TIME-DEPENDENT FLEXURE ON THE ICY SATELLITES OF JUPITER AND SATURN. A. L. Damptz and A. J. Dombard, Dept. of Earth and Environmental Sciences, University of Illinois at Chicago, 845 W. Taylor St., Chicago, IL 60607 (adampt2@uic.edu).

Introduction: Loads on the surfaces of the icy satellites of Jupiter and Saturn can cause flexure of the lithosphere, and observation of such flexure generally indicates an anomalous, elevated thermal state. Several groups have modeled this flexure to obtain the thickness of the lithosphere and investigate the thermal state of the body at the time the loads were emplaced. The use of simple models of the lithosphere has been exercised [1-5]. The problem with using such simple models is that they are equilibrium solutions, and there is the possibility that viscous creep within the lithosphere can cause evolution over time. In this work, we explore the "static" assumption, using a finite element model employing a time-dependent elastic-viscous-plastic rheology to investigate flexure on icy satellites. We propose a time dependency to the flexure problem on the icy satellites that thus far has been treated as static.

Methods: We use the commercially available MSC.Marc finite element package, which has been well vetted in the study of the lithospheres of icy satellites [6-8]. The code employs a composite rheology that captures the general behavior of geologic materials: elastic on short time scales and viscous on long time scales, with brittle failure (continuum plasticity) for high enough stresses. We use rheological parameters that have been measured in the laboratory [9-11]. We adopt a plane-strain, intact-plate formulation; however because our observed behavior is controlled by rheology and not geometry, our conclusions would be the same under other formulations (such as cylindrical, broken-plate, etc.). We apply a load along the central axis equivalent to a thin ridge 1 km tall. Thermal state is characterized by the surface temperature and an applied basal heat flux; thermal conductivity is inversely proportional to temperature [12]. We routinely test to ensure that our results are not affected by modeling assumptions such as distances to far boundaries or mesh resolution. We use a mass density of 950 kg m^{-3}, a value appropriate to icy lithospheres.

Results: A sample of our results is shown in Figure 1, using gravity appropriate to Ganymede (1.42 m s^{-2}). The surface temperature is varied from 70-130 K, which is the expected range on the icy satellites of Jupiter and Saturn. The applied heat flow is 100 mW m^{-2}, an approximate value expected for thermal excursions that result in flexure [1, 5, 13]. Simulations with heat flows of ~30 and ~300 mW m^{-2} are also being investigated. The dominating viscous creep mechanism in planetary ice is grain-size sensitive [10]; we consider a range of 0.1-10 mm [7] and show results for 1 mm in Figure 1. In their work on flexure at double ridges on Europa, Hurford et al. [3] measured the lateral distance to a flexural bulge (x_b) and converted this distance to an equivalent thickness of an elastic lithosphere (h). We adopt the same procedure here; we measure x_b directly from our simulations and note how the bulge migrates inward with time. In the top panel of Figure 1, we show the evolution of the position of the flexural bulge from our simulations. For a surface temperature of 70 K, the bulge is ~67 km out at short times scales (10 kyr) but migrates inward to ~52 km at 100 Myr (an ~22% change). For 100 K, the migration is from ~41 km to ~18 km (~56%). For 130 K, the bulge migrates in by ~81% (~23.5 km to ~4.5 km). In the bottom panel of the figure, we show the inferred thickness of the elastic lithosphere. For 70 K, the elastic lithosphere thins by ~29%, while for 100 K, the elastic lithosphere thins by ~67%. For 130 K, the lithosphere thins by about an order of magnitude (~89%).

Varying the grain size has minimal effect. For 70 K, the thinning of the elastic lithosphere is ~29% for 0.1 mm and ~30% for 10 mm. Similarly for 130 K, it thins by ~94% for 0.1 mm and ~84% for 10 mm. We are also running simulations varying the heat flow in either direction by a half order of magnitude. The simulations are not complete; however, preliminary results show similar trends. For a heat flow of ~316 mW m^{-2} and a surface temperature of 70 K, the inferred elastic lithosphere thins by ~44% (cf. ~22% for 100 mW m^{-2}).

