EXPANDED CRATERS IN ARCADIA PLANITIA: EVIDENCE FOR >20 MYR OLD SUBSURFACE ICE.

D. Viola[1], A. S. McEwen[1], C. M. Dundas[2], S. Byrne[1], [1]University of Arizona, Department of Planetary Sciences, [2]USGS, Astrogeology Science Center.

Introduction: The presence of extensive excess ice in the subsurface of the Martian northern mid-latitudes has been confirmed by a range of observations, including orbital measurements [1], surface observations [2], and the detection of new impacts that expose ice in the shallow subsurface [3]. Impact craters can be useful probes of subsurface properties; in particular, secondary craters not only provide information about the subsurface, but can also serve as a temporal "snapshot" of broad-scale conditions present at the time of their (simultaneous) formation. In this abstract we discuss the abundance of ice-related secondary crater morphologies in Arcadia Planitia, with implications for the long-term persistence of ice in the region and significant ice loss at the time of crater formation.

Study Area. Arcadia Planitia is located in the northern midlatitudes of Mars (35-65°N, 180-240°E). While secondary crater fields tend to be fairly uncommon at mid- to high-latitudes, we find four primary craters with abundant, well-preserved secondaries in this area (Table 1). The expected time for these primaries to accumulate within an area this size would be ~37±19 Myr using the Hartmann (2005) production function [4], and individual primary ages have been estimated using superposed crater counts (Table 1).

Table 1: Primary Crater Parameters

Primary	Coordinates	Diameter (km)	Depth (m)	Age (Myr)
Steinheim	54.6N, 190.7E	11.3	600	18.6 ± 3.2
Gan	61.7N, 229E	19.3	900	70 ± 10
Domoni	51.4N, 234.4E	13.8	800	19.2 ± 5.3
Unnamed	43.2N, 225.8E	6.0	700	24.3 ± 5.5

Expanded craters. Many of the secondary craters associated with these Arcadia Planitia primaries show evidence for "expansion," meaning that they have a central crater bowl surrounded by a shallow extension to the surface (Figure 1). These features are thought to result from impacts which destabilize excess ice in the subsurface; unstable under Martian atmospheric conditions, the ice will sublimate, allowing the overlying dry regolith to collapse and causing the crater's diameter to increase. Thermal and landscape evolution models [5] have demonstrated that impacts into ice can produce the expanded morphologies observed in this region.

Methods: Clusters of secondary craters were mapped [6] using data from the Context Camera (CTX), which covers 75% of the study area at a resolution of ~6 m/pixel (Figure 3). Several HiRISE Digital Terrain Models (DTMs) were used to characterize planar and 3-dimensional parameters of expanded craters, including depths, diameters, and volumes.

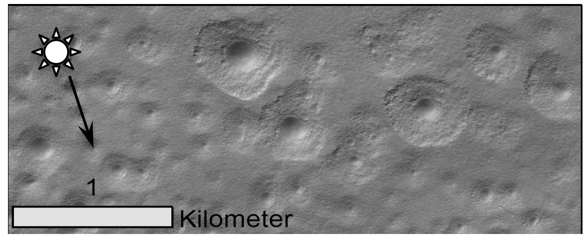

Figure 1: Example of expanded secondary craters HiRISE image ESP_028411_2330.

Expanded crater volumes and ice loss. To first order, crater bowl volumes are typically approximately the same as the volume of their rim and ejected material. However, we find that expanded craters do not retain any rim, and instead have wall slopes that smoothly transition into the surrounding topography (Figure 2), presumably because any rim that was once present has collapsed into the crater during expansion or, if composed of ice, sublimated. Therefore, we posit that the expanded crater volume below an interpolated pre-impact surface is approximately the same as the ice volume sublimated during expansion. This allows us to estimate the total amount of ice that sublimated during the formation of these secondary crater fields.

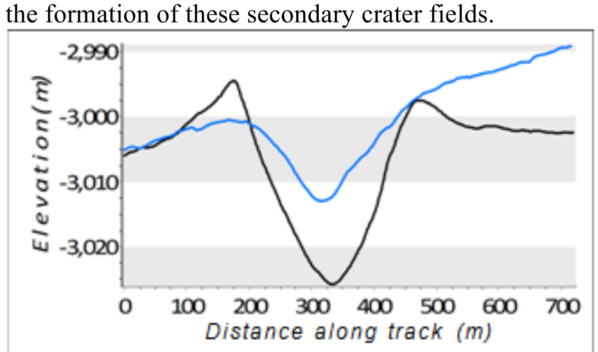

Figure 2: Elevation profiles of an expanded secondary crater (blue) and a non-expanded primary crater (black).

