BURIED ANCIENT ICE DEPOSITS WERE LIKELY DISPERSED DUE TO BALLISTIC SEDIMENTATION. C. J. Tai Udovicic[1], K. R. Frizzell[2], G. R. L. Kodikara[3], M. Kopp[4], K. M. Luchsinger[5], A. Madera[2], M. L. Meier[6], T. G. Paladino[7], R. V. Patterson[8], F. B. Wròblewski[6], and D. A. Kring[9,10]. [1]Northern Arizona University, (Email: cjtu@nau.edu), [2]Rutgers University, [3]University of Wisconsin - Milwaukee, [4]Boston College, [5]New Mexico State University, [6]University of Idaho, [7]Idaho State University, [8]University of Houston, [9]Lunar and Planetary Institute, Universities Space Research Association, [10]NASA Solar System Exploration Research Virtual Institute.

Introduction: The lunar south polar region is the initial target of the NASA Artemis human exploration program, which will investigate the availability of water-ice and other *in-situ* resources [1, 2]. Some permanently shadowed regions (PSRs) remain cold enough to trap ice [3]. However, the Moon lacks massive ice deposits at the surface, which has been attributed to short ice stability timescales and impact gardening, the churning of the regolith by small impact bombardment [4, 5].

A mechanism for preserving ice at depth was proposed by [6] who noted that surface cold trap ice deposits may be preserved if buried by ejecta from nearby craters. Repeated deposition of ice and ejecta could then form a stratigraphic sequence below a cold trap, storing ice over geologic time. An initial study of this concept revealed the potential for "gigaton" ice deposits below lunar polar cold traps [7]. However, that work did not account for ballistic sedimentation, the vigorous mixing of ejecta into a potentially icy target. In this work, we develop a model to predict the amount of ice lost to ballistic sedimentation during an ejecta blanketing event of a particular cold trap. We then apply it to the Monte Carlo model of [7] to investigate how ballistic sedimentation would have influenced the ice retained below cold traps over geologic time.

Methods: Our Monte Carlo model, Moon Polar Ice and Ejecta Stratigraphy (MoonPIES), tracks the deposition and removal of ice and ejecta from 4.25 Ga to the present in 10 Myr time steps. The model outputs a stratigraphy column with layers of ice and ejecta for each cold trap of interest. Ejecta are sourced from proximal polar craters and basins formed at times randomized within crater-count model age uncertainties. Ice is sourced from: icy impactors (size and abundance randomly drawn according to the lunar production and chronology functions [8]), volcanic outgassing [9], and solar wind H^+ deposition [10, 11]. Impact gardening and ballistic sedimentation remove ice from the top of each column [12, 13]. The model assumes a static polar orientation over the 4.25 Ga timespan such that each cold trap is stable from its formation to the present.

Ballistic Sedimentation. Ballistic sedimentation occurs when crater ejecta of sufficient velocity mechanically disrupts and mixes with a target planetary surface [12]. We used a 1D heat conduction model assuming that ejecta and local materials are in contact and vigorously

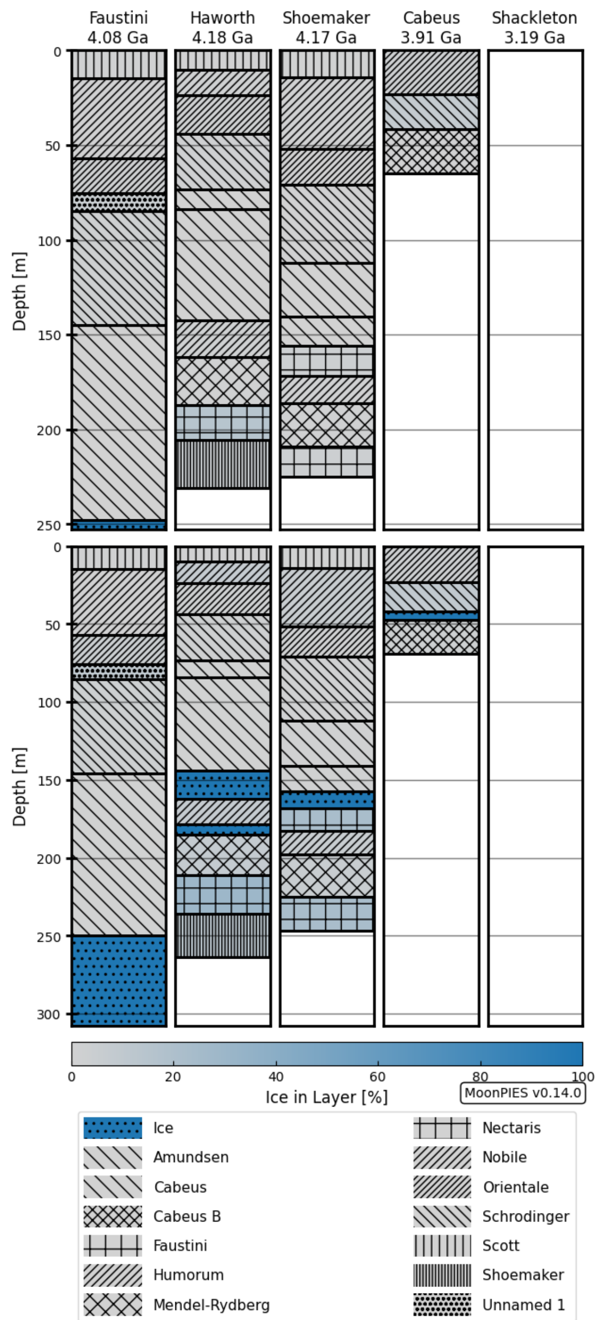

Figure 1: MoonPIES stratigraphy columns for a single run with ballistic sedimentation (top) and without (bottom). Pure ice layers are disturbed (lost or redistributed) when accounting for ballistic sedimentation.

