or treated as confirmed if High Resolution Imaging Science Experiment (HiRISE [5]) color data reveals relatively-blue (less red) coloration relative to surrounding terrain (Fig. 1). In regions of dense pitting such as scalloped terrain, it was not practical to inspect every depression, but the most prominent candidates were examined along with hundreds of less-distinct candidates which almost invariably lacked ice exposures. The survey does not have a well-defined lower-limit size, but we estimate that it is near-complete in the latitudes searched for scarps at kilometer size and larger, since the THEMIS mosaics have near 100% high-quality coverage. HiRISE was used to confirm scarp color when possible but the survey is not limited to HiRISE data.

Fig. 3 (following page) shows the distribution of observed scarps. In both hemispheres, the scarps are strongly concentrated in latitude, with nearly all between 54–61°. Southern hemisphere scarps occur only south and southeast of the Hellas basin, between 47–137° E. In the north, there is a dense concentration of >60 candidate scarps in Milankovič crater (54°N, 212°E) with scattered examples elsewhere.

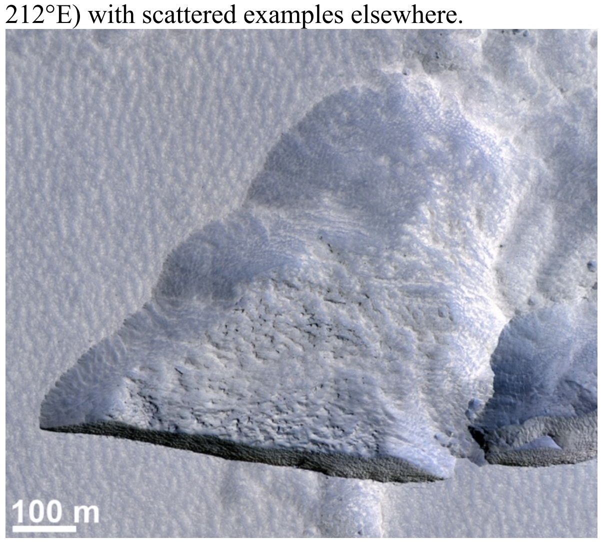

Figure 2: Scarp in Milankovič crater (54.1°N, 212.1°E) lacking icy coloration. HiRISE enhanced-color observation ESP_052529_2345; north is up, and illumination is from the lower left.)

Observed scarp lengths range from 200 m–6.5 km, with plan-view widths from 20–200 m. The one scarp with high-resolution topography has a slope near 45° [1], so the widths likely approximate the scarp height in near-nadir images. Likewise the vertical resolution of exposed material is similar to HiRISE's horizontal resolution (~30 cm/pix). Most scarps with this distinctive morphology have coloration indicative of clean ice exposures when imaged by HiRISE, but in some cases the ice appears to be mostly or entirely covered by a veneer of dust that may represent a sublimation lag (Fig. 2). The scarps mostly face slightly east of poleward and occur in mantling units. The scarps themselves are typically in crudely triangular pits that have grown by widening while the scarp retreats equatorward. Some are near scalloped depressions but these appear to be distinct landforms. Notches in the plan-view shape suggest that in some cases the scarp retreat halts and then resumes over only part of its width. Few-meter-scale and finer layering observed by [1] is uncommon, with most scarps having at most crude banding or thick layers.

Discussion: The limited latitude range of the scarps suggests that either the occurrence of the host icy units or their ability to maintain exposures is controlled by temperature and insolation, and possibly related processes such as seasonal frost. Concentration at certain longitudes indicates that appropriate materials for forming the scarps are not ubiquitous and suggests that these areas are regions where snow was preferentially deposited and/or preserved. Scarps appear to correlate with rugged mesoscale topography such as massifs and craters, which may influence ice deposition and flow.

In some instances, ice-exposing scarps are found in the vicinity of candidate sublimation-thermokarst features such as scalloped depressions and expanded craters [e.g. 6–11]. However, such features are often not well-defined. The scarps appear to indicate a different style of ice loss, which could relate to sublimation of exposed ice (favored where surface ice is maintained) versus through a lag (favored on warm slopes). Irregular pitting is common on the surface near the scarps.

