CRYOGENIC PROPERTY MEASUREMENTS ON ICY COMPOSITIONS WITH APPLICATION TO SOLAR SYSTEM ICES.

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Introduction: To fully appreciate the discoveries made by the *Cassini-Huygens* and *Galileo* missions, to prepare for the *Dawn* and *New Horizon* missions, and to look forward to potential missions to Europa, Enceladus, and Titan, we present the motivations, objectives, and preliminary experimental results for a new experimental cryo-ices initiative launched at JPL. This work is a joint effort among experimentalists and theorists at JPL, in collaboration with specialists in icy material properties the world over.

Science Motivation: In response to observations and theoretical modeling need for realistic input we are developing an experimental initiative aimed at understanding the link between ice composition (including structure) and icy satellite observations.

Icy satellite internal evolution. Internal evolution models depend upon accurate characterization of the elastic moduli, deformation pathways and mechanisms, and solid-state rheology of the component materials. Ice rigidity and viscosity play a role in the modeling of convection, differentiation, , ice behavior at premelting conditions, cryovolcanism, and other geological activity. Spacecraft observations of planetary surfaces, which can provide use with more information on the history of the satellites, regard geological features such as lithospheric response to loading, crater relaxation, folding/faulting as a function of strain rate. The role of ice properties in many of these processes is addressed by [1]. Also these properties play a major role in the tidal response of the bodies, and associated tidal dissipation. For the icy moons of the outer satellites, cosmochemical arguments suggest that these materials will be dominated by water, with variable amounts of materials plausibly including ammonia [2], methane clathrate hydrates [3], salts [4], and other materials.

Enceladus' resurfacing processes. A major discovery of the Cassini-Huygens mission is the observation of a hot region surrounding Enceladus' South pole, associated with a surface likely less than 1 My old, faults (the "tiger stripes"), and intense plume-generating activity [5, 6]. Plausibly cryovolcanic landforms have been identified on Titan [7-9], which may be ammonia hydrate slurries and which are associated with methane, and possibly containing organics. Cryovolcanic activity has been suggested to be responsible for resurfacing and/or landform construction on the surfaces of Ganymede, Miranda, Ariel, Triton, and others, driven by radiogenic heating and/or tidal heating [10]. However, our understanding of mechanisms behind these processes is limited; in particular, how ice responds mechanically to tidal stresses, and the behaviour of eruptive materials during flow, are poorly constrained.

Titan's complex environment. Titan's atmospheric and crustal volatile chemistry produce a complex assemblage of materials, in some cases beyond those of other icy bodies, that may be mobilized surficially and in the upper crust [11], and could exhibit a wide range of behaviours. These may play an important role in limnologic (lake) [12], fluvial, sedimentary, aeolian [13], glacial and periglacial processes [11, 14]. Despite some successful characterization of Titan's surface and atmospheric materials by Cassini VIMS spectral analysis [15], it is unclear whether Cassini will be able to determine much of the range of important surface materials through Titan's obfuscating atmosphere Therefore, in order to understand the materials involved in the various processes on the surface of Titan, we need to use a less-direct approach.

We use combinations of observation, theory and experiment to relate primarily morphological observations of surface features to the processes and materials that could have formed them. On Titan, such materials most likely include liquid methane and/or ethane, cryovolcanic ammonia hydrate slurries (possibly containing organics), and a variety of carbonaceous compounds, organics, tholins, salts and hydrates.

In the above cases, our ability to relate landforms and other observations to the processes that formed them is sorely limited by physical models that contain incomplete databases of the physical properties of the candidate materials. These properties include the rheological behaviour of candidate cryovolcanic slurries, the loss tangent of liquid methane/ethane, rates of dissolution and wetting angles of liquid methane and ethane on candidate surface materials, and the mechanical properties and mobility of surface solids (water-ice, ammonia hydrates, acetylene, etc.).

Experimental Approach: A range of experiments are being devised which will improve our ability to model ice-rock body internal evolution and geological processes using modern synthesis and characterization techniques under cryogenic conditions. Initial experiments will involve pure water (H_2O), methanol-water (CH_3OH-H_2O), ammonia-water (NH_3-H_2O) and ammonia-water-methanol mixtures, relevant to a range of icy satellites and processes. Ammonia is considered to be play and important role in Titan cryovolcanism, whereas methanol is chosen primarily due to its suitability as an experimental analog as well as its each-of-use in the laboratory, although it has been considered previously as a potential cryovolcanic material in the outer solar system (e.g. [16]). Where beneficial, we will determine basic thermophysical properties and phase diagrams using a Differential Scanning Calorimeter.

Solids. First, we plan to analyze samples from terrestrial glaciers, which are relevant to both the terrestrial and planetary geology and geophysical communities. Terrestrial glaciers appear as realistic analogs for modeling processes taking place in icy satellite outer icy shells [17-19]. These results will better enable us to predict the long-term evolution of terrestrial glaciers and ice shelves.

Also, we will develop specimen with controlled properties. The synthesis methods for icy specimens will exploit equilibrium and non-equilibrium methods. Equilibrium methods, e.g., conventional (slow) freezing in a mold, will provide microstructural length scales, *d*, in the range ~200 µm to 10 mm (with and without preferred orientation, e.g., columnar grains). Non-equilibrium methods, e.g., rapid-quenching, will vitrify the specimens, and we will control the specimen microstructure (e.g., grain size) via low temperature annealing.

Post-synthesis microstructural characterization will be performed using Cryogenic Optical Microscopy integrating a cross-polarizer to analyse thin sections, and a Cryogenic Scanning Electron Microscope.

Mechanical property measurements on solid specimens will be performed between 80 and 270 K with a cryogenically cooled Instron measurement system. Compression measurements will be conducted as a function of temperature, strain-rate, microstructural length scale and orientation. The time dependent viscous response will also be measured by performing creep (applied load versus time) measurements over the same range of temperatures. Using low-frequency cyclic loading, we will measure the dissipation factor at frequencies approaching satellite orbital frequencies. We will report preliminary mechanical property measurements of Antarctic glacial specimens at cryogenic temperatures. These measurements will be of great importance to support the preparation of flagship missions to Enceladus, Titan, Europa, and the Jupiter System currently under study.

Fluids. In order to improve our understanding of effusive cryovolcanism, we will measure rheological properties of liquid and mixed (slurry) materials between 80 and 300 K using a cryogenically cooled *Brookfield* rotational rheometer, based on the experimental procedures of Kargel *et al.* [16], but over a much wider range of parameters and with a greater degree of automation. Control and data acquisition will be carried out using a *LabView* custom interface. The results will be integrated into parallel modeling efforts that include the slurry rheology modeling discussed above.

We will report preliminary measurements of the temperature dependence of the viscous response for several compositions in the Methanol-Water System $(CH_3OH)_x(H_2O)_{1-x}$. Also, we will describe an experiment designed to measure methane wetting and dissolution on water ice. These experiments will be carried out in order to explore the effects of the presence of methane lakes on Titan's surface.

We are developing the capability to investigate more complex materials relevant to surface processes on Titan, including methane-ethane phase studies, hydrocarbons such as acetylene and benzene, as well as tholins and clathrates, which should exhibit a range of rheological and mechanical properties from fast-moving fluids to glacial creep.

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