Search for remnant water ice from past glacial climates on Mars: the Mars Odyssey Neutron Spectrometer.

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Introduction: The ancient yet well-preserved geomorphology and mineralogy of Mars provides ample evidence that liquid water and ice were stable near the surface on early Mars at low-to-mid latitudes [1-5]. These features inspired much speculation that the atmosphere of Mars was once much thicker than it is now so that surface temperatures and the accompanying relative humidity were both high enough to make near-surface water ice stable. These conditions are not thought to prevail generally today.

The only locations where near surface ice is now stable is close to both poles, and at high latitudes just below the surface. Nevertheless, several recent studies have shown that both high-latitude deposits would have become unstable within the last several Ma in response to changes in the obliquity to values above 35º [6], and become stable as tropical mountain glaciers near the equator [7-9]. There is sufficient water ice at both poles that water-ice deposits could build up at tropical latitudes to several tens to hundreds of meters in a period of 10^5 years [10], the main period of these obliquity variations [6]. Subsequent reduction in the obliquity past the present 25º level to about 15º would then destabilize these new tropical deposits and redistribute them in steps to mid and higher latitudes.

Although this reversal should destabilize the newly precipitated water-ice and coupled dust deposits at most locations at low latitudes, surface conditions at some locations may have sufficiently high albedo, low thermal inertia, or dust cover that water ice may still be present within ~1 m of the surface after 1 to 10 Ma [11]. Basically, high albedo and low thermal inertia will reduce the penetration depth of the thermal wave, and reduce surface temperatures. If this prediction is correct, then deposits of "bulk" water ice (ice having a weight percent larger than what can fit within the assumed maximum regolith pore volume of 50% [12]) should be detectable in those places by the Mars Odyssey Neutron Spectrometer (MONS).

MONS Data Modelling: A new method to self-constently determine all three parameters of a 2D distribution of water-equivalent hydrogen (WEH) (W*up*, *D*epth, and W*dn*) from the three measurables acquired by an orbiting neutron spectrometer (thermal, epithermal and fast neutron count rates) has recently been developed [13]. Initial analyses of MONS data used only a 1D model derived from epithermal count rates alone. This enhanced capability now allows a unique identification of buried deposits of "bulk" water ice at low to mid latitudes of Mars.

Search for Bulk Water Ice: We start our search for "bulk" water ice by identifying likely locations that are characterized by relatively enhanced WEH that lie within domains of relatively high albedo and low thermal inertia. The relatively high WEH deposits were derived from MONS epithermal neutron data using a 1D model of the regolith [14], as shown in the left-hand panels of Figure 1. We note that these 1D estimates are lower limits to W*dn* beause of the ice burial depths. Three of five domains that we will illustrate in this abstract overlay, 1) a thin constant-longitude strip centred at -143 E just to the west of the Tharsis highlands, 2) a similar strip just to the west of Elysium Mons at 132 E, and 3) a thin constant longitude strip that covers Alba Patera centered at -110 E, 40º N. Plots of thermal and epithermal count rates overlying appropriate simulation grids for these three domains are shown in the second column of Figure 1. We note they display a characteristic "J" shape shown in [13] to be a required characteristic needed to identify buried "bulk" water ice. Also required is the self-consistent agreement of the upper-layer water content, W*up*, identified by the alignment of the linear portion of the "J", which is measured at successively lower latitudes, and the simulation grid line that terminates on W*up*. This content is determined from the cross-over of a linear fit to the correlation between 1D fast and epithermal estimates of W*up* within these domains using the fast and epithermal count rates and the unity line [13], as shown in the third column of Figure 1.

Conclusion: We conclude that there are at least three likely target locations of presently existing deposits of buried "bulk" water ice that may be remnants of multiple episodes of dirty ice precipitation events at low to mid Martian latitudes driven by climate changes during the last 1 to 10 Ma. All three are overlain by regolith having high albedo and low thermal inertia, criteria identified [11] as necessary to insure sufficiently low surface temperatures to stabilize previously precipitated thick deposits of dirty water ice close enough to the surface to be observable by a neutron spectrometer probe. All deposits are located at places predicted by the Laboratoire de Météorologie Dynamique GCM (7-10] to be sites of thick water-ice

