OVERVIEW OF THERMAL AND RHEOLOGICAL PROPERTIES OF ICES ON PLUTO AND OTHER BODIES OF THE OUTER SOLAR SYSTEM. C. Ahrens[1], O. M. Umurhan[2,3], and V. Chevrier[1], [1]University of Arkansas (ca006@email.uark.edu, vchevrie@uark.edu), [2]SETI Institute, Mountain View, CA orkan.m.umurhan@nasa.gov, [3]NASA Ames Research Center, Moffett Field, CA,

Introduction: Pluto's surface is an active low temperature physics laboratory [1]. From the solid-state convection-induced pit featuring ovoid patterns of Sputnik Planitia (SP), the glacial flow onto SP from the surrounding highlands of Eastern Tombaugh Regio, the ubiquitous glacially eroded terrain, the high-standing bladed terrain constructs of Tartarus Dorsa, the washboard terrain in surrounding Voyager and Pioneer Terra, the scarps of Piri Planitia, the putative cryovolcanic constructs of Wright and Picard Mons, and the apparent flow-emplaced tholin-covered surfaces around Virgil and Inanna Fossae, Pluto's surface exhibits geology shaped by volatile materials in all phases [2]. Understanding the geophysics of these features and crafting an evolutionary history of these places hinges on knowing the thermophysical and rheological properties of the materials in question. This presentation is an outline of the review manuscript in preparation intended as a compilation of what is known about these volatile ice material properties in the temperature range 20-91K. We will also discuss the methods by which these quantities are measured in laboratory experiments.

The cast and roles: The main volatile ices found on Pluto as observed by New Horizons were N_2, CH_4, CO, and these were found alongside relatively stable and dark H_2O ice. The low albedos are likely due to the spectroscopically identified presence of organic "tholin" compounds painted upon surface H_2O. The current surface temperature conditions are around 40K, but owing to their highly insulating nature, the volatile ices can reach temperatures can reach temperatures as high as 60K underneath as little as 500-750m of cover. Interestingly, these surface volatiles are not very far from their triple points which is probably why Pluto's surface geomorphology shows rich variety. Given the ubiquity of these materials on the icy bodies of the outer solar system --e.g., like Titan, Triton as well as the Kuiper Belt objects like Eris and Makemake -- it will be of utility to compile the known thermophysical and rheological properties of these volatiles in the temperature range 20-91K. By way of example below, we *present a limited selection* of various landforms found on Pluto in relation to their attendant processes and we highlight the required physical inputs necessary to explain and predict what is happening in them.

Solid state convection and Sputnik Planitia. Spectroscopy of SP's shows significant abundance of all three volatiles N_2, CH_4, CO and the leading interpretation of the observed ovoid patterning is that SP is filled with predominantly N_2 ice undergoing solid state convection (Figure 1A) [3]. Modeling infinite Prandtl number convection requires understanding (i) the rheology of the convecting material (i.e., how the ice deforms when stressed), (ii) the temperature dependence of solid density (its equation of state) and (iii) coefficient of thermal expansion, (iv) the thermal conductivity. Moreover, knowledge of these quantities is needed for these materials as binary and ternary alloys. SP probably sits upon a H_2O ice bedrock that likely passively conducts geothermal energy into the volatile ice layer above.

Glacial flow and glaciated terrain. In addition to rheology, understanding the observed glacial flow of volatile ices (Figure 1B) requires reliable knowledge of the flowing material's phase transitions and their associated energies [4,5]. For example, owing to their strong insulation, thick layers of N_2 ice might flow as a wet-glacier requiring reliable data about liquid N_2 like its density and, furthermore, how effective tracers diffuse through the liquid. Also, N_2 ice glaciers likely flow over and erode a H_2O ice bedrock. As such, it is essential to have information on the compressive and brittle fracture strength, Young's modulus in order to assess rates of erosion and other related surface modification processes.

Bladed terrain and pitting on SP. Tartarus Dorsa's high standing bladed terrain structures are believed to be CH_4 instances of penitentes found in dry terrestrial climes like the Atacama Desert (Figure 1C) [6]. The development of penitentes involves a subtle atmosphere-surface exchange processes requiring detailed knowledge of vapor pressure curves and latent energies [7,8]. Supporting such structures requires reliable information on grain-size dependent rheology of CH_4, and (perhaps) H_2O-CH_4 clathrates. Suncups, which are muted versions of penitentes, are thought to describe the widespread pitting seen on convection cells in SP. These pits involve the complex interplay of insolation, temperature, reradiation rheology and sublimation [9].