mixed such that they reach thermal equillibrium before radiative terms begin to dominate [14]. Using a simple ice stability threshold of 110 K, we track the fraction of icy regolith elements that exceed the threshold temperature as the surface equilibrates. We then remove this fraction of ice from each ice layer to the ballistic mixing depth given by [15]. This process is repeated each time ejecta enters a modeled cold trap.

Results and Discussion: We find that ballistic sedimentation has a significant effect on lunar cold trap stratigraphy. An example model run in Figure 1 shows that without ballistic sedimentation (bottom panel), large ice deposits are preserved at depth. However, when we account for ballistic sedimentation (top panel), nearly all deep ice layers are reduced or lost. Since MoonPIES is a Monte Carlo model, the sequence and thickness of ejecta and ice layers retained varies from run to run.

To examine overall trends, we ran the MoonPIES model 10,000 times with and without the effects of ballistic sedimentation (Figure 2). We find that the total ice retained throughout each stratigraphic section decreases when accounting for ballistic sedimentation. Most Nectarian and older PSRs retained a median of about 10 m of ice across the stratigraphic section. Assuming typical ice density, 100 m of ice corresponds to about 1 gigaton per square kilometer of cold trap. Therefore, most cold traps retain less ice in total than the gigaton deposits reported by [7]. This retained ice is likely dispersed throughout the stratigraphic section (up to 100s of meters), since the vast majority of ice layers have been disturbed by at least one ballistic sedimentation event.

Conclusions: Our updated polar stratigraphy model suggests that ballistic sedimentation would have disrupted hypothesized deep ice reservoirs first presented by [7]. Even so, up to 10 meters of ice is retained below most cold traps studied, but this ice is likely dispersed throughout the stratigraphic section. Of the cold traps studied, Faustini, Haworth, Amundsen, Cabeus, Cabeus B, and Idel'son L are the PSRs most likely to contain large quantities of ice at depth. These PSRs should be considered for characterization by future *in-situ* observations, particularly with ground-penetrating radar [6].

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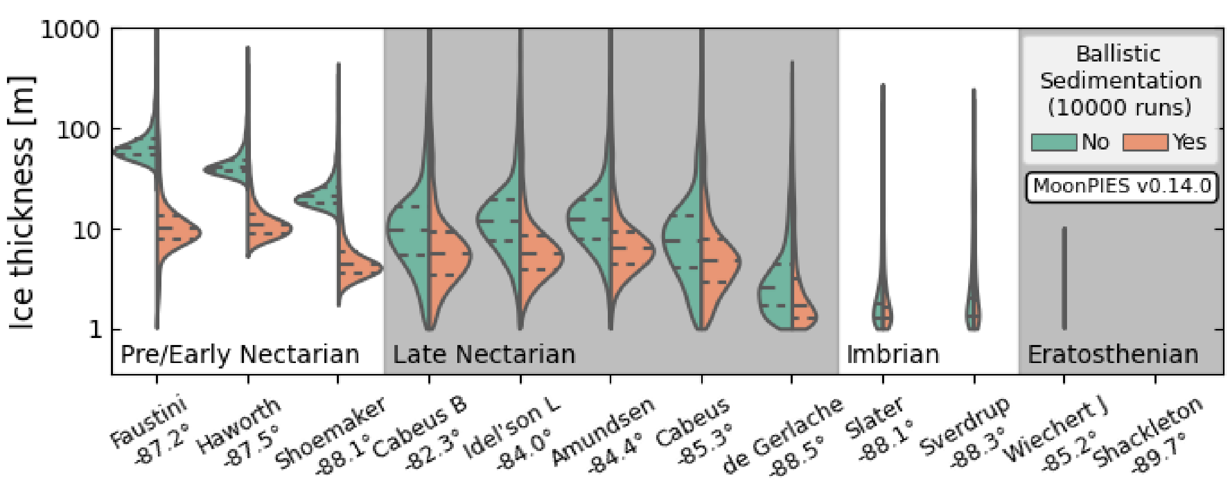

Figure 2: Histograms of total ice thickness retained across 10,000 model runs for each cold trap. Cold traps are arranged from left to right by decreasing latitude within each lunar geologic era. Runs with ballistic sedimentation (orange) retained less ice than those without (green). Nectarian and older cold traps retained up to 10 m of ice, distributed throughout the entire stratigraphic section (up to 100s of meters), while younger cold traps rarely retained more than 1 m total ice.