DOME CRATERS ON GANYMEDE AND CALLISTO MAY FORM BY TOPOGRAPHIC RELAXATION OF PIT CRATERS AIDED BY REMNANT IMPACT HEAT. M. Caussi[1], A. J. Dombard[1], D. G. Korycansky[2], O. L. White[3,4], P. M. Schenk[5] , J. M. Moore[4]. [1]Dept. of Earth & Environmental Sciences, Univ. of Illinois at Chicago, Chicago, IL (mcauss2@uic.edu), [2]Dept. of Earth & Planetary Sciences, Univ. of California, Santa Cruz, CA, [3]SETI Institute, Mountain View, CA, [4]NASA Ames Research Center, Mountain View, CA, [5]Lunar and Planetary Institute (USRA), Houston, TX.

Introduction: The icy Galilean satellites host a variety of large impact features that are rare on other bodies in the Solar System, including impact basins with central pits and domes [1]. Large craters on Ganymede and Callisto possess a central pit in place of central peaks seen elsewhere, and at larger crater sizes, these central pits host a dome (Fig. 1). The emergence of central dome craters occurs for crater diameters > 60 km, which is also the approximate diameter above which central pit craters cease to occur [1]. It has been suggested [2,3] that there is a genetic link between pit craters and dome craters. Understanding how these features formed can clarify our picture of outer-planet satellite evolution, and here, we focus on the formation of the central dome.

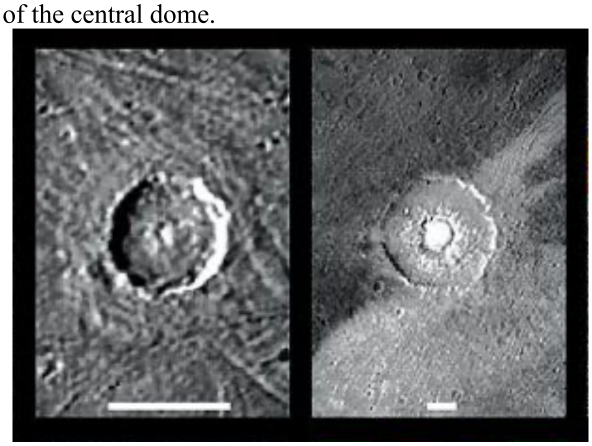

Figure 1. Central pit crater (left). Central dome crater (right). The scale bar in both measures 30 km [4].

Several models for dome origin were developed after Voyager, including refrozen impact melt, post-impact intrusion, and uplift during impact. Following the acquisition of Galileo's higher resolution observations, the melt and intrusion hypotheses began to be disfavored as no indications of flooding or fractures were found [1].

Here, we explore whether central uplift could occur by topographic relaxation of an initial central pit, evolving a central pit crater to a central dome crater over longer, post-impact time scales. The mechanism of topographic relaxation has been used to explain the extreme uplift of some central peak craters on Saturn's moon Dione [5], in which a thermal anomaly in the center of the crater, left over from the impact, can enhance the creeping flow of ice and uplift the center of the crater on which the central peak lies. A similar mechanism might explain central dome craters.

Methods: The viscoelastic relaxation of a 108-km-diameter (Osiris-sized) pit crater on Ganymede is investigated using finite element modeling. These simulations are conducted using the commercially available Marc package, which we have used previously to explore relaxation on these moons [e.g. 5,6]. We simulate the evolution of a pit crater over 100 Myr. First, a thermal simulation that tracks the diffusion of the impact heat is performed, the results of which are then mapped into a mechanical simulation that solves the long-term evolution of the topography.

Crater shape. The initial crater shape (black line in Fig. 2) is that of an unrelaxed pit crater with the same horizontal dimensions as Osiris dome crater on Ganymede. The pit floor is seeded with a very small dome representing a possible initial extrusion, to account for the higher albedos observed in domes. The shape of the main crater depression is a 4^{th} order polynomial, while the crater rim is modeled following an inverse 3^{rd} power law [6], with elevations extrapolated from depth-diameter relations for fresh craters on these worlds [4].

Temperature structure. Because the instantaneous temperature field strongly influences the viscosity and hence the rate of relaxation, a thermal simulation is performed first to determine the subsurface temperature evolution as the remnant heat from the impact diffuses. We start our simulations at the final solidification of any impact melt. The dimensions and magnitudes of the impact-induced thermal anomaly are constrained from impact simulations [7]. The maximum thermal-anomaly temperature is 273 K, located at the center of the crater, very near the surface. A background heat flux is applied to the elements at the base of the mesh, with a value of 3 mW m^{-2}, expected in the present epoch. The sides of the mesh are set to zero heat flux, and the surface temperature is fixed at 120 K. We apply a thermal conductivity of ice that follows an inversely proportional relationship with temperature [e.g. 6], and a specific heat corresponding to 120 K.