Wright/Picard Mons, Virgil Fossae and cryovolcanism. Wright Mons (Figure 1D) and Picard Mons are considered putative cryovolcanic structures [10] while the darkened ammonia laden lanes found inside various fossae like Virgil Fossae are suggested to be emplaced by some kind of cryovolcanic flow [11]. H_2O cryovolcanism has been proposed as the responsible mechanism in these places. To test these hypothesis through modeling, information about the viscosity of H_2O ice slurries, with and without thickening agents like NH_3 and CH_3OH (methanol).

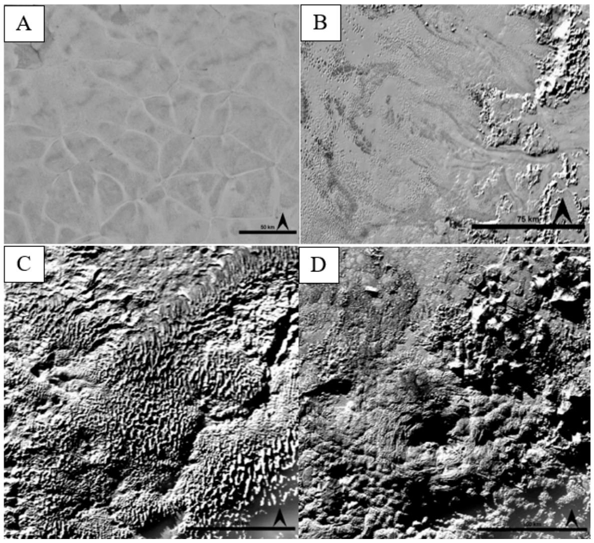

Figure 1: A) N_2 convective flowing on SP (scale bar 75 km); B) Glacier on western shores of SP (scale bar 50 km); C) Tartarus Dorsa bladed terrain (scale bar 100 km); D) Wright Mons (scale bar 100 km). Arrow points north.

Quantities of interest: The review manuscript will contain a comprehensive compilation of the aforementioned quantities references in the 20-90K range in the form of tables and graphs. This discussion will include literature references to all pertinent published laboratory and theoretical results. Our attention will be restricted to pressures not to exceed 1 MPa. Each section will contain a terse primer discussing how various quantities are used in modeling associated physical processes, e.g., a discussion on solid-state convection will review the definition of the Rayleigh number, how it is understood and what basic inferences can be drawn from it. For H_2O and each of main the volatiles of interest -- and (wherever this information is available) their alloy mixtures -- we will compile all published information about:

Thermophysical data: including the temperature dependence of (i) coefficients of thermal expansion, (ii) specific heats, (iii) latent energies, (iv) liquid and solid densities and (v) coefficient of thermal conduction. These will include the phase transitions

Vapor Pressure data: Tables and formulae describing vapor pressures.

Rheological data: The ice viscosity dependencies including activation energies, grain size dependence, a discussion on the preferred mode of deformation (e.g., whether by creep, grain-boundary sliding, etc.) We will include known laboratory measurements on water ice slurries.

Material properties: The temperature dependencies of (i) Young's modulus, (ii) compressive strength, (iii) brittle fracture strength.

Transport properties: The ability of trace species to diffuse through solid and liquid phases of each material. Diffusion coefficients will be tabulated for several species.

Mitigating matters and open questions: The many outstanding challenges in obtaining these quantities will be discussed. For example, there are challenges to experimental work, mainly the control of the ice sample production, accidental sticking of the ice sample with instruments, contamination of sample, and technical support for measurements and instrumentation [12]. A tentative list of challenges and questions, which will be elaborated at length in the final manuscript, include:

- Understanding rheological properties of Pluto's surface can help us answer how the observed geomorphology took root,
- What is the composition and structure of subsurface material? How does this effect what is seen on the surface?
- What is the structure of surface material (especially in pure vs complex mixtures)? Can we understand the observed appearances based on published data or are further experiments warranted?
- What are the power sources and processes driving geologic evolution?
- What is the extent and quality of cryovolcanism on places like Pluto?
- What is the diffusion coefficients of materials in liquid/slushy states in relation to volatile transport? Can this be used to explain the observed surface coloration?
- What are the effects of organic/tholin particles (as a bulk or intimate ice mixture)?

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