Discussion and Conclusions: The assumption of a static lithosphere may not be robust for the icy worlds of Jupiter and Saturn. The reason is that viscous creep rates are not necessary negligible in the lithospheres. Because of the composite rheology, viscous creep operates within the lithosphere at rates that decrease as the surface is approached. Thus, stresses relax near the base of the lithosphere, allowing it to thin. Factors that affect this time-dependent response are those that control creep rate: surface temperature, heat flow, and grain size. Of these, it appears that surface temperature has the strongest effect. For sufficiently low surface temperatures (< 70 K), creep in the upper portions of the lithosphere maybe so slow that the static assumption may be valid. Consequently, this effect may only be observed on the icy satellites of Jupiter and Saturn.

The heat flows at which these lithospheres appear to flex (of order 100-1000 mW m^{-2} [1, 5, 13]) is significantly higher than the quasi-steady state heat flows that are expected for the satellites. These heat flows thus indicate a thermal event that allowed the lithospheres to flex. Our results indicate that the duration of this thermal event is an important factor that needs to be considered. For instance, Hurford et al. found elastic lithospheres generally ~100-300 m thick for flexure at double ridges on Europa. It is entirely possible that instead of sampling different thermal environments, the variation seen in the flexure of the lithosphere may be largely due to variation in the time scale over which the heat flow was elevated [3]. Hurford et al. speculated that this variation may be due to the relaxation of the lithosphere; however, this speculation was premised on long-term relaxation since the loads' emplacement and not specifically the time scale over which the heat pulse was extant. Furthermore, our results, derived for Ganymede, are not strictly applicable to other satellites because of the different strengths of the surface gravity; however, gravity has a very small controlling effect of the flexural response. Thus, any variation in lithospheric thickness inferred from other flexural models [1-2, 4-5] could also be due to this time dependency.

Our results indicate that for the icy worlds of Jupiter and Saturn, static models of lithospheric flexure should be used with caution. The near surface may not be able to be segregated into elastic (or elastic-plastic) lithospheres and viscous substrates, because viscous creep in the lithosphere is non negligible. Because a pulse of high heat flow is likely required, our results suggest that the duration of this heat pulse is an important factor in the study of the flexure of these icy lithospheres.

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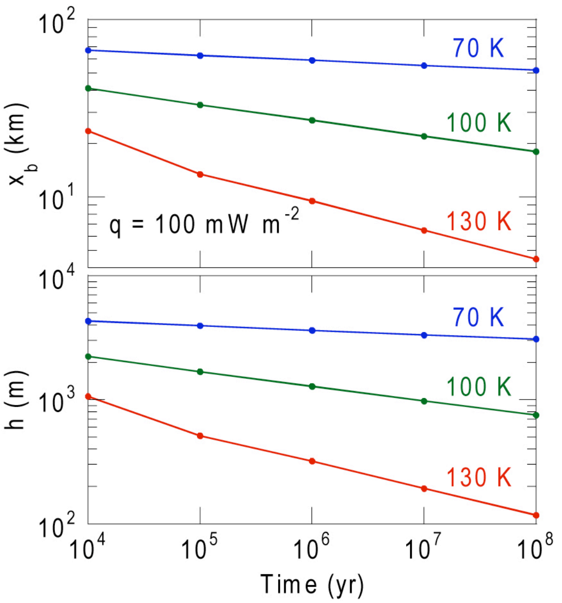

Figure 1. This figure shows the inward migration of the flexural bulge (top panel) and the thinning of the inferred elastic lithospheric (bottom panel) thickness as a function of time, for three different surface temperatures (labeled with colors). For this suite of simulations, we assume an applied heat flow of 100 mW m^{-2}, a grain size of 1 mm, and surface gravity of 1.42 m s^{-2}.