Ground Ice on Terrestrial Worlds: The importance of laboratory data

Hanna Sizemore Planetary Science Institute

Since the mid-1960s, thermophysical and molecular diffusion models have been powerful tools for predicting where buried water ice can be found in the inner solar system. These models predicted the wide-spread occurrence of shallow ice on Mars, as well as regional and local variations in burial dept. They predicted the presence of a global shallow ice table on Ceres and other main belt asteroids. They have also been applied to glacial ice in the Antarctic Dry Valleys and to problems in cometary outgassing. Broadly, spacecraft observations have supported the thermophysical modeling approach that has become standard. However, in every location, there are observational details that are difficult to reconcile with existing models and the limited body of empirical constraints on regolith and ice properties. A general theme of these small inconsistencies is that spacecraft have observed somewhat more ice than expected on multiple bodies over the past 20 years, while at the same time, a small set of laboratory studies have indicated that silicate regoliths are less able to protect ice than had been previously assumed. Ground ice is wider spread (Mars, Ceres), shallower (Mars, Ceres, Antarctica), more concentrated (Mars), and older (Antarctica) than models readily predict. The responsible processes are likely unique to each of these planetary environments; however, a lack of key material properties data is a common theme. We will describe specific areas of friction between models and observations on multiple terrestrial bodies. We will then discuss how laboratory investigations targeted to planetary environments and materials can complement future spacecraft investigations and improve our theoretical understanding of the history and accessibility of water ice in the inner solar system.

A sublimation-based framework for generating protrusion of marker beds within the icy Martian Polar Layered Deposits

Ali Bramson Purdue University

Alyssa Pascuzzo Brown University

Patricio Becerra Universität Bern

The polar caps of Mars are mostly comprised of the Polar Layered Deposits (PLD), kilometers-tall stacks of water ice layers with variable amounts of dust. These layers are exposed at troughs and scarp faces. Dark-toned layers, sandwiched between brighter (and thus presumably icier) layers, that are traceable across large portions of the PLD are known as marker beds. At trough and scarp exposures, these marker beds are found to protrude topographically relative to their surrounding layers, and this protrusion is generally considered a proxy for the layers' resistance to erosion (Becerra et al. 2016). Given the marker beds have a lower albedo, they should absorb more sunlight than surrounding higher-albedo layers. Thus, it could be expected that they would undergo more sublimation (i.e., be recessed), which would make their protrusion confounding. We tested the role of differential sublimation of icier vs. dustier layers and developed a framework for generating protrusion of dustier layers in the PLD. Dust content plays an important role in the amount of lag left behind as the layers undergo sublimation during periods of instability. This lag then insulates the ice from temperature perturbations and can prevent further sublimation. We find that the amount of protrusion observed for the marker beds can be explained completely by differential sublimation and the interplay between dust content, lag thicknesses, mechanical erosion of the lag, and the amount of time that the layers experience sublimation. We also find that the amount of protrusion (on the order of meters) can be generated within a few thousand years, or, within one obliquity cycle on Mars. This offers an explanation to the morphology of ice layer exposures within Mars' polar ice caps.

Subsurface-Atmosphere Exchange of Water Vapor in Sublimation Environments

Norbert Schorghofer Planetary Science Institute

This presentation will provide an overview of the theoretical framework for near-surface ice on Mars that has emerged over the last two decades, and, where possible, it will draw parallels with near-surface ice in the Dry Valleys of Antarctica. On present-day Mars the annual mean temperature (160-230K) and the frost point temperature (about 200K) are far below the melting point (273K), and ice exists in a sublimation environment. Ice-rich landforms where melting never occurs are rare on Earth, but may be present in portions of the Antarctic Dry Valleys. On Mars, the distribution of near-surface ice is governed by vapor exchange with the atmosphere, whereas terrestrial permafrost processes are dominated by melting and the associated energetics, resulting in two substantially different theoretical frameworks. The diffusion of water vapor in soil is a complex physical process, but theory has provided general insights. A subsurface ice table can be in vapor exchange equilibrium with a humid atmosphere, and that equilibrium is characterized by the frost point associated with the long-term mean of the absolute humidity of the atmosphere. Data from the Dry Valleys illustrate how the vapor pressure on an ice-free and snow-free surface can exceed the vapor pressure of buried glacial ice, due to the decay of the seasonal temperature amplitude with depth. A closely related process, absent from the terrestrial permafrost literature, is thermal pumping of vapor into the subsurface, which can result in the sequestration of ice. Laboratory experiments have revealed that vapor-deposited ice grows in intergrain spaces in the shape of tendrils, and this desublimation ice even includes bubbles, despite the absence of the liquid phase.

