MELT VOLUMES AND GALILEAN SATELLITE IMPACT FEATURES: VOLUME COMPARISONS AND INFILTRATION MODELING. D. G. Korycansky, *CODEP, Department of Earth and Planetary Sciences, University of California, Santa Cruz CA 95064* , O. L. White, *SETI Institute, Mountain View CA*, M. L. Caussi, *Department of Earth and Environmental Sciences, University of Illinois at Chicago* , A. J. Dombard, *Department of Earth and Environmental Sciences, University of Illinois at Chicago* , P. M. Schenk, *Lunar and Planetary Institute (USRA), Houston TX* , J. M. Moore, *NASA Ames Research Center, Mountain View CA* .

Introduction

The Galilean satellites with icy surfaces (Ganymede, Callisto, Europa) are host to a variety of large impact features that are, if not unique to these bodies, rarely encountered on planetary and satellite surfaces in the Solar System. These features include impact basins with central pits, domes, and so-called "penepalimpsests" and "palimpsests" in the terminology of Schenk *et al.* 2004. Our project seeks to establish the effects of several factors in explaining the origin and evolution of these features. In particular we aim to establish the roles played by: 1) the presence or absence of liquid water (at depth below the surface, or generated during the impact) vs warm ice (again, either pre-existing or impact-generated), 2) the lithospheric temperature gradient, 3) surface gravity (as compared to smaller gravity on mid-sized satellites, where the features of interest are not found, and finally 4) the role of the characteristics of the impactor: specifically, the impactor's size, velocity, composition, and the angle of the impact.

Pit/Dome volumes vs. inferred melt volumes

We compared melt volumes expected from large impacts with the volumes of pits and domes from several pit, dome, and anomalous-dome craters on Ganymede for which we have performed geologic and topographic mapping and morphometry. Pit and dome volumes were extracted from digital elevation models for the pit craters (diameters are given in parentheses) Achelous (40 km), Isis (75 km), and Tindr (76 km), dome craters Melkart (103 km), Eshmun (96 km), and anomalous-dome craters Neith (170 km), Doh (annulus diameter 106 km), and Har (platform diameter 110 km).

The combination of impactor properties that produces an impact feature of a given diameter is in general non-unique. That is, there is a trade-off among impactor diameter, velocity, and impact angle. (Secondarily, impactor and target density and target strength may also influence the result.) Thus we resorted to a Monte Carlo calculation to produce a distribution of possible melt volumes for each impact that feature we looked at. We simulated an impactor population with suitable characteristics and calculated the resulting melt volume for every impactor that produced a crater of the size corresponding to a particular impact feature from the list given above. The Monte Carlo calculation was done along the same lines as that done by Korycansky and Zahnle 2005 for simulating crater populations on Titan, with parameters adjusted for Ganymede. Melt volumes were calculated for each impact using the prescription given by Kraus *et al.* 2011.

Results for each of the impact features are shown in Fig. 1.

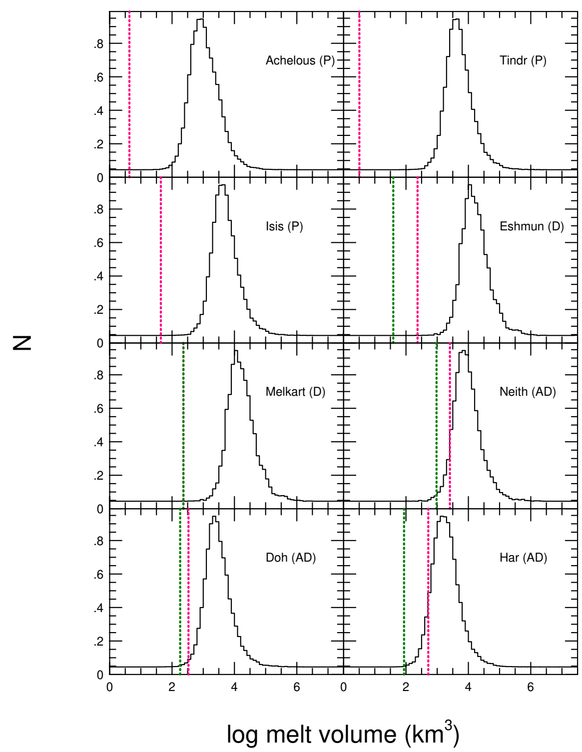

Figure 1: Comparison of Monte Carlo calculations of melt volumes vs. pit and dome volumes for eight impact features on Ganymede. In each panel, the histogram is the distribution of melt volumes (on a relative scale) from the Monte Carlo calculations. The vertical red line shows the pit volume measured for each feature and the vertical green line is the dome volume. (For Melkart, pit and dome volumes are almost the same ~ 231 km^3 so the vertical lines overlap.)

