TOWARD A HISTORY OF THE MOON'S ICE CAPS: SYNTHESIZING SURFACE AND SUBSURFACE MEASUREMENTS. A. P. Jordan[1,2*], J. K. Wilson[1,2], N. A. Schwadron[1,2], H. E. Spence[1,2], and Noah Petro[3], [1]EOS Space Science Center, University of New Hampshire, Durham, NH, USA (*email: a.p.jordan@unh.edu), [2]Solar System Exploration Research Virtual Institute, NASA Ames Research Center, Moffett Field, CA, USA, [3]NASA Goddard Space Flight Center, Greenbelt, MD, USA.

Introduction: It has been difficult to determine the history and distribution of water ice in the Moon's polar regions due to the heterogeneity of ice deposits on crater-scales and to differences in interpretation between multiple datasets. For example, some permanently shadowed regions (PSRs) lack ice, others seem to contain only surface ice, and still others seem to contain only buried ice [e.g., 1].

Though it is important to understand lunar ice on these smaller scales, there is much to learn from larger scales. For example, using data from the Neutron Spectrometer on Lunar Prospector (LP-NS), [2] found that the northernmost and southernmost maximum concentrations of buried hydrogen are antipodal yet not co-located with the current poles. This suggests that the buried ice is ancient, deposited when the Moon had a different spin axis.

Thus, the large-scale distribution of ice can help determine its history. On this basis, we develop a framework that can use these datasets to help determine, as a function of depth, the history of ice on the Moon. As a first step in this direction, we show how to synthesize surface and subsurface measurements to determine the extent of the Moon's ice caps.

Ice Cap Framework: Although [2] considered the maximum concentrations of hydrogen, they did not determine its latitudinal extent. That extent, when combined with the maximum, can constrain what processes have affected the origin, loss, and/or migration of ice. Figure 1 illustrates several potential scenarios with different combinations of ice cap maxima and boundaries. In each scenario, we mark latitude 70°; this is predicted to be approximately the lowest latitude where water ice can be trapped [3, 4].

In the first scenario (Fig. 1A), we assume that the ice is ancient and was deposited when the Moon's spin axis was different. Furthermore, no ice has been added or lost. In this case, the ice would have a maximum at the palaeopole, and the boundary of the ice cap would be centered on the palaeopole.

The second scenario (Fig. 1B) differs from the first in one way: ice has been lost. This would create an asymmetric ice cap, part of which would follow a current line of latitude, and part of which would follow the line of latitude when the ice was deposited.

In the third scenario (Fig. 1C), we assume some ancient ice is lost, but new ice is added. In this case, the maximum would still be at the palaeopole. If enough ice is added, however, then the maximum could shift toward the current pole (Fig. 1D). In these last two scenarios, the boundary of the ice cap would be centered on the current pole.

Another scenario--not shown--is possible: new ice could be added, with little or none of the old being lost. Then the ice cap would be centered on neither the palaeopole nor the current pole.

Consequently, for a given depth, the maxima and the boundaries of the ice caps can help determine the processes that have affected the ice. But this framework also enables us to determine these processes as a function of depth. For example, assume that ice at ~1 m depth is ancient--suggested by [2]--and that little or no ice has been added or lost at that depth. This would create a buried ice cap whose boundary and maximum are both centered at the palaeopole (as in Fig. 1A). Now assume that the ice at the surface is more recent, as suggested by [5]. At the surface, then, we would expect the scenario shown in Fig. 1D. The combination is shown in Figure 2.

In this situation, the surface and subsurface datasets would differ, but this difference would show that the ices at these two depths have different origins and ages. In a sense, there would be two ice caps: a polar-centric cap at the surface and an off-centered cap at depth. The histories of these caps would be further constrained by another dataset sensitive to middle depths (~1-10 cm), such as proton albedo [6] (see below).

Synthesizing the Data: Because these datasets have not yet been analyzed so as to determine both the location of the maxima and the extent of the ice caps, we do not know which combination of scenarios has occurred. Even so, a number of surface and subsurface datasets do generally agree about the boundaries of the ice caps, laying a foundation for future analyses.

