TESTING THE HYPOTHESIS THAT CURVILINEAR GULLIES, LOBATE DEPOSITS AND PITTED TERRAIN ON VESTA AND CERES WERE FORMED BY SHORT-LIVED, DEBRIS-FLOW-LIKE PROCESSES. J. E. C. Scully[1], M. J. Poston[2], E. M. Carey[1], S. R. Baker[1,3], J. C. Castillo-Rogez[1] and C. A. Raymond[1]. [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA (jennifer.e.scully@jpl.nasa.gov), [2]Southwest Research Institute, San Antonio, TX, USA, [3]University of Chicago, Chicago, IL, USA.

Introduction: Prior to the Dawn mission, Vesta was thought to be depleted in volatiles while Ceres was predicted to be volatile rich [1]. Ceres was confirmed to have a volatile-rich crust and low density, likely heavily hydrated, rocky mantle [e.g. 2-4]. Unexpectedly, the discovery of pitted terrain [5], curvilinear gullies and lobate deposits [6] in vestan impact craters indicated that Vesta might contain a significant amount of volatiles, at least on a local scale.

[6] hypothesize that localized deposits of subsurface water ice were heated by impacts, releasing liquid water onto the walls of newly formed impact craters. This liquid water would be unstable, but [6] propose is was transiently present for a sufficient time to form curvilinear gullies and lobate deposits via a debris-flow-like process, in a timescale on the order of tens of minutes. Vaporization of the liquid water could also lead to pitted terrain formation [6]. Similar geomorphological features to those described in [6] have also been observed on Ceres [7]. We evaluate this hypothesis via laboratory experiments and geomorphological analyses.

Laboratory experiments – set-up: We investigate the behavior of liquid water/brine under vestan/cerean conditions immediately following an impact. We use the modeled transient atmospheric pressures of ~10^{-4}-10^{-5} torr [8], and we use heat tape to keep the antechamber at a consistent temperature, slightly above ambient (~25°C). This consistent temperature reduces potential complications in interpretation caused by changes in ambient temperature, and is representative of the hotter than average temperatures expected in the impact crater shortly after formation. We perform the experiments in the JPL Extraterrestrial Materials Simulation Laboratory (EMSiL)/Ice Physics Lab.

The main components of our set-up are: (i) a 2.65 cubic-foot cryogenic vacuum chamber (main chamber), (ii) an antechamber and (iii) a large valve that connects the main chamber to the antechamber (Figure 1). The valve allows us to isolate the internal pressure of the antechamber from the main chamber. We place the sample container in the base of the antechamber, on top of a mass balance. Samples consist of (a) pure water, (b) brine, and (c) pure water or brine mixed with glass beads, to simulate the debris-flow-like material that is hypothesized to form the curvilinear gullies and lobate deposits.

We output the following data to LabView: (i) pressure, (ii) temperature of the antechamber/sample, and (iii) mass of the sample. We also record video of the experiments through the top viewport of the antechamber. Three thermocouples are taped to the inside of the sample container, which report temperatures from the same depth in the sample container in each experiment. Pressure gauges monitor the antechamber and main chamber pressures.

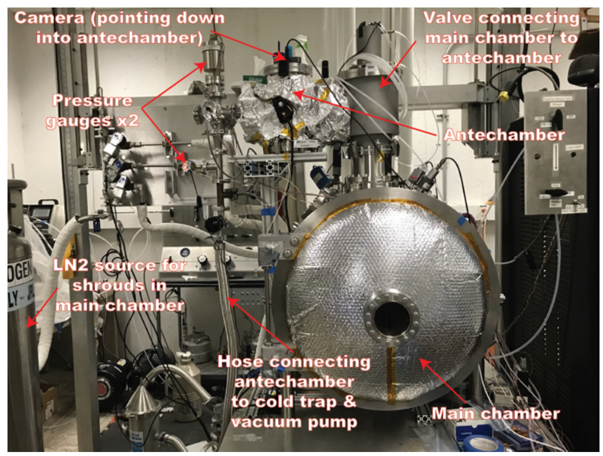

Figure 1. The main components of the experimental set-up are labelled.

Laboratory experiments – procedure: We reduce the main chamber down to 10^{-4}-10^{-5} torr by both active pumping and cryogenic cold trapping on the shrouds in the main chamber. This effectively eliminates interparticle collisions on the size scale of our apparatus (mean-free-path greater than the distance between chamber walls) and simulates the transient atmospheric pressures expected on Vesta's/Ceres' surfaces shortly following an impact into a volatile-rich target [8].