In each panel, the histogram is the distribution of melt volumes (on a relative scale) from the Monte Carlo calculations. The vertical green line shows the pit volume for each feature and the vertical red line is the dome volume. As can be seen from the plots, in general, inferred melt volumes are much greater (typically one to two orders of magnitude) than pit or dome volumes. This is particularly true for the smaller features (the pit and dome craters). For the largest features (anomalous dome craters Neith and Har), dome volumes do approach melt volumes, but are still several times smaller.

While the relation between impact melt and the surface expressions of pits and domes is unclear, our results suggest that a modest amount of melt drainage along with infiltration or refreezing played a role in generating these features. In general, there is ample melt available to be mobilized for surface process and surface feature formation (Caussi *et al.*, this conference). Such ideas have been explored by others, e.g. Elder *et al.* (2012) who proposed similar ideas and suggested that drainage of melt through impact-generated crevasses could account for crater pits on Ganymede and other bodies in the solar system.

Infiltration modeling

It is no doubt the case that the sub-surface configuration of impact craters is complex, with an unknown degree of fracturing and connectivity below the craters. Geological studies on Earth are as yet the only means of studying these conformations, with a limited amount of information available from gravity data for lunar craters from missions such as *GRAIL*, as well as Mars. Models for infiltration and drainage of impact melt might explain observed features. For example, Elder *et al.* 2012 proposed an idealized model of cm-scale vertical crevasses that provided drainage of melt.

A similarly idealized but sufficient starting point would be to treat the target substrate as a variably saturated medium in which melt drains by infiltration. Models like these have long been discussed in the literature on terrestrial groundwater. Crudely speaking, we envision an approach in which fractures and crevasses are treated as a medium with possibly anisotropic averaged porosity that is spatially variable on large scales. A variety of approaches are possible, but one widespread strategy that we borrow from the hydrology literature is a formulation in terms of the so-called Richards equation (e.g. Klute 1952, or recent discussions by Farthing and Ogden 2017, Zha *et al.* 2019):

$$\frac{\partial \theta}{\partial t} = \nabla \cdot [K(h)\nabla h] - \frac{\partial K}{\partial z}, \quad (1)$$

where θ is the fluid concentration, $h = \Psi/g\rho$ is the moisture potential scaled in terms of the so-called pressure head h, and $K(h)$ is the nonlinear conductivity for unsaturated porous flow. The second term on the right-hand side accounts for vertical gravity-driven drainage. Given a relation between $\theta(h)$ between the concentration and the pressure head, the time-dependent term $\partial\theta/\partial t$ is commonly expressed in terms of h, i.e. $\partial\theta/\partial t = C(h)\partial h/\partial t$, where $C(h) = d\theta/dh$.

The Richards equation is a highly nonlinear equation of mixed type, parabolic in the unsaturated regime, and elliptic for saturated regions where θ equals the saturated value θ_s and $C(h) = 0$. Solution of the Richards equation is subject to some complications but is relatively straightforward if discretized with an implicit time-stepping scheme (cf. Sadegh Zadeh 2011). Work is ongoing at time of submission of this abstract. We envision including a second component equation that models non-thermal energy in a non-equilibrium system with two temperatures T_{melt} and T_{ice}, as has been done for modeling convection in porous media (e.g. Siddheshwar and Siddabasappa 2017). We will include thermal energy of the melt $e_m = c_v T_{melt} + H$, where H is the latent heat of the melt thermal energy of the frozen substrate $e_I = c_v T_{ice}$, and a term that models thermal coupling between melt and porous ice.

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