Implications for the distribution of brain terrain in Arcadia Planitia, Mars

Shannon Hibbard	University of Western Ontario
Gordon Osinski	University of Western Ontario
Nathan Williams	Jet Propulsion Laboratory
Matthew Golombek	Jet Propulsion Laboratory
Etienne Godin	Université Laval

Arcadia Planitia is a flat-lying region in the northern hemisphere of Mars where significant evidence indicates an ice-rich subsurface. Near-surface ice becomes less stable at lower latitudes under present climate conditions. However, Shallow Radar observations indicate a 10s of meters thick, relatively pure buried ice deposit, interpreted to be an ice sheet, exists across much of Arcadia extending north from ~38°N. Mid-latitude ice distribution and preservation have important implications for both Mars' past climate and in situ resource utilization for future human exploration. We are using small-scale (i.e., meters) surface morphologies and their relationship to glacial and periglacial Earth analogues as a means of better understanding the stability of mid-latitude ice in Arcadia Planitia. The surface of our study site in Arcadia is characterized by three distinct morphologies, typically found across the mid-latitudes and associated with subsurface ice, including polygonally patterned ground, polygonally patterned ground with pitted troughs, and brain terrain. Brain terrain is proposed to represent a lag deposit formed atop thick glacial ice as a result of ice sublimation. The Canadian High Arctic is used to investigate an analogous brain-like landform to identify surface-subsurface relationships and formation mechanisms. We document a new landform, termed Vermicular Ridge Features (VRFs), that has a circular, sinuous and anastomosing morphology, with similar morphometrics to brain terrain observed at Arcadia Planitia on Mars. Aerial drone imagery, digital elevation models, grain size analysis, and field observations of VRFs were used to compare morphology, morphometry, environmental conditions, substrate characteristics, and formation mechanisms to other morphologically similar terrestrial periglacial and glacial features. We interpret VRFs to be of paraglacial origin produced from the passive ablation of buried glacial ice remnants. Using VRFs as an analogue for brain terrain on Mars, we support that brain terrain can form largely via disintegration of underlying glacial ice, likely via sublimation. A latitudinally-dependent relationship in brain terrain occurrence in Arcadia Planitia suggests a northward regression of ice stability. However, we propose regions that are indicative of less ice degradation in the lower latitudes of Arcadia Planitia based on surface morphology.

Boulder halo rock distributions on ice-rich latitude dependent mantle indicate large role for cold-permafrost cryoturbation processes at some sites on Mars

Joseph Levy Colgate University

Boulder halos are rings of large (>25 cm) clasts present on the martian surface at middle and high latitudes that are arranged in diffuse, quasi-circular annuli. The halos are hypothesized to form when meteorite impacts punch through ice-rich surface soil layers, excavating underlying bedrock. These ice-rich surfaces are portions of the latitude dependent mantle (LDM), a young (10s of ka to a few Ma) ice rich deposit inferred to have been emplaced through either airfall of ice and dust or large scale vapor deposition into regolith. Regional deflation of ice and/or infilling of the crater result in flattening out of the terrain, leaving only a ring of boulders at the surface. However, questions remain as to whether the boulders represent primary impact ejecta, and whether they are in place or have been reworked by cold permafrost processes (e.g., some form of cryoturbation). LDM surfaces are extensively polygonally patterned, but show little evidence for freeze-thaw processes, as wet active layers are not predicted to have been present outside of steeply sloped surfaces over the past 4 Ma. Here we present boulder size-distribution counts for boulders in halos. We find that the boulder size-frequency power law exponents are inconsistent with fresh impact ejecta from existing lunar and martian impact craters. While some boulder halos show nearly size-distance and density-distance relationships that suggest little reworking of the boulders by permafrost processes, other halos have nearly flat density-distance and size-distance curves, suggesting considerable movement and reworking of boulder populations by permafrost processes. Several cold-cryoturbation processes are considered to explain this evolution of boulder densities, including tumbling and slumping of boulders into expanded thermal contraction crack polygon troughs and surface creep associated with seasonal dry ice layers at high latitudes.

A review of terrestrial analogs for Martian glacial, periglacial, and permafrost studies

Eric Petersen University of Alaska Fairbanks

Terrestrial analogs have been instrumental in developing our modern understanding of the Martian cryosphere. Even the knowledge we obtain from applying geophysical techniques and geomorphic analyses is informed directly or indirectly from terrestrial analogs. Often the analogs employed are enigmatic features in their own right, the study of which leads to advances in our understanding of processes on both planets. In this sense, we can conceive the endgame of terrestrial analog studies to be the merging of Earth sciences and planetary sciences along specific disciplines such as the cryosphere.

In this presentation the use of terrestrial analogs in Martian permafrost and periglacial sciences will be reviewed. Investigated features include terrestrial debris-covered glaciers and rock glaciers as stand-ins for Martian viscous flow features, thermal contraction crack polygons on both planets, various landforms indicative of deglaciated landscapes, and terrestrial debris-covered glacial ice cliffs as possible analogs to Martian icy scarps. The strengths and potential pitfalls of analog research will be investigated, as will potential future avenues for research. Among these is a renewed focus on investigating the processes that occur in the murky regime between glacial and permafrost environs—an arena of historical controversy and persisting questions in the terrestrial literature, but one which is seemingly ubiquitous for the formation of landforms on Mars.