MELT VOLUMES FROM IMPACTS ONTO ICY GALILEAN SATELLITES . D. G. Korycansky, *CODEP, Department of Earth and Planetary Sciences, University of California, Santa Cruz* , 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* , O. L. White, *SETI Institute, Mountain View CA*, P. M. Schenk, *Lunar and Planetary Institute (USRA), Houston TX* , J. 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.

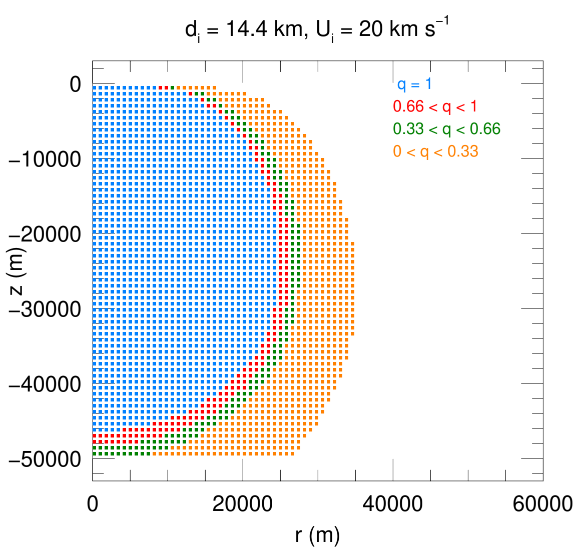

Figure 1: Partial and fully shock-melted region for a vertical impact of an ice body of $d_i = 14.4$ km diameter with velocity $U_i = 20$ km s^1 into a target of at $T = 125$ K. The melt region is delineated by tracer particles, shown in their initial positions and color-coded by degree of melting $0 < q < 1$. Melting is determined by the peak shock pressure as described in the text following the procedure of Kraus *et al.* 2011.

Here we present results for a basic property of the impact process and crater formation, namely the volume of melt produced. Previous work (Pierazzo *et al.* 1998, Kraus *et al.* 2011) has produced melt and vapor scaling as a function of velocity and other properties of the impactor and target (impact angle, target temperature). Kraus *et al.* used the CTH code and conducted calculations for a 1-km diameter object into a half-space. They looked at impactor/targets combinations of silicate as well as ice, whereas we are interested only in ice impactors and targets. Our work serves as a validation test comparison between their work and ours.

We follow the procedure described by Kraus *et al.* to determine melt volume. The assumption is that target material shocked to sufficiently high pressure will unload adiabatically into the melt (or vapor) region of the equation of state. More precisely, it is the entropy that is reached in the shock that determines the degree of post-shock melting, but pressure (which is related to entropy along the shock Hugoniot) is easier to extract from simulation output. Kraus *et al.* identify entropies and corresponding pressures of incipient and complete melting (and vaporization, but we are primarily interested in the former), for various initial target temperatures (50, 150, and 250 K). Melt volumes are thus computed by extracting the volume of target material that is shocked to the relevant pressure (or higher, if completely melted). We assumed that the degree of partial melting is linearly dependent on the pressure value between the incipient and complete melting points.

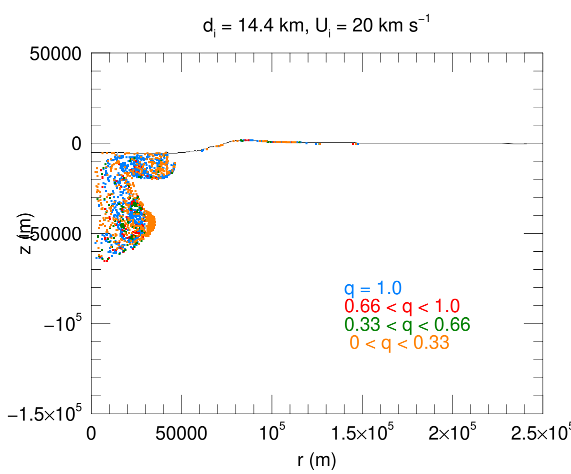

Figure 2: Partial and fully shock-melted region for a vertical impact of an ice body of $d_i = 14.4$ km diameter with velocity $U_i = 20$ km s^1 into a target of at $T = 125$ K. The melt region is delineated by tracer particles, shown in their final positions at the simulation's end, and color-coded by degree of melting $0 < q < 1$ as in Fig. 1.

