CONTRASTING GEOLOGIC SETTINGS FOR LUNAR ICE DEPOSITS NEAR SHACKLETON CRATER VERSUS MONS MOUTON. L. Keszthelyi[1], K. Hibbitts[2] and C. R. Neal[3], [1]U.S. Geological Survey, Flagstaff, Arizona USA (laz@usgs.gov), [2]John Hopkins Applied Physics Laboratory, Laurel, Maryland, USA. [3] University of Notre Dame, Notre Dame, Indiana, USA.

Introduction: Lunar exploration plans for many entities are built on the postulates that (1) there is ice at the lunar south pole and (2) this ice will enable a sustained human presence. However, the multiple lines of evidence for lunar ice remain indirect and not entirely consistent with each other. This makes lunar ice a speculative resource, not a reserve [1]. Currently, humankind lacks the basic understanding of lunar ice deposits necessary to make reliable predictions about their characteristics and locations. Therefore we are not (yet) ready to make use of lunar ice.

The key missing information is ground-truth data that quantifies the range of properties that ice deposits have in a variety of settings. To reach the status of a "reserve," many measurements will be needed from multiple different sites. Realistically, this can only be achieved via a coordinated international lunar resource prospecting campaign [2].

Here we illustrate how observations from two disparate locations would help differentate between plausible hypotheses for the formation of lunar ice deposits. This, in turn, would provide the understanding needed to mature lunar ice prospectivity models [3], building toward quantitative assessments and, potentially, reserve status for some ice deposits.

Hypotheses for the Origin of Lunar Ice Deposits: Currently, there are three main ideas for the source of the water molecules that may be trapped in cold areas near the poles of the Moon: solar wind, volcanism, and meteorites.

Solar wind. The stream of material from the sun includes protons which can interact with the oxygen in the lunar regolith to form hydroxyl or water [4]. These molecules can then be mobilized by impacts or heating and migrate to cooler regions. This could be an ongoing, but slow, process. If it dominates lunar ice deposit formation, the deposits are likely to be coatings only molecules thick on regolith grains. At present, it is unclear if this process can build deposits faster than they are destroyed by erosion [5].

Volcanism. The eruptions of lava that flooded the basins on the lunar near-side also injected gasses into the lunar environment. This may have created a temporary atmosphere that froze in polar cold traps [6]. If lunar ice is primarily volcanic in origin, it should have formed mostly between 2 and 3 billion years ago. Substantial amounts of sulfur, carbon, alkali, and halogen compounds, but few nitrogen compounds, would be expected to be associated with the water.

Meteorites. While asteroids and comets continually deliver water and other material to the Moon, the vast majority of the volume of meteorites arrived before 3.8 billion years ago [7]. If impacts provided most of the lunar water, substantial deposits formed only in the most ancient craters. Which craters remained shadowed and thus were able to retain such ancient ice will be affected by changes in the obliquity of the Moon [8]. More recent deposits will have formed as layers at distinct times and the ice composition will be a mix of hydrogen, carbon, nitrogen, and sulfur compounds. This stratigraphy is likely erased in the uppermost meter of the regolith but may be preserved at greater depths.

Current Understanding: The available data on lunar ice paint a confusing picture. Orbital nuclear spectroscopy shows the unmistakable signature of increased hydrogen in the upper meter of the regolith at the lunar poles. However, the spatial resolution of these data is no better than tens of kilometers and different neutron spectrometer teams do not agree on which craters have higher concentrations of hydrogen. Furthermore, the suggested concentrations differ by about an order of magnitude [9,10]. Some optical systems suggest patches of ice at the surface while others do not [11-13]. The instruments that do indicate surface ice do not agree on its distribution. Radar data show some craters have anomalous properties consistent with blocks of ice, but their interpretation is non-unique [14]. This pattern of inconsistent interpretation of remote sensing data is consistently associated with insufficient ground truth data.

The one *in situ* observation of lunar ice comes from the Lunar Crater Observation and Sensing Satellite (LCROSS) impact in an extremely cold part of Cabeus crater. The average water concentration was estimated to be 5.6 wt.%, but, at the 95% confidence level, the value ranges from zero to >11% [15]. If the average concentrations of nitrogen, sulfur, and carbon compounds are taken at face-value, a volcanic origin for the water at this location can be ruled out. However, the results are also not entirely consistent with any mix of hypothesized processes [16].

