MODELING THE FORMATION OF SIMPLE CRATERS IN ICE-RICH POLAR TARGETS ON THE MOON. Ross W. K. Potter[1,2] and Ariel N. Deutsch[3], [1]Clarivate, 160 Blackfriars Road, London, SE1 8EZ, [2]Department of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI, USA 02912 (ross_potter@brown.edu), [2]NASA Ames Research Center, Mountain View, CA, USA 94035.

Introduction: The lunar poles are exciting science and exploration destinations due to various observations indicating the presence of water ice [e.g., 1–8]. While much of this ice is expected to be cold-trapped below the subsurface [1–5], various observations of the lunar poles suggest that ice is also exposed directly at the surface [6–8]. These observations indicate that ice is present at various spatial scales, cold-trapped within both large and small impact craters (**Fig. 1**), as well as in smaller, micro-cold traps [6–9]. Today, questions remain regarding when and how this ice became cold-trapped at the lunar surface.

If ice at the lunar surface was delivered after the formation of the cold traps in which they are observed, then the ages of the cold traps provide upper limits on the ages of the ice they contain. While large (D >15 km) ice-bearing craters on the Moon are typically ancient (> ~3.5 Gyr) [10–12], smaller craters are usually younger. Thus, the presence of surface ice within smaller craters is intriguing. If the ice present at the surfaces of smaller, younger impact craters was delivered after these craters formed, then that ice is also young. However, if the ice existed prior to the formation of their host craters, then perhaps surface ice exposures in smaller craters are the remnants of ancient ices, exposed during the impact cratering process.

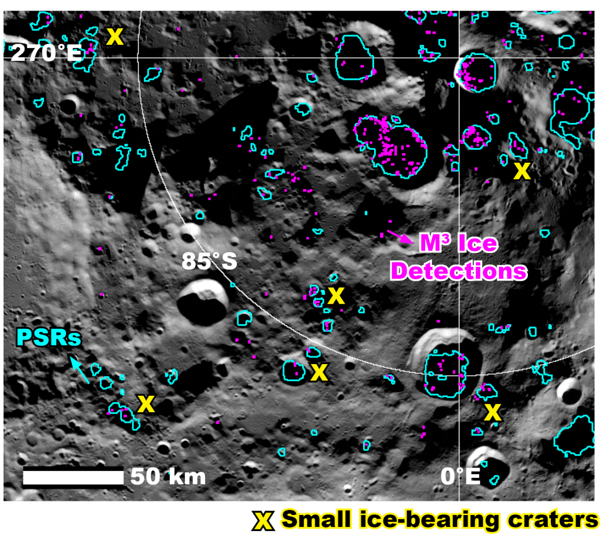

Fig. 1. Distribution of surface ice detections [8] at the lunar south pole. Examples of small (D <10 km) craters that host ice exposures are denoted by an X. PSRs: Permanently shadowed regions. (LOLA WAC image.)

Here we are interested in determining how surface/near-surface ice is redistributed by small impact events at the lunar poles. We numerically model these events into ice-rich targets to analyze the loss and redistribution of pre-existing ice layers in order to study the conditions under which these layers can be excavated to, and preserved at, the lunar surface. This work has important implications for the stratigraphies of ice-bearing craters, and thus, the ages and sources of surface ice observed on the Moon today.

Methods: The iSALE shock physics code [13–15] will be used to numerically model the formation of simple lunar impact craters (D <20 km) covering an impact velocity range of (~10–20 km/s) and impactor range of (D ~1–2 km). Simulations will be carried out in a two-dimensional half-space, with surface gravity set to 1.63 m/s^2. A semi-analytical equation of state for dunite [16] will represent the impactor. The target crust will be represented by an equation of state and strength model for gabbroic anorthosite [17–20]. A Tillotson equation of state for wet tuff, based on a Nevada tuff with a water content of 14.4 wt.% [21] will be used as an ice layer proxy and will be interspersed within the anorthosite. The proxy ice layer will vary in thickness (10 m, 50 m, 100 m) and depth (at the target surface, 10 m, 100 m, and 1 km). The location (inside vs. outside the crater) of ice post-impact, its temperature, and peak shock pressure will be tracked to determine if pre-existing ice is excavated and/or survives (i.e., not vaporized) impact. This work will provide important insight into the influence of ice (volatile) layers in the formation of lunar (simple) craters, building upon the Shackleton crater investigation of [22].

Discussion: The ages of exposed lunar surface ice have important implications for the source of the ice, given that different delivery mechanisms have operated at different times and intensities throughout lunar history. For example, large impacts [23–25] and large volcanic events [26, 27] can deliver water to the lunar surface, but these events were more active early on in lunar history, and have significantly declined through time [28, 29]. Micrometeoroid and solar wind bombardment can also lead to the delivery of water to the lunar poles, and these processes are still active today [e.g., 30–32].

Surface ice post-dating crater formation. Simple stratigraphic relationships between host craters and surface ice exposures have been previously used to place constraints on the age of the ice [11, 33]. For small (D <15 km) ice-bearing craters, measurements of surface roughness have been used to assess crater ages [33]. It was found that the roughness distribution of small ice-bearing craters is skewed toward roughness values that are higher than those of pre-Imbrian craters, suggesting that some small ice-bearing craters are younger than pre-Imbrian [33]. If the surface ice exposures within these craters indeed post-date the formation of their host craters, then the ices are also younger than pre-Imbrian.

Surface ice exposed from depth during crater formation. Alternatively, the ice exposures may have existed prior to the formation of the small craters in which they are observed. Today, ices are expected to be trapped in the polar subsurface, as inferred from neutron spectrometer data [e.g., 1, 2] and the LCROSS experiment [3, 34]. Furthermore, polar crater morphometries indicate a shallowing with latitude, suggestive of ice-rich regolith up to ~50 m thick [4, 5], and large volumes of subsurface ice are consistent with recent Monte Carlo modeling of ice deposition [12].

If ice has been excavated from depth during the formation of small (D <20 km) impact craters and is preserved at the surface today, then perhaps the ice exposures [8] observed in small craters are the remnants of earlier delivery episodes. This is more consistent with modeling of ice deposition [12] and regolith gardening processes [35], which predict the majority of ice is from relatively ancient, episodic deliveries. This is also consistent with ice present at the surface or near-surface of regolith particles (as sensed by the Lyman Alpha Mapping Project (LAMP) to a depth of <1 μm) being < 2,000 years old [32].

Conclusions: The stratigraphies of polar craters provide an important record of ice accumulation through time. However, this record must be read carefully, as it is complicated by discontinuities from various loss processes and by larger episodes of ice and ejecta emplacement. Understanding how small impacts play a role in modifying this record is essential for interpreting crater stratigraphies. Here, therefore, we are modelling the formation of small craters into ice-rich targets to study the modification and redistribution of pre-existing ice layers on the Moon. Our work will provide important insight into interpreting future ground-based measurements of polar crater stratigraphies, as NASA's Volatiles Investigating Polar Exploration Rover (VIPER) [36] is preparing to explore and drill at the lunar poles.

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