LARGE IMPACT FEATURES ON ICY GALILEAN SATELLITES. J. M. Moore[1], P. M. Schenk[2], and D. G. Korycansky[3], [1]National Aeronautics and Space Administration (NASA) Ames Research Center, Space Science Division, Moffett Field, CA 94035 (Jeff.Moore@nasa.gov), [2]Lunar and Planetary Institute, Houston, TX 77058 (schenk@lpi.usra.edu), [3]Deptartment of Earth and Planetary Sciences, University of California, Santa Cruz, CA 95064 (kory@pmc.ucsc.edu).

Introduction: Impact crater morphology can be a very useful tool for probing planetary interiors, but nowhere in the solar system is a greater variety of crater morphologies observed (Fig. 1) than on the large icy Galilean satellites Ganymede and Callisto [e.g., 1-3]. As on the rocky terrestrial planets, impact crater morphology becomes more complex with increasing size on these satellites. With increasing size, however, these same craters become less like their counterparts on the rocky planets. Several impact landforms and structures (multiring furrows, palimpsests, and central domes, for example), have no obvious analogs on any other planets. Further, several studies [e.g., 4-6] have drawn attention to impact landforms on Europa which are unusual, even by Galilean satellite standards. These radical differences in morphology suggest that impact into icy lithospheres that are mechanically distinct from silicate lithospheres may be responsible. As such, large impact structures may be important probes of the interiors of these bodies over time [e.g., 7].

The first goal of this work is to integrate and correlate the detailed morphologic and morphometric measurements and observations of craters on icy Galilean satellites [e.g., 4, 8-12] with new detailed mapping of these structures from Galileo high-resolution images. As a result, we put forward a revised crater taxonomy for Ganymede and Callisto in order to simplify the nonuniform impact crater nomenclature cluttering the literature. We develop and present an integrated model for the development of these unusual crater morphologies and their implications for the thermal evolution of these bodies.

Mapping Results: We have organized our classification scheme into 6 distinct impact morphologies for craters larger than 40 km on Ganymede and Callisto: (1) central pit craters, (2) central dome craters, (3) anomalous dome craters, (4) penepalimpsests, (5) palimpsests, and (6) multiring structures (Fig. 1). This diversity is a unique occurrence in our solar system. This new taxonomy is similar to but updated from that of [1]. These landforms are not solely part of a size-progression of crater morphologies but are rather major variations of crater style within the 60-250 km size range. Evidence indicates we are seeing a spectrum of changing landforms over time as well as scale.

Hypotheses for Modeling: In our modeling we consider hypotheses in which there are three major factors controlling large impact feature evolution: (1) the lithospheric temperature gradient during the geologic time-period of impact; (2) surface gravity; and (3) impactor velocity, size, and composition. A potential unifying concept and the subject of our initial investigation is the role of a promptly formed pool of (water) melt following impact and how that pool might change in size, shape and depth as a function of impactor energy and the state of the substrate at time of impact (Fig. 2). (Note that the subsurface melt pool concept is implicit in earlier work [e.g., 13].) So, for instance, the pits of pit craters may form in lieu of a central peak because the H_2O simply melted where otherwise the peak would have formed in a silicate target. A small subsurface lens of water later freezes under the pit, expanding and raising the rim of the pit. The domes of central dome craters form along the same lines as hypothesized for central pit craters but the size, volume and location of the melt pool is such that, once solidified, as warm ice it upwells diapirically to form a dome. The raised floors and rims of penepalimpsests are, in this scenario, the consequence of ever more extensive lenses of melt that expand upon freezing.

We have formulated specific and testable hypotheses about the role of each of above-mentioned factors (lithospheric temperature gradient, surface gravity, impactor characteristics) in the formation and evolution of the impact and the subsequent structures. For example, pre-existing sub-surface liquid H_2O layers should have testably different effects on impact morphology as compared to melt pools formed during impact. Our main tool for this work is the hydrodynamics (shock wave) code CTH from Sandia [14]. The CTH code also includes material property models (strength, fragmentation) and a simple formulation of heat diffusion. Simulation geometries in two and three dimensions are possible. We will present the results of our initial investigations.

References: [1] Passey, Q.R. and Shoemaker, E.M. (1982) In: *Satelllites of Jupiter*, 379-434, D. Morrison (ed) U of AZ Press. [2] Chapman, C.R. and McKinnon, W.B. (1986) In: *Satellites*, 492–580, J.A. Burns, M.S. Matthews (eds) U of AZ Press. [3] Schenk, P.M. et al. (2004) In: *Jupiter,* 427-456, F. Bagenal et al. (eds) Cambridge U Press. [4] Moore, J. M. et al. (2001) *Icarus* 151, 93–111. [5] Turtle, E.P. and Pierazzo, E. (2001) *Sci.* 294, 1326–1328. [6] Schenk, P.M. (2002) *Nature* 417, 419–421. [7] Shoemaker, E.M. et al. (1982) In: *Satellites of Jupiter*, 435–520, D. Morrison (ed) U of AZ Press. [8] Schenk, P.M. (1989) *JGR* 94, 3813–3832.

