CANDIDATE VOLCANIC ICE-CAULDRONS ON MARS: ESTIMATES OF ICE MELT, MAGMA VOLUME, AND ASTROBIOLOGICAL IMPLICATIONS. Joseph S. Levy[1], James W. Head[2], Caleb I. Fassett[2], Andrew G. Fountain[1] [1]Portland State Univ. Dept. of Geology, Portland, OR, USA. [2]Brown Univ. Dept. of Geological Sciences, Providence, RI, USA. jlevy@pdx.edu.

Introduction. Magma-ice interactions are a critical component of martian geological and climate history [1-5]. Classically observed examples of magma-ice interactions on Mars include magmatic fracture of the cryosphere, subglacial volcanism producing dikes and moberg-like ridges, synglacial volcanic deposits, pseudo-crater formation, volcano-flank melt channels, tindar-like features, and possible ice-cauldrons [2-8]. The formation of ice-cauldrons (glacial depressions caused by the volcanic melting of ice, and typically characterized by surficial concentric crevasses) (Fig. 1) [9-10] is of particular astrobiological interest [1] as ice-cauldrons commonly contain subglacial lakes that, on Earth, support microbial ecosystems, including methanogenic organisms [12], in nutrient-rich waters of neutral to mildly acidic pH [12-13], and that may persist through multiple episodes of jökulhlaup activity [9-10]. Magmatic intrusions may be able to support near-surface ice-melting conditions for ~10-100 ka even under present climate conditions [2-3, 6-8], suggesting that martian ice-cauldrons may represent a significant near-surface habitable zone [14].

Analysis of Candidate Ice-Cauldrons. Here, we discuss two candidate ice-cauldrons—one well-described feature in Galaxias Fossae (36˚N, 141˚E) [5], and one north of the Hellas Basin ("North-Hellas")(28˚S, 83˚E) (Fig. 1). Both features are topographic depressions with internal, concentric fracture systems morphologically similar to terrestrial crevasses (Fig. 1). [5] outlines the extensive evidence for previous volcanic and glacial activity in Galaxias. In North-Hellas, the depression is located in a filled crater containing "degraded concentric crater fill" and exposures of "brain terrain" (Fig. 2) interpreted to be of glacial origin [15], suggesting a buried ice substrate consistent with ice-cauldron formation. Cuspate pits surround the depressions, arranged both radial to and concentric with the depressions, and could be either impact ejecta [5] or ballistically-emplaced volcanoclastic deposits[5, 9-10]. HiRISE image data extensively cover the Galaxias depression, while HRSC high-resolution stereo DTM data [18-19] covers the North-Hellas depression, permitting detailed analysis of the morphological and morphometric properties of the two depressions.

Calorimetry: Ice and Magma Volumes. High-resolution image and topography datasets were used to characterize the volume of the two candidate ice-cauldrons. HRSC DTM data and CTX image data were used to measure the North-Hellas cauldron properties, and MOLA gridded topography and HiRISE image data were used to measure Galaxias cauldron properties. Measured volumes of the depressions are ~10^9 m^3 and 10^6 m^3, respectively (although volume derived from MOLA gridded data is likely an underestimation). Using the approach outlined in [10], the volume of magma required to melt this volume of material, assuming it is pure water ice, V_m, is:

$$V_m = (\rho_i L_i V_i)(\rho_m(L_m+c_p\Delta T))^{-1} \quad (1)$$
$$V_m = (\rho_i L_i V_i)(\rho_m c_m \Delta T)^{-1} \quad (2)$$

where i indicates ice, m indicates magma, ρ is the density, L is the latent heat of fusion, V is the volume, c is the specific heat, and T is temperature, with (1) implying crystallization and cooling of magma, and (2) indicating cooling of a magma without crystallization. All values were taken from [10] and references therein, save ρ_m (2700 kg/m^3) [16] and ΔT (1200˚C, a reasonable temperature drop from near-liquidus basaltic magma cooling to mean martian global surface temperatures). (1) and (2) are relatively uniform under these conditions, suggesting ~10^7-10^8 m^3 of magma may have been required to form the North-Hellas depression and ~10^5 m^3 for the Galaxias depression.