Calculations were done using the iSALE code (Amsden *et* *al.* 1980, Collins *et al.* 2004, Wünnemann *et al.* 2006) with resolutions of R18 and R45 (cells per impactor radius), for an impactor diameters of $d_i = 9, 14.4$, and 21.6 km across a range of impact velocities $5 \leq U_i \leq 30$ km s^{-1}. Lagrangian tracer particles with associated volumes calculated from their initial positions were used to track peak pressures to determine the volume $V(> P)$ that is shocked to or above pressure P. Combined with the method described above, we calculated melt volumes for each run. An example is shown in Fig. 1 where tracers in initial positions are plotted and coded by color according to degree of melting q. Figure 2 shows the same run but with tracers shown in the their positions at the end of the calculation. Most melt ends up in a region below and surrounding the crater, but a certain number follow ejecta patterns that may account for melt sheets observed around some impact features. However, larger volumes than can be accounted for solely by impact may be present for large features such as the palimpsest feature Buto Facula (Moore *et al.* 2022). Such features may require the presence of a fluid or slushy subsurface layer at the time of formation.

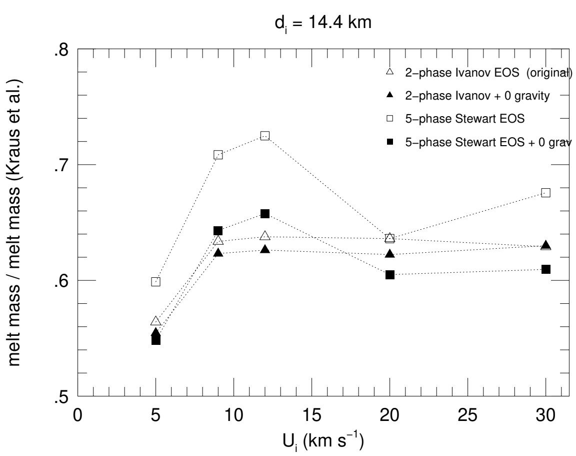

Figure 3: Ratio of melt mass as found in iSALE simulations, to the formula given by Kraus *et al.* 2011, for $d_i = 14.4$ km diameter impactor, plotted as a function of impact velocity U_i. Different symbols refer to EOSes as indicated and the absence or presence of a hydrostatic density gradient in the target.

Along with the values of parameters (impactor diameter, velocity) we also ran calculations for two equation of state (EOS) tables that were available for the calculations. These were the two-phase Ivanov EOS that is supplied with the iSALE code, and a 5-phase EOS developed by S. Stewart. We ran calculations with and without gravity in the target; inclusion of gravity means that density gradients induced by hydrostatic compression in the target affect the mass of melted material. For sufficiently large impact domains, phase transition occurs at ~ 70 km depth in targets with Ganymede gravity (1.43 m s^{-2}) which also affects values of melt mass.

Figure 3 shows our results, normalized to the formula for melt mass provided by Kraus *et al.* 2011. In general the results are quite comparable with our values being about 60-70% of those found by Kraus *et al.* Given the differences between our calculations and those of Kraus *et al.*, the degree of agreement between the sets of calculations seems quite reasonable.

Results from these calculations can be compared with potentially associated formations in large impact features on Ganymede and Callisto, such as domes and pits. Melt volumes are in general found to be an order of magnitude larger than the volumes of the impact-formed domes and pits as inferred from surface topography. In turn, this has implications for hypotheses of formation mechanisms for these formations.

Acknowledgments

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