ICE DEPOSITS AT MERCURY'S NORTH POLAR REGION: HOST CRATERS PROVIDE MAXIMUM AGE.

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Introduction: Earth-based radar observations and results from the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) mission have provided strong evidence that permanently shadowed regions near Mercury's poles host deposits of water ice. Radar-bright deposits observed near the planet's poles [1] collocate with regions of permanent shadow [2], and enhanced hydrogen concentrations measured by MESSENGER in Mercury's north polar region are consistent with models for the radar-bright deposits to be composed primarily of water ice [3].

Although the polar ice deposits have a well-characterized spatial distribution [1–4], their age and source are poorly constrained. One approach to constraining the age of the ice is to determine the age of the host craters in which the ice deposits occur. Here we present crater counts done using images acquired by MESSENGER and available on the Planetary Data System, and use crater size-frequency distributions (CSFDs) to estimate the maximum age of polar deposits in Mercury's north polar region. Determining the age of the youngest ice-bearing craters is an important constraint for Mercury, because it provides an upper limit for the age of their polar ice deposits. Such a constraint has implications for the source, history, and evolution of water and other volatiles in the inner Solar System.

Age Calculations of Polar Ice Deposits: Using a geologic map of Mercury from 70°N to 90°N [5], we identified all Kuiperian and Mansurian craters ≥40 km in diameter. From maps of permanent shadow and radar-bright deposits [4], we identified which of these craters host water-ice deposits. We investigated the morphology of each permanently shadowed crater hosting a radar-bright deposit using MESSENGER images. Each crater was evaluated for the degree of freshness: the freshest craters display bright, radial rays, crisp rim crests, crisp wall terraces, distinct floor-wall boundaries, radially textured continuous ejecta deposits, well-defined continuous fields of secondary craters, and a general lack of superposed craters [6]. Based on crater morphology, we classified Prokofiev and Stieglitz as two of the youngest, primary impact craters ≥40 km in diameter between 70°N and 90°N that host water-ice deposits and are large enough to obtain useful CSFDs. Kandinsky is a smaller primary crater (60 km in diameter) that hosts a water-ice deposit and predates Prokofiev, but it is not large enough for the analysis. Other permanently shadowed primary craters may also be younger than Prokofiev and Stieglitz, but they do not host a radar-bright deposit [1].

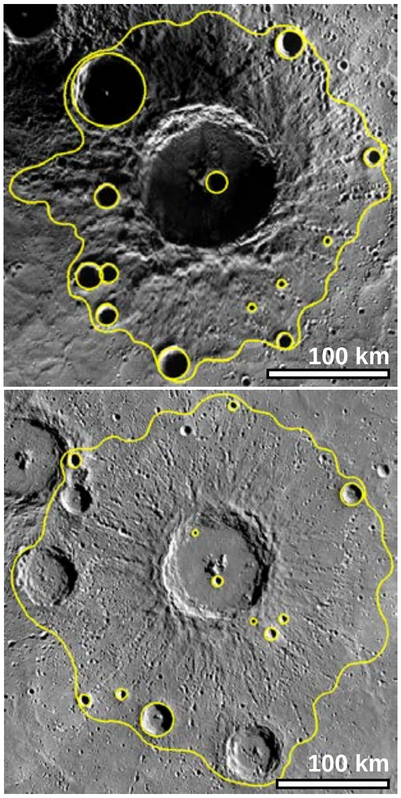

Fig. 1. Mosaics of regions surrounding (a) Prokofiev and (b) Stieglitz. The ejecta deposits of Prokofiev and Stieglitz are traced in yellow and primary impact craters (≥4 km in diameter) that post-date the craters (within the crater and ejecta) are circled.

Crater counts for these two specific craters were completed using the crater interior and ejecta deposit as the count area (Fig. 1). To avoid including secondary craters, only fresh, circular impact craters ≥4 km in diameter were included; a more strict limit of craters ≥10 km in diameter does not significantly change the calculated ages. We estimate the absolute ages of Prokofiev and Stieglitz craters using CraterstatsII [7] and a range of chronology and production systems (Table 1). Stieglitz has an age younger than that of Prokofiev. These ages and the craters' morphologies [11] imply that the craters are Calorian-to-Mansurian in age. These ages provide upper limits for the age of the ice present within Prokofiev and Stieglitz. If the polar ice deposits were emplaced all at once, then the age of Stieglitz crater provides a maximum age for all water ice deposits in the north polar region of Mercury.

