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Probing for Ground Ice on Mars with Impact Craters

S. Byrne (1), C.M. Dundas (2), M.R. Kennedy (3), M.T. Mellon (4), I.J. Daubar (1), S.C. Cull (5) and A.S. McEwen (1)
(1) Lunar and Planetary Laboratory, AZ, USA. (shane@lpl.arizona.edu) (2) US Geological Survey, Flagstaff, AZ, USA. (3) Malin Space Science Systems, CA, USA. (4) Laboratory for Atmospheric and Space Physics, CO, USA. (5) Washington University, MO, USA.

Abstract

Ground ice exists less than a meter beneath a substantial fraction of the martian surface. Through analysis of images from the Context Camera (CTX) and the High-Resolution Imaging Science Experiment (HiRISE) hundreds of newly-formed impact craters have also been detected. Thirteen of these craters have excavated ground ice that appears surprisingly low in dust. Ice at some sites has faded, most likely due to build up of a sublimation lag; however, there are sites where the brightness of the exposed material has not changed or has even increased. We report on these natural probes of the martian ice table and their implications for the nature and extent of ground ice on Mars.

1. Introduction

Pore-filling ground ice on Mars has long been expected in the mid- to high-latitudes [1]. Theoretical models suggest that this ground ice has its extent set by annual average temperatures and atmospheric water vapor content [2] via diffusive exchange with the atmosphere. Although atmospheric conditions (and so the ice extent) vary with the changing orbital parameters of Mars [3-4], the ice table at any given moment is expected to be in equilibrium with its environment. Ground ice is expected to be present at increasing depths further from the pole until it becomes unstable at all depths in the mid-latitudes. This transition from stable to unstable conditionals is spatially abrupt and its position places strong constraints on the recent atmospheric water content of the planet. Over the past 10Kyr this transition has been migrating north as ice is removed from the mid-latitudes in response to changes in the argument of perihelion of Mars [4].

Observational constrains on the current location of the icy to ice-free transition come from the neutron and gamma-ray spectrometers aboard Mars Odyssey. However, the spatial resolution of these data is ~600km and so precludes an accurate determination of the transition's location. The Phoenix lander accurately measured the depth to ice at 69N, far poleward of the mid-latitude transitional area [5].

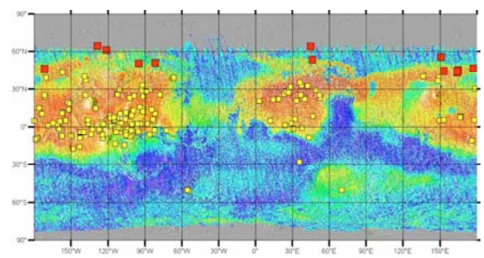

Figure 1: Locations of newly-formed impact craters (yellow [6]) and icy craters (red). Background is a spectral index of surface dustiness (red=dustier) [7].

2. Ice-Exposing Craters

Hundreds of newly-formed impact craters have been confirmed on Mars through a combination of CTX and HiRISE imaging [6]. Such discoveries are limited to dusty regions on the planet (figure 1) where even small craters can produce large surface markings. Nonetheless there is overlap between the dusty regions of the surface and those regions expected to host ground ice. Several craters formed in this overlap region have been discovered (e.g. figure 2) and have exposed buried ice [8,9].

This discovery allowed for both the determination of the icy to ice-free transition latitude and a characterization of the dust content of the ice (through assuming that the observed ice-fading was caused by a build up of a sublimation lag). Using the first five of these craters, it was determined that the edge of the ice table suggested an atmospheric water vapor content of 20 precipitable microns (higher than today's value, but within the range suggested by [10]) and that the exposed ice had <1% impurities. A subsequent Mars year of observations has raised the number of known ice-exposing craters to thirteen. While the original five craters were restricted in longitude to 150-190E, the current population now spans all longitudes.

The locations of the ice exposures remain consistent with an atmospheric water vapor content of 20 precipitable microns. Their radiometric behavior is more complex with few sites fading in the same way that the original site 1 of [8,9] did. Many sites show little evidence of any fading. The 1% impurity concentration at site 1 was an upper limit as an unknown fraction of the fading of the ice was due to dust fallout from the atmosphere. Given these new data, it is possible that most of the ice fading at site 1 was due to dust fallout and the actual impurity concentration of the ice itself is closer to 0% than 1%.

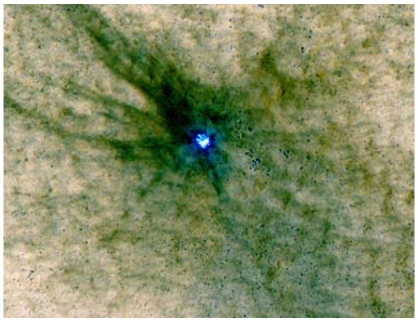

Figure 2: HiRISE image ESP_017789_2335 at 53N 46E. Image is 800m across with north up.

3. Discussion

What causes such widespread pure ice beneath the surface of Mars?

A buried former surface ice sheet is one possibility investigated by [11]. However, such ice sheets are efficiently removed by diffusion through the overlying regolith (while diffusion in the opposite direction can only create pore-filling ground ice). Modeling of an initial extensive ice sheet emplaced 5 Myr ago showed that it would retreat poleward of 60N in <1 Myr [11]. This may provide an explanation for the clean ice excavated by the Phoenix lander, but not by craters in the mid-latitudes. Models suggest ice at ~45N is less than a few 10s of Kyr old [3,4,11] and the presence of surface rocks throughout the northern plains is also difficult to reconcile with a buried ice layer.

Repeated thermal expansion and contraction of pore-filling ice has been proposed as a mechanism to expel intervening regolith grains and create clean ice [12]; although this is thought to operate over Myr.

On the Earth, the process of frost heave commonly produces almost pure ice lenses through the thermo-molecular forces associated with migrating thin films of liquid water. Such films can exist below the freezing point, but at temperatures appropriate for stable martian ground ice (within a few degrees of 200K) this process should be extremely slow [13]. The presence of salts may alter the rate at which this process operates on Mars making it a viable candidate to produce this ice.

We will report on our monitoring of these ice exposures and what their behavior can tell us about the nature and extent of ground ice on Mars.

Acknowledgements

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