We slightly decrease the pressure in the antechamber to degas the sample, so that dissolved atmospheric gases will not complicate our observations. We note that on Vesta and/or Ceres, dissolved gases may exist, and may inhibit or slow freezing, thus making our experiments a conservative case. The liquid water/brine in the sample container is stable at the pressures (~18 torr) and temperatures (~25°C) in the antechamber prior to initiation of the experiment. This simulates the stability of liquid water beneath the surfaces of Vesta/Ceres, after it was released from localized deposits of subsurface water ice by heating during the crater-forming impacts.

By opening the valve, we suddenly expose the liquid water/brine to pressures of 10^{-4}-10^{-5} torr, simulating the sudden release of the liquid(s) onto the crater walls. The liquid water/brine is not stable because conditions are near or below the triple point. We measure the time it takes for the liquid water/brine to evaporate/freeze, to test if liquid would be present long enough to form the curvilinear gullies and lobate deposits, before vaporization of liquid that seeped into the crater floor formed the pitted terrain. We test whether liquid longevity is affected by composition and the presence or absence of particles of varying sizes.

Laboratory experiments – initial results:

Pure water. The water begins the experiment in the liquid form. Once the valve to the main chamber is opened, the liquid water is at or below triple point conditions. Thus, it rapidly evaporates/boils and the liquid rapidly changes state to a solid and a gas. No liquid remains ~4 seconds after the valve is opened: water ice remains in the sample container/antechamber and vapor has migrated to the cold shrouds in the main chamber.

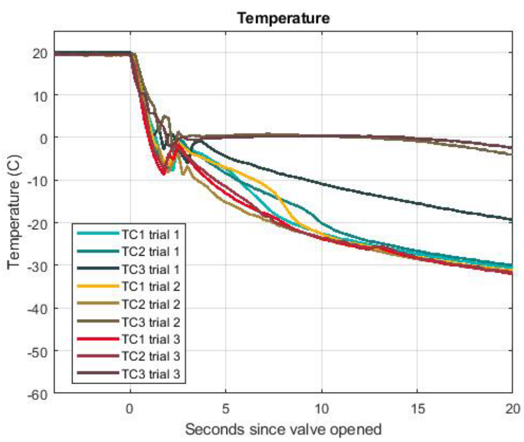

Figure 2. Temperature data (three thermocouples: TC1–3) from three repeat pure water experiments. Discontinuities at 0–5 seconds are due to sample freezing.

Pure water or brine mixed with glass beads. Liquid water or brine is mixed with glass beads (~20% liquid and ~80% beads). For both pure water and brine mixed with glass beads, the behavior is very similar: once the valve to the main chamber is opened, rapid evaporation/freezing occurs, so that no liquid remains ~4 seconds after the valve is opened. The rapid freezing is likely because the glass beads act as nucleation sites. Glass bead size does not significantly change the results.

Brine. To date, we have used NaCl brines at the eutectic concentration. Once the valve to the main chamber is opened, there is rapid evaporation/freezing of the top of the liquid sample. However, in contrast to the pure water, freezing does not progress down throughout the sample: a solid lid forms on top of the brine, which remains liquid below. The solid lid initially appears to be water ice. The underlying brine periodically breaches the solid lid, and freezes on the surface to become an opaque white solid. This opaque white solid appears brighter than the material that appears to be water ice. We are investigating whether it could be a NaCl hydrate. No underlying liquid brine appeared to remain after at least 55 minutes. Upon returning to atmospheric pressure, the opaque white solid melts at -21°C, consistent with a eutectic NaCl-water mixture.

Laboratory experiments – initial conclusions and future work: A brine forming curvilinear gullies and lobate deposits is plausible on Ceres, because there are numerous salts available [e.g. 9] to mix with impact-melted water. We plan to investigate the possibility that water/rock interactions preceding the impacts could also produce limited amounts of salts and brines on Vesta.

For Ceres, we plan to test brines made from other observed salts (e.g. Na_2CO_3 and NH_4Cl). We are also developing a method to agitate the samples, which will be more analogous to the proposed debris-flow-like process. We hypothesize that agitating the sample will prolong the presence of the liquid water/brine, in contrast to the current static samples.

Geomorphological analyses: We investigate whether there are additional geomorphological indicators for the presence of volatiles. We have made mosaics of ten Vestan impact craters and of ten Cerean impact craters in which curvilinear gullies, lobate deposits, pitted terrain and/or other geomorphological indicators for the presence of volatiles have been definitively or tentatively identified [5-7,10]. We are currently searching for curvilinear gullies and lobate deposits on Ceres. We are also searching for geomorphological indicators for the presence of volatiles on both Vesta and Ceres, including: channels, fractures whose formation is associated with volatiles, pits possibly formed by sublimation, mounds/domes formed in a pingo-like process and lobate landslides/ejecta interpreted to be rich in water ice [features summarized in 10].

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