[9] Schenk, P.M. (1991) *JGR* 96, 15635. [10] Schenk, P.M. (1993) *JGR* 98, 7475– 7498. [11] Moore, J.M. et al. (1998) *Icarus* 135, 127–145. [12] Schenk, P.M. and Ridolfi, F.J. (2002) *JGR* 29, 31–1. [13] Senft L.E. and Stewart, S.T. (2011) *Icarus*, 214, 67-81. [14] McGlaun, J.M. et al. (1990) *Int. J. Impact. Eng. 10*, 351-360.

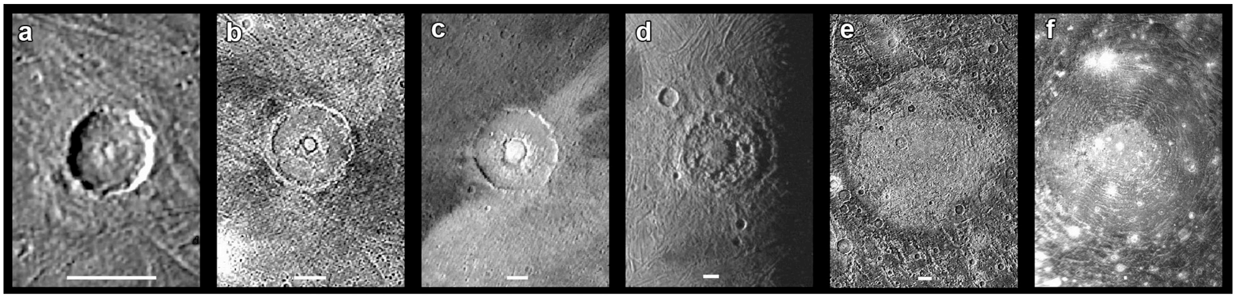

Figure 1. The classification scheme for large impact features on icy Galilean satellites of ever increasing size used in this study. Note scale bars in each frame equals 30 km. They are (**a**) Pit Crater; (**b**) Dome Crater; (**c**) Anomalous Dome Crater; (**d**) Penepalimpsest; (**e**) Palimpsest; and (**f**.) Multi-ring structure.

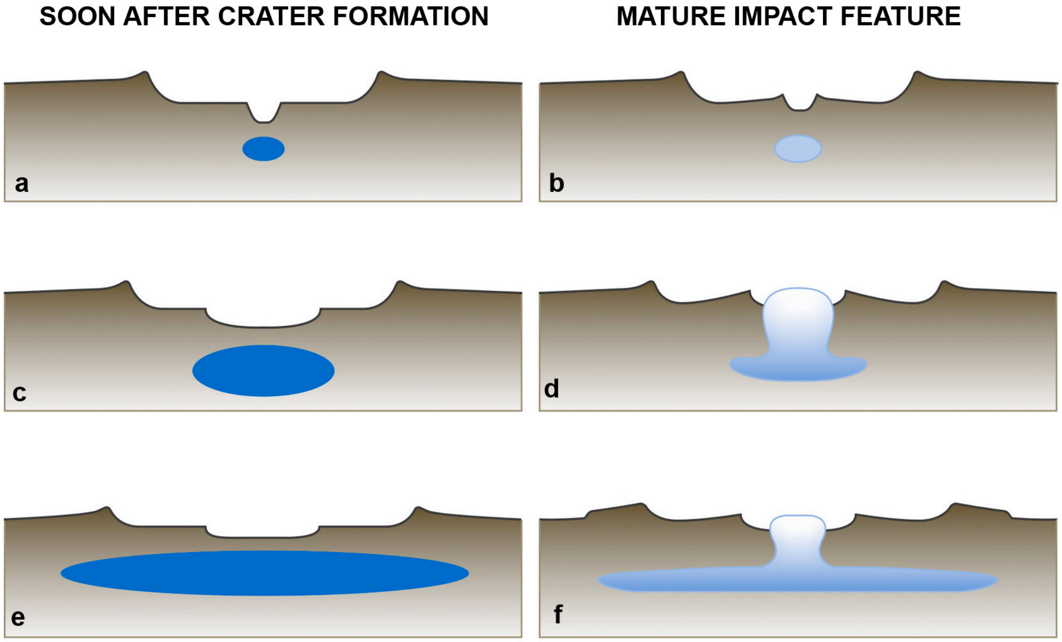

Figure 2. Schematic illustration of one of the hypotheses we are evaluating in this study. The left column represents crater profiles and simplified substructure at early time following the formation of the initial crater. The right column represents the end-member evolution of the impact feature's morphology. Frames **a**-**b**, **c**-**d**, and **e**-**f** represent a pit crater, dome crater, and penepalimpsest respectively. Here we consider the possibility of the role of a promptly formed pool of (water) melt following impact and how that pool might change in size, shape and depth as a function of impactor energy and the state of the substrate at time of impact (dark blue pools in the left column). In this case the central pits of craters form in lieu of a central peak, for example as seen in (**a**). A small subsurface lens of water eventually freezes under the pit, expanding and raising the rim of the pit as seen in (**b**). The domes of central dome craters form along the same lines as hypothesized for central pit craters but the size, volume and location of the melt pool is such that, once solidified, as warm ice it upwells diapirically to form a dome as seen in (**d**) and (**f**). The raised floors and rims of penepalimpsests (**f**) are, in this scenario, the consequence of ever more extensive lenses of H_2O melt that expand upon freezing.