Substrate Properties. In order to assess the likelihood that the identified depressions represent examples of martian ice-cauldron formation, it is useful to compare the material properties of the fractured material to those of ice under martian conditions [17]. The strain rate of the fracturing material can be estimated for a brittle shell over viscous material using the approximation provided in [10] based on observed crevasse depth, d:

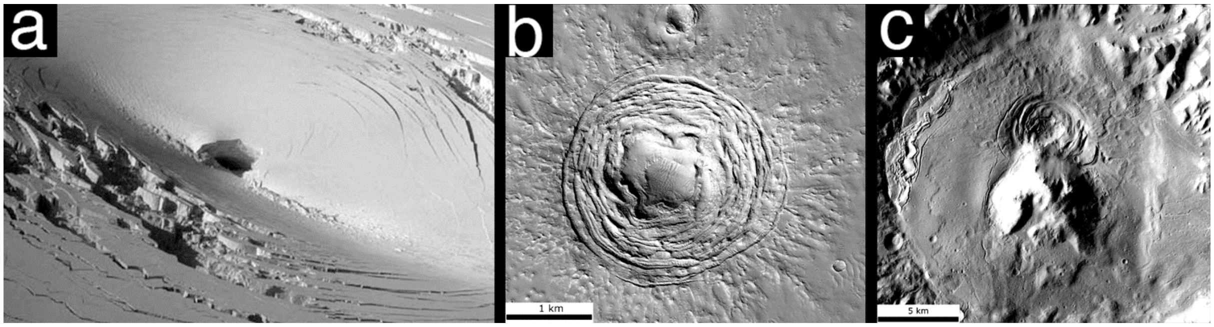

Fig. 1. a) Air-photo of the Gjálp ice-cauldron from [10]. b) Candidate ice-cauldron in Galaxias Fossae. Portion of PSP_005813_2150. c) Candidate ice-cauldron in North-Hellas. Portion of P03_002387_1506.

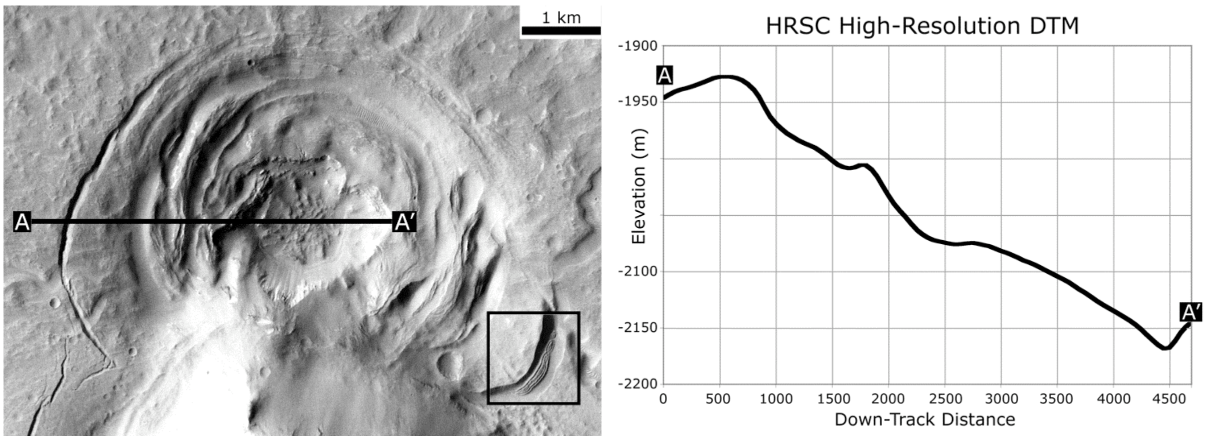

Fig. 2. a) Close-up of candidate cauldron in Fig. 1c. A-A' marks profile for part b. "Brain-terrain" crater fill surface texture in box. b) Topographic profile into the candidate cauldron showing crevasse structure.

$$d = (\rho_i g)^{-1}(\varepsilon'_{xx}/A)^{1/n} \qquad (3)$$

where g is acceleration due to martian gravity, ε'_{xx} is the horizontal strain rate, A is an ice flowlaw parameter, and n is the ice flowlaw exponent. d is measured directly from image data using shadow measurements of crevasse depth, g is 3.69 ms^{-2}, and A and n are taken from [10]. Strain rates predicted using (3) are between 10^{-8} and 10^{-9} s^{-1} for the observed depressions, relatively consistent with a thick accumulation of deforming ice [e.g., 15], or relatively warm ice [17].

Conclusions. The morphological properties of the North-Hellas and Galaxias Fossae depressions are strongly suggestive of ice-cauldron formation processes. Volumetric and calorimetric estimates suggest that up to a cubic kilometer of ice may have been removed in order to form these depressions (melted and/or vaporized), and that an ice-rich substrate may have cracked in response to surface subsidence to produce the observed concentric fracture (crevasse) morphology. The combined possibilities of liquid water with volcanic-gas enriched growing environments makes these features tantalizing astrobiological targets, and suggests the importance of in-situ and terrestrial-research in volcano-ice systems. Ongoing work will develop strategies for distinguishing these landforms from potential ice-impact interactions observed on the Tharsis Montes tropical mountain glaciers.

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