CRYOVOLCANIC HISTORY OF CERES FROM TOPOGRAPHY Michael M. Sori[1], Hanna G. Sizemore[2], Shane Byrne[1], Ali M. Bramson[1], Michael T. Bland[3], Nathaniel T. Stein[4], Christopher T. Russell[5], and Carol A. Raymond[6]. [1]University of Arizona (sori@lpl.arizona.edu), [2]Planetary Science Institute, [3]USGS Astrogeology, [4]California Institute of Technology, [5]UCLA, [6]NASA Jet Propulsion Laboratory.

Introduction: Cryovolcanism may be a fundamentally important process in shaping the surfaces of many planetary bodies, but remains poorly understood. Ceres represents our best opportunity to learn about this phenomenon because of the Dawn mission [1], which discovered Ahuna Mons (Fig. 1a), a mountain interpreted as a cryovolcanic construct [2]. An outstanding question has been why only one prominent cryovolcano was observed. A proposed solution is that cryovolcanic domes on Ceres viscously relax over geological timescales, precluding domes older than Ahuna Mons from easy identification [3].

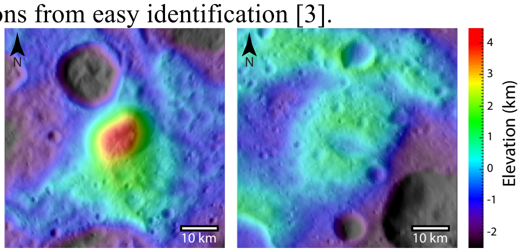

Figure 1. Shaded topographic relief of (left) Ahuna Mons, a putative cryovolcanic construct, and (right) one of 21 domes analyzed here, located in Begbalel crater.

Methods: We identify 21 large (>10 km in diameter, >1 km in height) domes that may be old cryovolcanic constructs [see also 4]. For these features, we measure the diameter, height, and slopes. One example is shown in Figure 1b. The dome contains a similar volume of material to Ahuna Mons, but has 1.7 km less topographic relief and is 15 km greater in diameter, consistent with a relaxed analog of Ahuna Mons.

Evidence for viscous relaxation is quantified using finite element flow models. We consider the case where a dome identical in size and shape to Ahuna Mons forms at a given time at every 10 degrees of latitude on Ceres. Using a thermal model [5] that calculates the annual-average temperature of domes at each latitude, we determine the expected aspect ratios of the domes after a given amount of time; lower-latitude (i.e., warmer) domes flatten more quickly. The observations and model results are plotted together in Fig. 2.

Interpretation: Model results show good agreement with observations of dome aspect ratios and the hypothesis that the domes represent viscously relaxed structures. The polar dome, Yamor Mons [6], especially lends evidence to the hypothesis. It is located at a latitude too cold to viscously deform, and is observed to have retained great topographic relief. This property is not shared by any other dome (except young Ahuna Mons, which has not had time to deform), nor is there a polar dome with low aspect ratio.

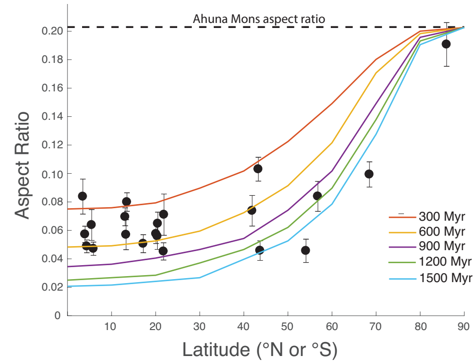

Figure 2. Aspect ratios of 21 domes on Ceres (black dots), compared to that of Ahuna Mons (dashed line) and the modeled aspect ratios of viscously deformed cryovolcanoes (50% ice by volume) at some time after formation (solid lines).

Our models constrain the age of the domes by estimating the time it takes for a dome of Ahuna Mons' aspect ratio to relax into the presently measured aspect ratio, for a constrained ice content. We find the observed domes to be 100s of Myr old (Fig. 2). Older domes are likely to be unidentifiable, with the possible exception of the polar dome Yamor Mons.

We will also discuss an alternative hypothesis, that the domes represent tectonic structures formed by upwelling of low-viscosity, low-density material driven by differential topographic loading [7].

Conclusions: We conclude Ceres contains domes that are consistent with viscously relaxed cryovolcanic constructs. Ahuna Mons is the youngest cryovolcano, but does not represent a unique event in Ceres' geological history. We estimate, for the first time, the cryovolcanic rates of a solar system body. Our results are consistent with a cryovolcanic construct forming every ~50 Myr over the past ~1 Gyr, for an average cryovolcanic rate ~10^4 m^3/yr.

The Cerean cryovolcanic extrusion rate in this scenario is orders of magnitude less than the average volcanic extrusion rate estimated for the terrestrial planets [e.g., 8], even when normalized by surface area. Therefore, cryovolcanism is a significant process in shaping the surface of Ceres, but is not as important as basaltic volcanism on terrestrial planets.

References: [1] Russell et al. (2016), *Science* 353. [2] Ruesch et al. (2016), *Science* 353. [3] Sori et al. (2017), *GRL* 44. [4] Sizemore et al. (2018), *LPSC 49th*. [5] Bramson, Byrne, and Bapst (2017), *JGR Planets* 122. [6] Ruesch et al. (2017), *Icarus*, in press. [7] Bland et al. (2018), *LPSC 49th*. [8] Crisp (1984), *J. Volcan. Geotherm. Res.* 20.