Viscoelastic relaxation. A mechanical simulation is next performed using the results from the thermal simulation. For the mechanical simulation, motions on the side and bottom boundaries are restricted to free-slip. A uniform gravity load is applied to all elements

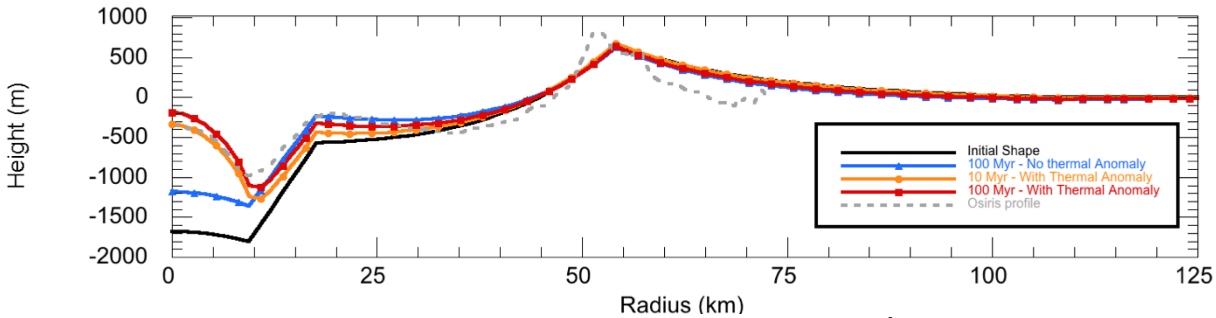

Figure 1. Topographic profiles of a relaxing crater under a heat flux of 3 mW m^{-2}. A dome is formed in 10 Myr when a thermal anomaly is included (orange line); further evolution to 100 Myr is shown in red. The observed topographic profile of Osiris crater as measured from a photoclinometric digital elevation model [9] is shown as a dashed line for comparison. A simulation using no remnant impact heat is shown in blue. The assumed initial crater shape is shown in black.

in the mesh, corresponding to Ganymede's gravitational acceleration of 1.44 m s^{-2}. This term, combined with a mass density corresponding to ice, provides the gravitational force that generates the stresses driving relaxation. For this rheology, we use linear, isotropic elasticity with a Young's modulus of 9.33 GPa and a nominal Poisson's ratio of 0.33. Because of the long time scales, viscous flow is considered to be solely due to steady state creep [8], assuming a grain size of 1 mm.

Parameter space. Simulations with different initial shape and diameter were conducted using the same basic methodology. Different thermal anomaly sizes and higher heat fluxes were also explored.

Results and Discussion: Crater topography constitutes a perturbation in the near-surface, deviatoric-stress state of the area. To relax the induced stresses and restore a flat surface, ice flows downward from the rim and upward from the crater depression and the pit over long timescales. Because viscosity decreases with increasing temperature, relaxation is enhanced if ice is warm [cf. 6]. Hence, both the heat left over from the impact and the background heat flux aid relaxation.

When a thermal anomaly is applied, the simulation results show that a central dome is formed in 10 to 100 Myr (Fig. 2). The thermal anomaly softens the ice below the pit, enhancing its upward flow as compared to the rest of the crater depression. The resulting topographic profiles resemble that of Osiris (dashed gray line in Fig. 2), a young dome crater on Ganymede. This rapidity suggests that even young dome craters may be relaxed pit craters.

Contrastingly, when no thermal anomaly from the impact is applied (blue line in Fig. 2), there is an overall uplift of the crater depression, but a dome does not form, indicating that there is no preferential uplift of the material below the pit. The profile of the relatively small scale pit changes little and is essentially shifted upwards by the overall relaxation of the basin.

The background heat flux acts to soften the ice that surrounds the thermal anomaly. The material in the vicinity of the anomaly accommodates the enhanced uplift of the pit floor. If the ice surrounding the thermal anomaly is stiff, such as when temperatures increase slowly with depth under lower heat flow conditions, the impact-heated ice will uplift less than when background heat flux is higher. Thus, the morphology of dome craters might be an indicator of background heat flow at the time of impact. For craters the size of Osiris, a modern heat flow of 3 mW m^{-2} is sufficient.

A crater diameter of 100 km on Ganymede with a flat pit floor yields similar results [10]. The same is observed for an 80-km crater on Callisto. This suggests that the outcome is independent of changes in initial shape and size, as long as the crater stays in the size-range observed for domes.

Conclusions: We find that dome craters on Ganymede and Callisto could form by relaxation of pit craters, aided by remnant impact heat. Given the long timescales involved and the dependence on heat flux, this model for dome formation could be used to constrain the moons' thermal histories, as well as crater ages.

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