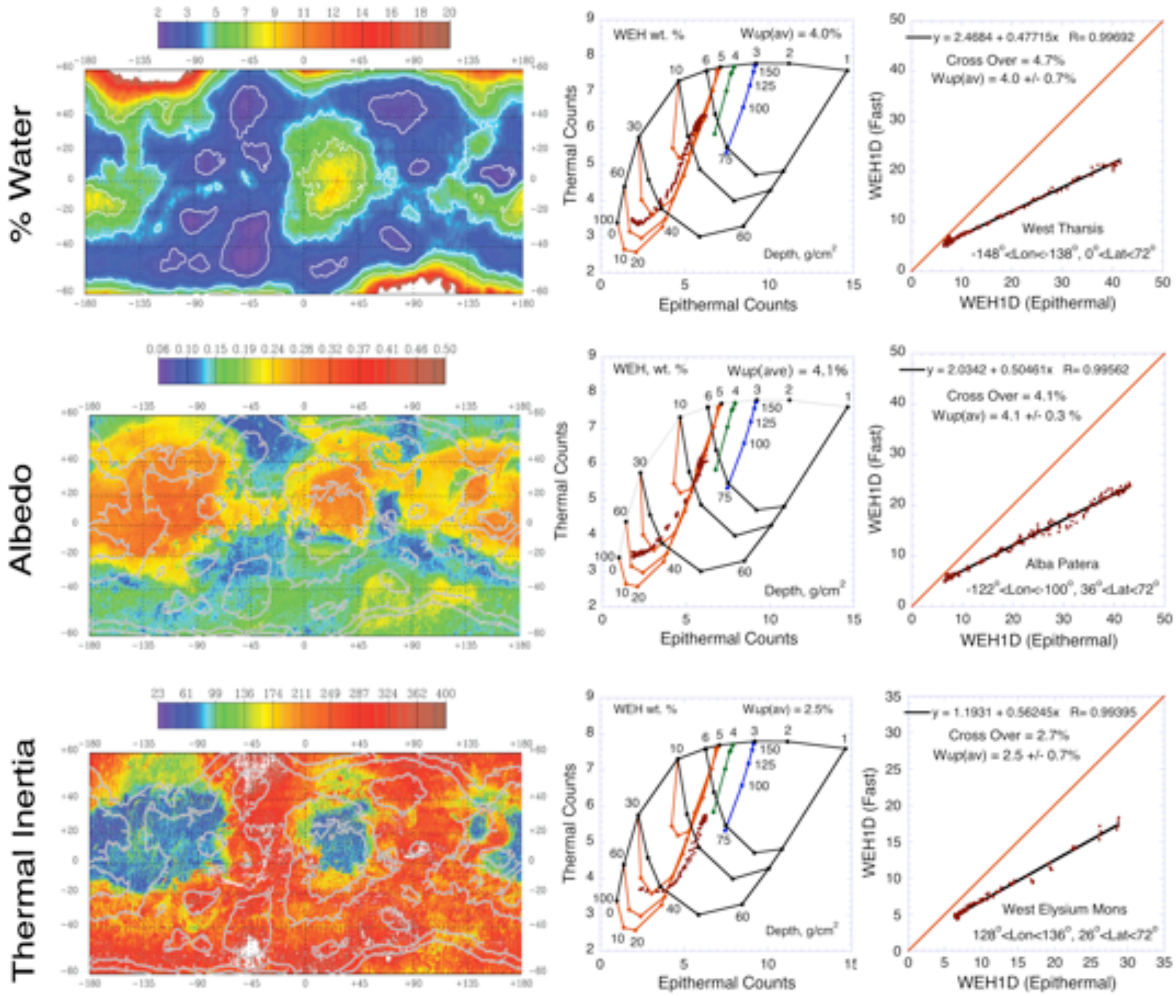

Figure 1. Maps of the 1D abundance estimates of water-equivalent hydrogen, WEH, albedo, and thermal inertia at latitudes less than 60º from the equator (left column of panels). The middle column of panels give the run of thermal and epithermal count rates along three constant-longitude strips that overlay, 1) the western edge of the Tharsis highlands, 2) Alba Patera, and 3) the western edge of Elysium Mons . The right-hand column of panels give the correlations between 1D estimates of the WEH content within these strips derived from Fast and Epithermal neutron counting rates. The alignment of the upper linear portions of the "J" shaped patterns in the thermal-epithermal correlations with constant W*up* grids of simulated count rates identifies theW*up* WEH abundance. The cross-over of the Fast-Epithermal WEH1D correlation with the unity line also identifies W*up*. Agreement between both values of W*up* after correcting the cross-over estimates for a 1% to 1.5% systematic deficit is a necessary condition for the existence of a buried deposit of "bulk" water ice.

precipitation events during previous low-latitude glacial epochs driven by obliquities greater than 30º.

References: [1] Squyres, S.W., 1979, J. Geophys. Res. 84, 8087-8096. [2] Carr. M.H., 1996, *Water on Mars*, New York: Oxford University Press, 229pp. [3] Mustard, J.F., C.D. Cooper, M.K. Rifkin, 2001, Nature 412, 411-414. [4] Milliken, R.E., J.F. Mustard, D.I. Goldsby, 2003, J. Geophys. Res. 108 (E6), 5057, doi:10.1029/2002JE002005. [5] Head, J.W., D. R. Marchant, M.C. Agnew, C.I. Fassett, M.A. Kreslavsky, 2006, Earth Planet. Sci. Lett. 241, 663-671. [6] Laskar, J., A.C, Correia, M. Gastineau, F. Joutel, B. Levrad, P. Robutel, 2004, Icarus 170, 343-364. [7] Levrard, B., F. Forget, F. Montmesin, J. Laskar, 2004, Nature 431,1072-1075. [8] Levrard, B. F. Forget, F. Montmessin, J. Laskar, 2007, J. Geophys. Res. 112, E06012 doi:10.1029/2006JE002772. [9] Forget, F. R.M. Haberle, F. Montmessin, B. Levrard, J.W. Head, 2006, Science 311, 368-371. [10] Madeleine, J.-B, F. Forget, J.W. Head, B. Levrard, F. Montmessin, E. Millour, 2009, Icarus 203, 390-405. [11] Paige, D.A., 1992, Nature 356, 43-45. [12] Arvidson, R.E., J.L. Gooding, H.J. Moore, 1989, Rev. Geophys. 27, 39-60. [13] Feldman, W.C., A. Pathare, S. Maurice, T.H. Prettyman, D.J. Lawrence, R.E. Milliken, 2010, J. Geophys. Res. in Prepraration. [14] Feldman, W.C., T.H. Prettyman, S. Maurice, et al., 2005, J. Geophys. Res. 110, E11009, doi:10.1029/2005JE002452.