First, the Lyman Alpha Mapping Project (LAMP) on the Lunar Reconnaissance Orbiter (LRO) detects UV reflected off the surface, and its off-band to on-band signal ratio indicates the presence of surficial water ice, even in PSRs. Poleward of -75°, this ratio increases toward the south pole and is independent of large PSRs [7]. When extrapolated, the data suggest that surface water ice may extend to about -70°.

Second, the Moon Mineralogy Mapper (M3) on Chandrayan-1 has detected the specific absorption features of water ice in indirectly illuminated PSRs [8].

This surface ice extends no further equatorward than about ±70°.

Neutron data probe down to ~50 cm. Both LP-NS and the Lunar Exploration Neutron Detector (LEND) measure large polar regions where the neutron flux is reduced [9, 10]. These depressions extend from the poles to about ±70° and are present in the LEND data even when large neutron suppression regions have been removed [11]. Despite the depressions being averaged over a hemisphere, they seem to be asymmetric, suggesting that perhaps Fig. 1A or B may describe the situation.

Finally, the Cosmic Ray Telescope for the Effects of Radiation (CRaTER) on LRO detects protons ejected from regolith by cosmic ray collisions creating neutrons and protons. Although hydrogen suppresses the neutron flux, it enhances the "albedo" proton flux [6]. This flux is sensitive to hydrogen in the top ~1-10 cm, so it provides a critical link between the surface data and the neutron data.

Previously published CRaTER data show that albedo protons increase from the equator to the pole, but their resolution is too low to show whether there is a boundary near ±70°. We will use new data with improved statistics and background corrections [e.g., 12] to determine if such a boundary exists.

Conclusion: Recent surface and subsurface data have shown that the Moon's ice caps extend to latitudes of about ±70°. This agrees with previous predictions [3, 4]. Further analysis will show whether the ice caps are symmetric about the current poles or palaeopoles and how this changes as a function of depth. This method will help determine the history of lunar ice.

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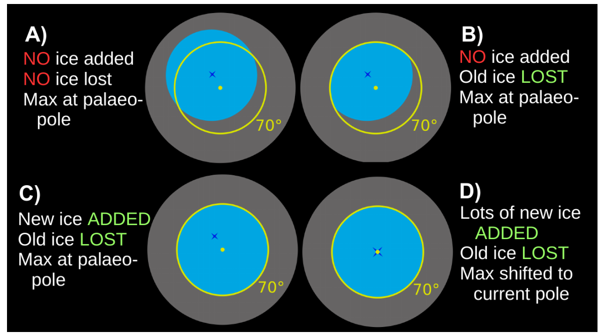

Fig. 1. Some possible scenarios for water ice in the polar regions of the Moon. All views look down on a pole, marked by the yellow dot. Light blue areas represent ice, and dark blue "x"s represent the maximum concentrations of ice.

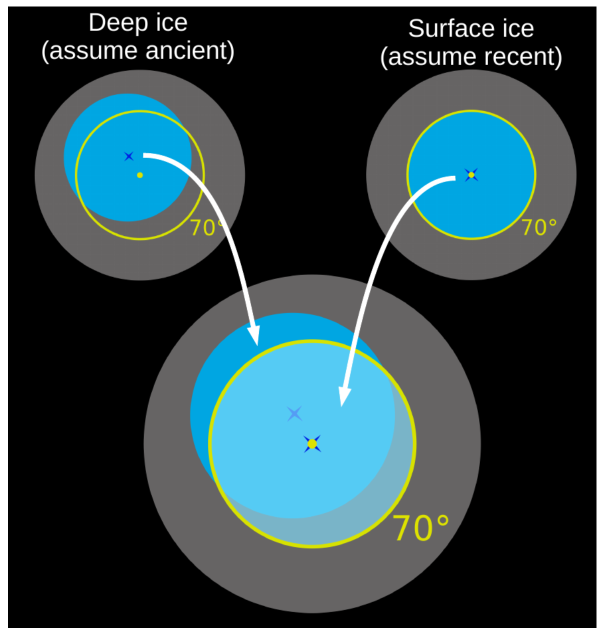

Fig. 2. A possible scenario showing the importance of the distribution of ice as a function of depth. We assume buried ice is ancient and surface ice is recent. Markings are as described in Fig. 1.