CONVECTION-INDUCED MICROSTRUCTURE AND TIDAL DISSIPATION IN POLYCRYSTALLINE ICE; AN EXPERIMENTAL APPROACH T. E. Caswell¹ and R.F. Cooper¹, ¹Brown University, Providence, RI, USA (tess_caswell@brown.edu).

Introduction: Many outer planet satellites, such as Europa, Ganymede, and Enceladus, possess thick, icy crusts over oceans of liquid water. Maintaining an ocean over geologic time may require internal heating of an ice shell by tidal dissipation (or “attenuation” in the materials science and geophysical literature), which transforms tidal strain energy into heat within the ice shell. This process does not occur alone; the interiors of many of these moons are suspected to undergo convection, which imposes a persistent, long-term stress upon the ice shell and is manifest as a deformation texture. Creep and attenuation are interrelated, so developing an extrapolatable understanding of tidal dissipation requires knowledge of how short term tidal stresses interact with deformation microstructure that is imposed and sustained over convective timescales.

The physics of dissipation at tidal frequencies (the “high temperature background”) are dominated by stress-induced chemical diffusion, which has a distinct length-scale dependence that is frequently cited as the grain size. The experiments of McCarthy & Cooper (2016), however, which measured dissipation in polycrystalline ice that was simultaneously creeping at steady state, showed distinctly grain size-insensitive dissipation over three orders of magnitude in grain size [1]. These data can instead be normalized by the steady-state creep stress, suggesting that stress-effected microstructure dominates the length scale of diffusion. Unfortunately, microstructural observations were not available to link the McCarthy & Cooper attenuation data to microstructure.

More recently, the experiments of Caswell et al. (2015) discerned that for polycrystalline ice deforming via grain boundary sliding [2] (thought to be dominant within a convecting ice shell [3]), stress-sensitive microstructure is independent of grain and subgrain size [4]. This result suggests that the evolution of grain boundary structure with stress may form the basis of the creep-stress-sensitive dissipation observed by McCarthy & Cooper. It remains to be seen whether dissipation experiments conducted under the same conditions of the McCarthy & Cooper experiments display microstructures consistent with this hypothesis.

The McCarthy & Cooper data provided two other notable results. First, the ice data were an order of magnitude more attenuating than predicted by (a) the Andrade model, or (b) any defensible Maxwell model approximation – even when normalized by creep stress. Second, the observed dissipation was nonlinear in stress – suggesting that a mechanism other than diffusion was at work. These observations may be explained by glide of basal dislocations, which is a serial kinetic process in grain boundary sliding [2] and anticipated to occur at tidal strains (approaching 10⁻³). Tidal dissipation, however, is generally modeled as a linear process (i.e., the Maxwell model) – thus, whether dissipation in ice becomes linear at lower stresses (more closely approximating convection and tides within an ice shell) is a critical question addressed by our ongoing work.

We addresses three of the primary questions raised by the McCarthy & Cooper (2016) data: Is dissipation in creeping polycrystalline ice indeed grain size-independent? Are the microstructures in these experiments consistent with a response effected by stress-dependent grain boundary structure? Can a linear dissipation response be induced by lowering the stresses imposed on the ice?

Experiments: Our experimental approach combines creep/attenuation experiments with cryogenic microscopy.

Creep/attenuation experiments are conducted in a servomechanical apparatus modified by the addition of a low-temperature cryostat and high-resolution displacement measurement system.

Samples of polycrystalline ice (d=25–200 μm) are creep to steady-state in the grain boundary sliding regime (T = 200–240 K, σ_c = 0.5–1.0 MPa). Once at steady-state, simulated tidal stresses (σ_i = 0.05–0.10 MPa) are overlain on the creep stress. The total stress applied to the ice is thus σ_t = σ_c + σ_i sin(ωt) for 3–5 cycles of σ_i, depending on frequency. The magnitude of σ_t is designed to explore a range of conditions between tidal stresses imposed on, e.g., Europa, and lower stresses that may induce a linear response. Dissipation (or attenuation, Q⁻¹) is then directly obtained from the phase lag, δ, between the peak stress and resulting peak strain in the sample: Q⁻¹ = tan(δ).

Following deformation, samples are analyzed via cryogenic microscopy to evaluate the microstructures associated with each type of experiment.

Preliminary results of this study will be presented.