Results and Discussion: Since the expanded secondary craters in Arcadia Planitia are preserved to this day, we suggest that the ice layer into which they penetrated must also be preserved. Significant loss of this ice due to climate variations, such as the terrain dissection observed across much of the northern and southern mid-latitudes [7], would have disrupted the expanded morphologies and destroyed the secondary crater fields. Therefore, based on the ages of the primary craters (and thus their secondary crater fields), the

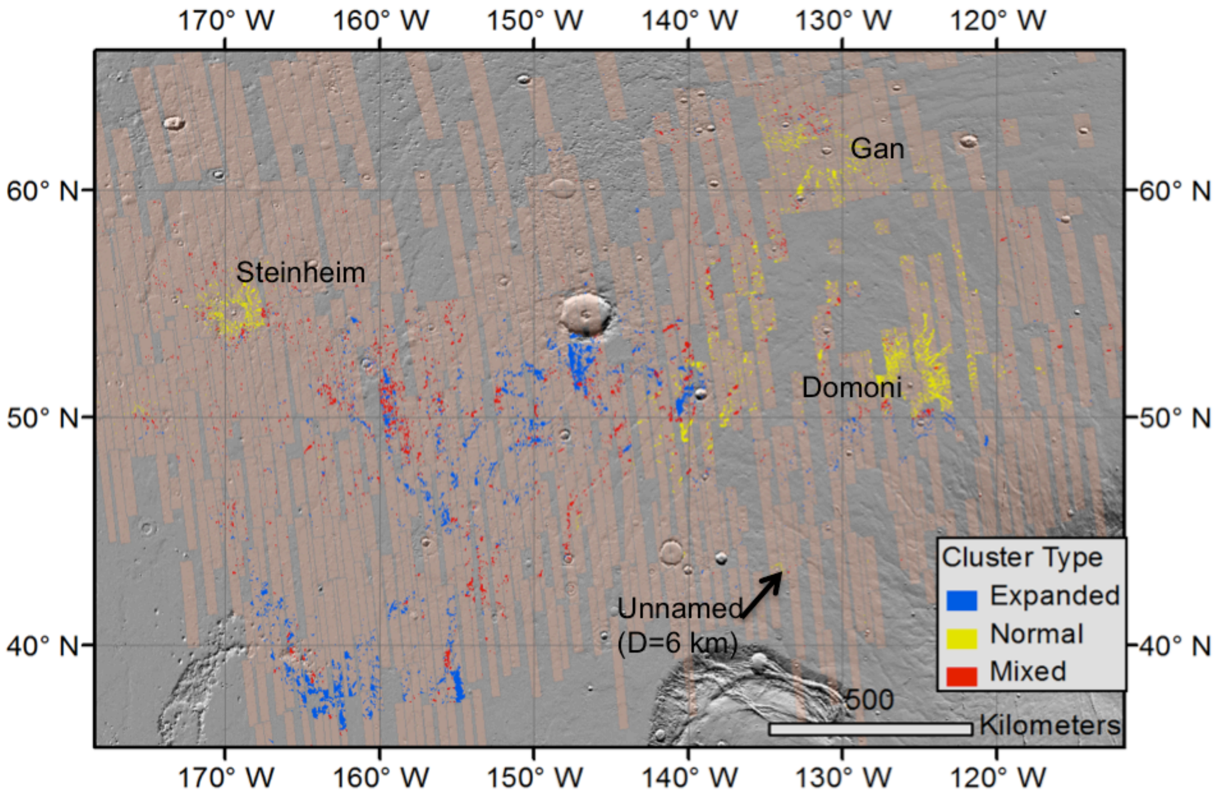

Figure 3: Map of expanded secondary crater clusters in Arcadia Planitia. Cluster types are based on morphologies: expanded, "normal"/non-expanded, or a mix of the two.

subsurface ice in Arcadia Planitia must be on the order of tens of millions of years old.

It is surprising that such ancient excess ice can be present on Mars today. There are a few hypotheses for the formation of excess ice on Mars, such as thin films of water that develop into ice lenses [8, 9] or buried snowfall [10, 11]. However, it is thought that obliquity-induced climate change should have resulted in cyclic periods of ice instability in the mid-latitudes on timescales of hundreds of thousands of years [12]. Furthermore, it has been argued that the ice present today must have been deposited in an ice age approximately 2 Myr ago, and should be actively retreating due to current instability [7, 13]. This work, on the other hand, suggests that long-lived ice has been preserved in the Martian mid-latitudes, at least in this region of Arcadia Planitia.

It has been posited that past climate variations could have been induced by the release of significant quantities of subsurface water or ice from the secondary craters of large impacts [14]. We estimate the total amount of ice lost from the expanded craters in each DTM, and extrapolate to the total area of expanded craters mapped in Arcadia Planitia. This is only a first-order estimate since the size distribution of expanded craters across the entire region is not necessarily the same as the distribution of those that were analyzed in the DTMs. We estimate a lower bound on the volume of ice lost during the formation of the Arcadia Planitia expanded craters was ~150-350 km^3, equivalent to a global layer of ~1-2.5 mm. The release of this much water vapor into the atmosphere over time could have had an effect on the Martian climate, especially just after impact or during northern summer when sublimation rates would be highest. The amount of ice remaining in the un-cratered terrains of Arcadia Planitia is expected to be much greater.

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