ICE RHEOLOGY IN THE PLANETARY CONTEXT

W. B. Durham (1), S. McDaniel (2), L. A. Stern (3), S. H. Kirby (3)

(1) Lawrence Livermore National Laboratory, Livermore, CA 94550, (2) Dept. of Earth and Space Science, Univ. of Washington, Seattle, WA (3) U.S. Geological Survey, Menlo Park, CA

The rheological properties of water are a basis for modeling dynamic processes on and within low-density planetary satellites and on the surfaces of Earth and Mars. The model changes quickly, however, if one includes natural complexities that affect the texture and composition of the ice. The study of the effects of these complexities on the rheology of ice and icy compounds is not far advanced, but there already have been a number of interesting findings. Among these are (1) the presence of NH3 in water ice significantly weakens the ice and increases the possibility of a melt phase being present; (2) dispersed hard particulates strengthen ice slightly in most cases, but significant strengthening requires very high particulate concentrations; and (3) in multi-phase mixtures, minor concentrations of a weak phase can have a disproportionate softening effect on the aggregate. In this talk we focus on two additional behaviors with important planetary applications: the very high strength of gas hydrates and sulfate hydrates, and the role of grain size in the creep of ice I.

Hydrated sulfate salts and gas hydrates, candidate planetary building materials, are orders of magnitude more viscous than water ice. Methane hydrate is sufficiently strong and potentially present in sufficient volume to radically alter icy models of certain moons (Titan). CO2 hydrate, weaker than methane hydrate but still much stronger than water ice, may be stable in the interior of the Mars south polar cap. Hydrated sulfate salts in turn are much stronger than even methane hydrate, and where they exist in the Europan crust, must be considered essentially undeformable.

Laboratory experiments have clearly shown that at finer grain sizes the rheology of ice is strongly dependent on grain size (referred to as grain-size-sensitive (GSS) creep) and that at larger grain sizes, the deformation mechanism is predominantly grain size insensitive dislocation creep. The two regimes have contrasting flow laws, especially in their stress dependence, and the effect on model predictions can amount to orders
of magnitude in viscosity. Grain growth in ice, on the other hand, is inhibited by dislocation creep but apparently proceeds freely in GSS creep. If so, we might expect to reach a state on the geologic time scale where deformation in a formation or ice cap is distributed in time and/or space between GSS and dislocation creep. Parameter values as currently understood cannot unambiguously delineate the creep regime of terrestrial ice sheets or the Europan ice shell.