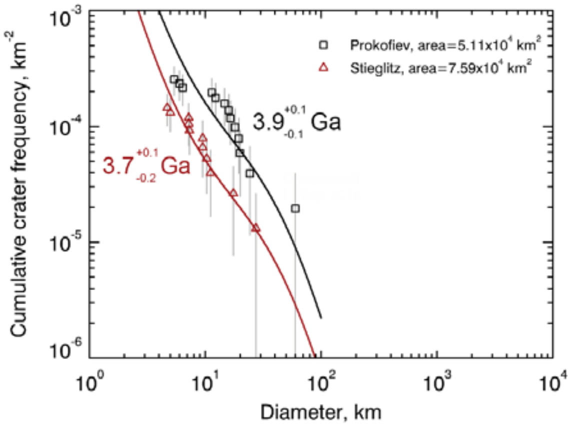

Fig. 2. CSFD illustrating crater counts for Prokofiev (black squares) and Stieglitz (red triangles), using chronology and production functions from Neukum et al. (2001) [9].

Crater	Chronology System			
	[8]	[9]	[10] non-porous	[10] porous
Prokofiev (*N* = 13)	4.0 Ga +0.1 -0.1 Ga	3.9 Ga +0.1 -0.1 Ga	3.7 Ga +0.1 -0.1 Ga	3.8 Ga +0.1 - 0.1 Ga
Stieglitz (*N* = 11)	3.7 Ga +0.1 -0.2 Ga	3.7 Ga +0.1 -0.2 Ga	1.7 Ga +1.0 -1.0 Ga	3.7 Ga +0.1 - 0.3 Ga

Table 1. Ages of Prokofiev and Stieglitz derived from a range of chronology and production systems [8–10]. Errors are from counting statistics alone and neglect systematic errors in the age model or fit.

Implications for the Source of Ice Deposits: It has been suggested that water ice was delivered to Mercury via episodic impacts of large comets or asteroids [12]. A recent impact could explain the fresh appearance of the sharp boundaries of the low-reflectance layers that insulate the majority of the polar deposits, for there is little positive evidence of regolith gardening having occured [13]. If a water-bearing impact did deliver the ice deposits to Mercury, then the maximum age of ~3.7 Ga determined here for the water ice also constrains the timing of the delivery to an impact that happened more recently than ~3.7 Ga.

Radar observations [14] indicate a dominantly pure water ice composition for the polar deposits, suggesting that the ice was emplaced all at one time. If the ice was delivered in a single event, the estimated ~3.7 Ga endmember age provides an upper boundary for the age of the ice-delivering impactor. Identifying the crater caused by an ice-delivering impactor can further constrain this estimation. Recently, mass estimations [15] suggest that the Hokusai impact could have contributed an amount of water ice comparable to the estimated total water mass on Mercury [3]. Hokusai is one of the largest and youngest craters on Mercury [11], with an extensive ray system and lack of superposed craters. The presence of rays indicates that Hokusai was formed in the Kuiperian period, and thus is younger than ~1 Ga [6], or possibly younger than ~140–320 Ma, as suggested by recently revised age constraints [16]. If Mercury's polar ice deposits were delivered in the Hokusai-producing impact, then the age of the polar deposits is much younger than the estimated host crater maximum of ~3.7 Ga, and could have been emplaced as recently as the Kuiperian (1 Ga [6] or 320 Ma [16]).

Alternatively, ice from multiple impacts may have accumulated over time, or ice may have been deposited, sublimated, and resupplied (these possibilities being not mutually exclusive). If the water-ice deposits are as old as the ~3.7 Ga host craters, then it is plausible that multiple impacts have delivered ice over this substantial geologic time. It is unlikely that Hokusai is unique as a candidate for delivering substantial amounts of ice, and many large impacts could have delivered ice over the last ~3.7 Ga.

Finally, it is possible that some of Mercury's polar ice deposits originate from planetary outgassing, and this possibility needs to be explored further, given the substantial evidence for effusive and explosive volcanic activity [16]. Most of the volcanic activity on Mercury is ancient (~3.7–3.9 Ga [18]), although some small-scale and pyroclastic eruptions appear to be more recent.

Comparison to Lunar Polar Deposits: The Moon lacks the concentrated surface ice deposits seen on Mercury. The source of lunar ice deposits has also been suggested to be an episodic delivery mechanism, rather than a steady state source, because of the heterogeneity of the deposits [19]. A recent impact event on Mercury could resolve the lack of Mercury-type polar deposits on the Moon; if Mercury experienced a large cometary impact in the relatively recent past that delivered the majority or all of its observable water-ice deposits, then perhaps the Moon has not experienced a similar event as recently as Mercury.

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