A FRESH LOOK AT THE STRATIGRAPHY OF NORTHERN AUSTRALE.

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Introduction: The roughly circular collection of mare deposits centered at ~38.9°S, 93°E is often referred to as Mare Australe [1]. It is located outside of the Procellarum KREEP Terrain [2]. The circular arrangement of Australe's mare patches has suggested an ancient, heavily degraded or relaxed impact basin roughly 900 km in diameter [3]. The mare deposits are generally thought to have erupted into smaller post-basin craters [1]. The type, volume, and distribution of mare eruptions potentially resembles the early stages of basin-filling mare events, but which are preserved in Australe [1] and some farside locations [4,5].

Gravity data suggest that if there was a basin, it is much smaller than originally proposed (now ~600 km) and located in the northern part of Mare Australe **(Fig. 1, dotted ellipse)**, between Humboldt, Milne, and Jenner craters [6]. As a whole, Mare Australe lacks the topography typically associated with a basin; however, northern Australe has a slight topographic depression that roughly corresponds to the basin-like Bouguer gravity signature in the same area [6]. The compositions exposed in Humboldt crater suggest that a pre-existing basin might have excavated deeper crustal material [7]. However, the underlying cause of the circularity of Mare Australe's deposits, particularly those extending outside of the potential impact basin setting, is not yet understood. Thus, Australe may preserve fundamental information about mare volcanism potentially uncoupled from basin formation and structure.

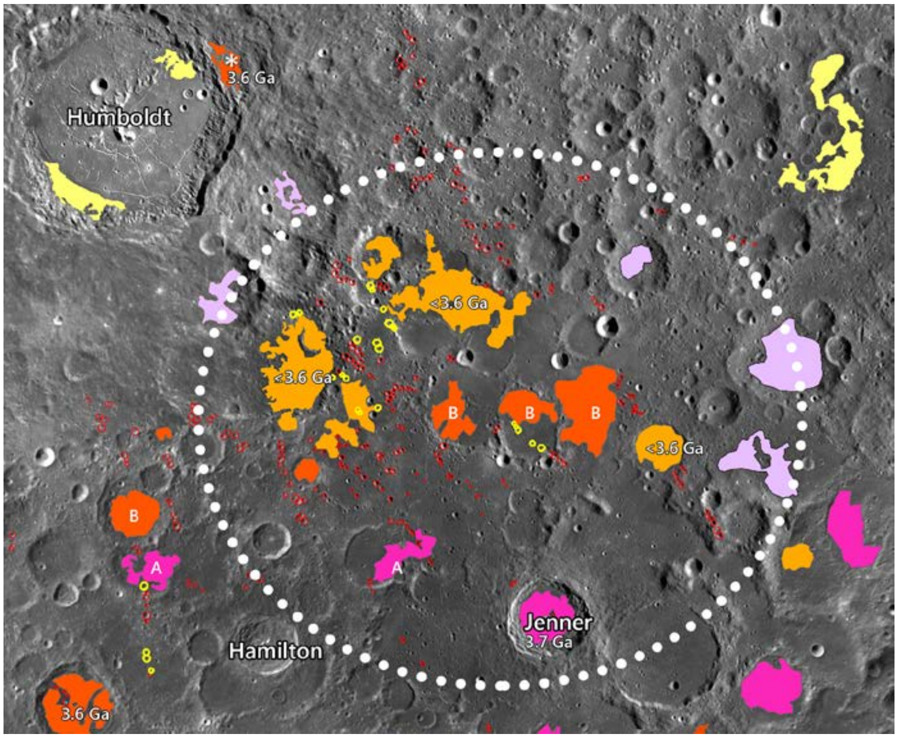

Figure 1. *Northern Australe. Dotted ellipse = approx. basin boundary. Small red circles = Humboldt's secondary craters. Yellow circles = modified or embayed secondary craters. Yellow polygons = mare deposits outside the basin. Lavender = older plains. Yellow-Orange = mare deposits <3.6 Ga (and younger than Humboldt crater). Dark orange = deposits roughly the same age as Humboldt, but which stratigraphically post-date its secondary craters (*melt deposit adjacent to Humboldt). Dark pink = deposits with CSFD ages significantly older than Humboldt. Deposits marked with "A" provide ages >3.6 Ga, but lack secondary craters and might be stratigraphically younger than Humboldt. Deposits marked with "B" provided ages ≥ 3.6 Ga, but which must be stratigraphically younger than Humboldt.*

The objectives of this study are to use new high-resolution data (images, gravity, topography, and composition) to reassess Australe's mare deposits, determine the timing and style of volcanism, identify discrete basalt deposits, and to further characterize the evolution of magmatism and subsurface structure in this area. Here, we focus on the northern Australe deposits (between Humboldt, Jenner, and Milne). As originally noted by Whitford-Stark (1979) [1], Humboldt crater and its ejecta make an excellent stratigraphic marker that can be traced across much of the Australe region. The ejecta serves as a stratigraphic constraint for absolute model ages (AMAs) derived from crater size-frequency distributions (CSFDs).