Landing Sites: In order to collect new ground truth data, it is necessary to first safely land on the surface of the Moon. Key considerations are slopes, temperatures, and the ability to see the Sun and Earth. The need for solar power and direct-to-Earth communications has made high-standing topography the preferred location for south polar landing sites. This is in direct conflict with the desire to investigate cold, shadowed, regions.

Without expensive long-range nuclear powered rovers, the necessities of survival are paramount and missions must seek to achieve their exploration goals outside the regions most favorable for ice deposition. Here we examine two locations that have been repeatedly discussed as targets for surface exploration: Shackleton crater and Mons Mouton.

Mons Mouton. This plateau is a surviving section of the rim of the South Pole Aitken (SPA) Basin, the largest known impact crater in our solar system [17]. This is also one of the oldest known impact craters on the Moon, with an estimated age of 4.3 Ga [18]. Mons Mouton is surrounded by 40-60 km diameter craters 4.2-3.8 Ga in age that have thrown hundreds of meters thick blankets of ejecta onto the rim of the plateau and tens of meters across the plateau (Figure 1) [19]. The great age of the surface means that the regolith is expected to be significantly thicker than average.

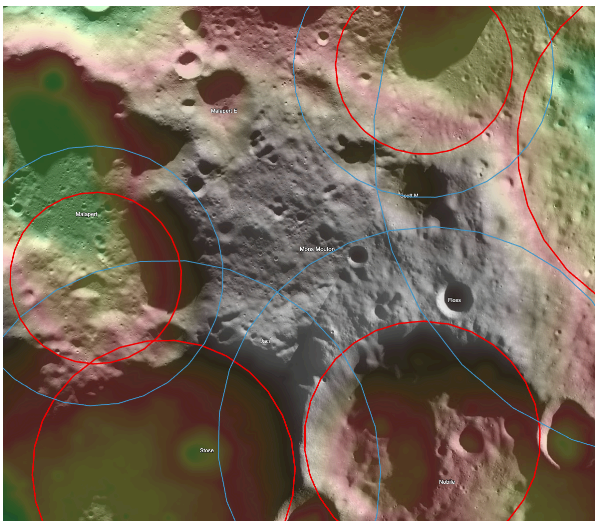

Figure 1. View of Mons Mouton colorized with topography. Red circles highlight the rims of major craters. Blue lines show the distance at which the thickness of the ejecta blanket is predicted to be 100 m.

This setting means that Mons Mouton is an ideal location for exploration of layers tens of meters thick deposited during the time that the Moon was undergoing its heaviest bombardment by meterorites. However, the fact that it has been a high-standing plateau makes it an unfavorable location for the formation of ice deposits with volumes of cubic kilometers.

Shackleton crater rim. This crater has a well-preserved morphology (Figure 2), consistent with the estimated age of ~3.1 Ga [20] corresponding to a time of waning impacts. The steep slopes to either side of the rim lead to downslope movement of the loose regolith. This movement, and the relatively young age of the crater, mean that the thickness of the regolith is expected to be relatively thin along the crater rim.

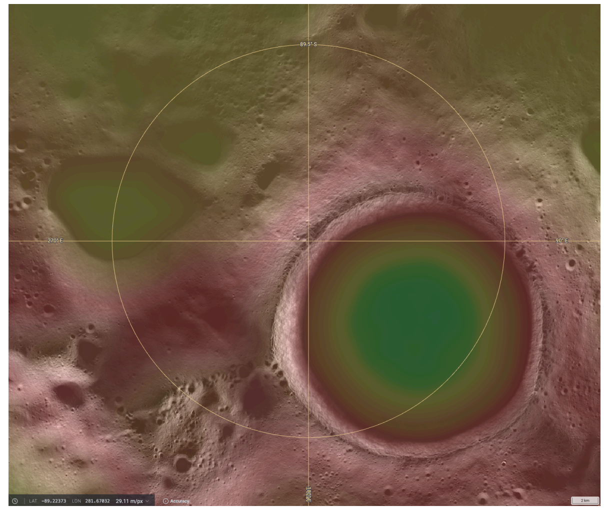

Figure 2. View of Shackleton crater colorized with topography. Graticle shows the location of the south pole.

This setting means that Shackleton crater is an ideal location for exploration of recent shallow deposits of ice with minimal contribution from ancient impacts. Exploration of ice within Shackleton could be important to understanding the contribution of volcanism but access to the interior from the rim is extremely challenging due to the steep slopes, deep shadows, and cold temperatures.

Conclusions: The fundamental questions about the formation of lunar ice deposits are unlikely to be answered by exploration of a single site. An understanding of the geologic setting for different locations is essential for identifying which questions can be addressed at specific locations.

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