Distinctive fine layers are rarely observed. There may be unresolved layers that provide a detailed temporal record, but it is also possible that the ill-defined layers that are commonly visible represent the major time units. The two locations with the most apparent layers also have cross-cutting layers and unconformities, suggesting either ice movement (flow or drifting of blowing snow) or accumulation at two distinct epochs with different climate conditions.

In aggregate, the scarps provide information about the distribution and thickness of thick, clean mid-latitude ice deposits on Mars. This information complements observations of ice-exposing craters [12–13], which only probe shallow depths but occur at a range of latitudes. Both indicate that a substantial fraction of Martian mid-latitude ice is in the form of excess or massive ice rather than pore-filling deposits.

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References: [1] Dundas et al. (2018) *Science,* 359, 199-201. [2] Edwards C. S. et al. (2011) *JGR*, 116, E10008. [3] Fergason R. L. & Weller L. (2019) 4th Planetary Data Workshop, abstract #7059. [4] Malin M. C. et al. (2007) *JGR*, 112, E05S04. [5] McEwen A. S. et al. (2007) *JGR,* 112, E05S02. [6] Morgenstern A. et al. (2007) *JGR*, 112, E06010. [7] Lefort A. et al. (2009) *JGR*, 114, E04005. [8] Lefort A. et al. (2010) *Icarus*, 205, 259-268. [9] Zanetti M. et al. (2010) *Icarus*, 206, 691-706. [10] Viola D. et al. (2015) *Icarus*, 248, 190-204. [11] Dundas C. M. et al. (2015) *Icarus*, 262, 154-169. [12] Byrne S. et al. (2009) *Science*, 325, 1674-1676. [13] Dundas C. M. et al. (2014) *JGR*, 119, 109-127.

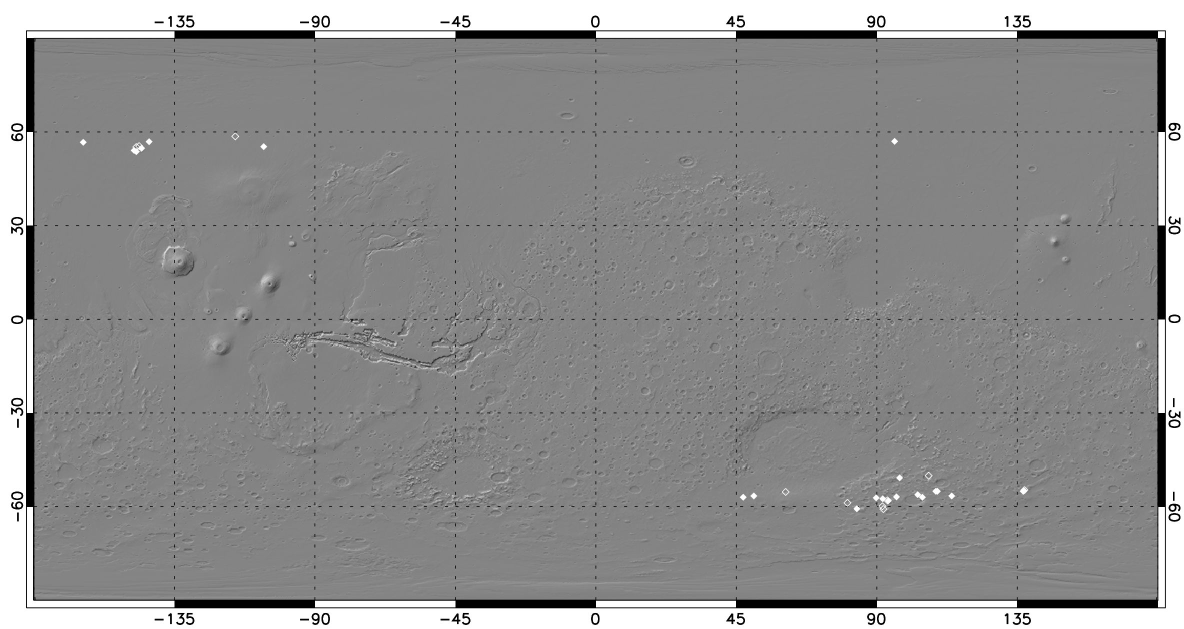

Figure 3: Map of confirmed (filled symbols) and probable (open) ice-exposing scarp sites. Some sites have more than one scarp. Latitudes searched were 45–65°N and 45–70°S.