**Mechanical failure of the icy moons: Modeling planetary ice with discrete ice sheet fracture models.** C. C. Walker[1] and J. N. Bassis[1], [1] Department of Atmospheric Oceanic and Space Sciences, University of Michigan, 2455 Hayward St., Ann Arbor, Michigan, 48109, U.S.A. Email: catcolwa@umich.edu

**Introduction:** At the South Pole of Enceladus, a small icy moon orbiting Saturn, is a heavily fractured ice plain surrounded by a nearly-circular mountain range. Remarkably, the Cassini orbiter detected jets of water emanating from the icy shell and into space, originating from 4 parallel "tiger stripe" rifts within the center of the ice plain, e.g. [1]. Similarly, Europa, an icy moon of Jupiter, is likely to have a relatively thin ice layer overlying a water ocean. Europa also exhibits widespread fracture systems, e.g. [2]. The rifts and cracks imaged on the moons are morphologically similar to rifts observed to form under extensional stress regimes in terrestrial ice shelves; the putative subsurface ocean hypothesized beneath the icy shells strengthens the analogy that their formation may have similar mechanical origins. We assume an ice-over-water analogy applies to the moons and attempt to investigate the fracturing of the moons' ice surfaces through the lens of a terrestrial ice shelf fracture model [3].

Especially in the case of Enceladus, in an attempt to understand the formation of these tiger stripes and their relationship to the observed mountain chains, we apply a conceptual model in which the ice is considered to be less like a continuous fluid body and, instead, behaves like a granular material made up of discrete blocks of ice. The tidal forces on the small moon tug on the shell enough that it has been cracked many times over, motivating the assumption that the ice exists in a continuum between wholly intact ice and highly pre-fractured ice. We employ several experimental setups with the intention of mapping the deformation of the south polar segment of the shell, to determine the processes that may contribute to its observed morphological state. These setups range from large scale topographical models, e.g., simulating the build up of mountains [4] and processes that lead to overall elevation differences in the region, to small-scale, and focus on the more detailed level of fracturing. We explore our ice-shelf rifting analogy by modeling both icy moon fracturing and ice shelf rifting to compare and contrast the failure modes that we observe, results that bolster both our comparative platform and, importantly, our understanding of fracture in ice shelves on the Earth as well.

A similar approach is applied to the chaos regions of Europa, where fractures are prevalent and whose underlying causes are not well understood. It is likely that our discrete model of ice fracture can accommodate the formation of thinned pockets, allowing for upwelling of subsurface water that may permeate the near-surface ice (e.g., [5]).

**Model Description:** We employ a conceptual model of ice that was created to simulate fractures in ice in the terrestrial context. The model has been calibrated to Earth's ice, and correlates well with lab measurements of the yield strength of ice. Parameters within the model allow for settings as to whether one would like to model in a continuous fashion or discretely. Spheres of ice within the model interact through elasticity, friction, and bond forces, which can be set accordingly (e.g., [6]).

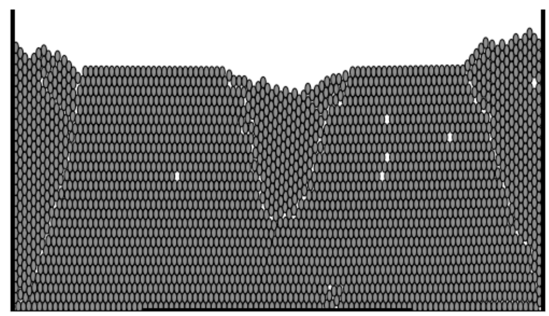

**Figure 1.** Example model run shows uplift at sides of Enceladus' Sout Polar Terrain.

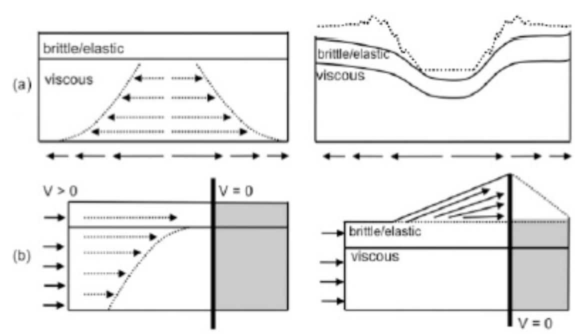


**Figure 2.** Two models. (a) vertical shear causes topography and uplift at sides; (b) flow into a zero-velocity "wall" causes build-up of material.

**References:**
[1] Porco, C. C., et al., Cassini Observes the Active South Pole of Enceladus, Science, 311, 1393-1401, doi:10.1126/science.1123013, 2006.

[2] Kattenhorn, S. A., Nonsynchronous Rotation Evidence and Fracture History in the Bright Plains Region, Europa, Icarus, 157, 490-506, doi:10.1006/icar.2002.6825, 2002.
[3] Walker, C. C. and Bassis, J. N., Simulations of mechanical failure in ice: Implications of terrestrial fracture models as applied to they icy satellites of the outer solar system, AGU Fall Meeting, abstract #C11A-0663, San Francisco, CA, December 2011.
[4] F. A. Dahlen, J. Suppe, and D. Davis. Mechanics of fold-and-thrust belts and accretionary wedges Cohesive Coulomb theory. J Geophys Res, 89:10087–10101, November 1984.
[5] Schmidt, B. E., et al., Active formation of `chaos terrain' over shallow subsurface water on Europa, Nature, 479, 502-505, doi: 10.1038/nature10608, December 2011.
[6] Bassis, J. N., and Walker, C. C., Upper and lower limits on the stability of calving glaciers from the yield strength envelope of ice, Proceedings of the Royal Society, rspa.2011.0422v1-rspa20110422, published online November 2011.