Methods and Data Sources: We utilized a variety of data from NASA's Planetary Data System, JAXA's Kaguya archive, and LROC Quickmap layers. We build here on our previous research [8,9] on Mare Australe, which included numerous CSFD AMA measurements, topographic assessments, and compositions. The CSFDs were measured using the standard approach [10,11] with CraterTools in ArcGIS [12] and the AMAs were fit with craterstats2 [e,g., 13]. We also mapped the distribution of secondary craters from Humboldt crater, and classified Australe's mare deposits as pre- or post-Humboldt **(Fig. 1)**. The age of Humboldt crater (diameter 207 km) was recently determined by Martinot et al. (2017) to be 3.5 +/-0.1 Ga using an exterior melt deposit [7]. In our studies, we derived a similar age of 3.61 Ga +0.02/-0.03.

Interpretations: We found AMAs ranging from ~3.3 to 3.8 Ga in north Australe. Hiesinger et al. (2011) [11] reported a similar range spanning 3.1 to 3.9 Ga [11] across the Australe region. Further, Hiesinger et al. did not find evidence to support the previously proposed ring of younger deposits suggested to be associated with an outer ring structure of a basin [1], which would also be inconsistent with the newer gravity-based interpretation of the north Australe basin [6]. We found that most of Australe's maria have ages >3.5 Ga and the younger deposits are concentrated in north Australe. Perhaps a smaller basin structure in this area enhanced the duration of volcanism by providing more pathways to the surface over time. However, we also observed that in some cases, CSFDs provided ages greater than the inferred stratigraphic age of the deposit (**Fig. 1**). Further work is needed to investigate these inconsistencies, but potential causes include: the variable effects of secondary craters on the CSFD ages, or thin or mixed mare deposits that yield CSFDs not completely representative of the surface unit.

Another outstanding question about Australe's mare deposits is the number and location of eruptive vents. The flow pathways and textures (**Fig. 2A**) in and around Barnard D (**Fig. 2B**) suggest that Australe's deposits are not always discrete, but can be interconnected. Mare flows could have drained into this crater from both the east and the south. On the other hand, Lyot crater exhibits two distinct-age mare units, previously interpreted as discrete small eruptions [1]. There are few obvious vents, few sinuous rilles, and no large floor fractured craters in Australe (other than Humboldt) [14], the latter suggesting that magma did not stall in the crust before erupting. The localized gravity anomaly and absence of a strong magnetic anomaly also suggest relatively few intrusions stalled out in the crust before reaching the surface, in contrast to South-Pole Aitken basin [15] or Marius Hills [e.g., 16]. In the future, we will continue to search for source vents and other indicators of the number and boundaries of mare flows. The type and form of eruptions will ultimately inform the structure of the subsurface and the style of mare eruptions in this area, as well as how they relate to other basin-filling maria.

Conclusions: So far, we have found that volcanism in northern Australe spans about 500 Ma (~3.3 to 3.8 Ga), excluding older cryptomaria. The age range is narrow compared to other mare deposits like those of Imbrium basin, which range from ~2 to 3.6 Ga [11], or South-Pole Aitken, which range from ~2.2 to 3.7 Ga [5], suggesting key differences in magmatism experienced at Australe and other basin-filling mare deposits.

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References: [1] Whitford-Stark 1979 Proc. 10th LPSC 2975-2994. [2] Jolliff et al. 2000 JGRP 105: 4197-4216. [3] Stuart-Alexander and Howard 1970 Icarus 12: 440-456. [4] Haruyama et al. 2009 Science 323: 905-908. [5] Pasckert et al. 2018 Icarus 299: 538-562. [6] Neumann et al. 2015 Sci. Adv. 10.1126/ sciadv.1500852. [7] Martinot et al. 2017 JGRP 10.1002/ 2017JE005435. [8] Lawrence, S. et al. 2015 LPSC #2739. [9] Lawrence, S. et al. 2017 LPSC #1844. [10] Neukum et al. 2001 SSR 96: 55-86. [11] Hiesinger et al. 2011 GSA Spec. Paper 477: 1-51. [12] Michael and Neukum (2010) EPSL 294: 223-229. [13] Kneissl et al. 2011 PSS 59: 1243-1254. [14] Jozwiak et al. 2015 Icarus 248: 424-447. [15] Purucker et al. 2012 JGRP 10.120/ 2011JE003922. [16] Deutsch et al. 2019 Icarus 331: 192-208.

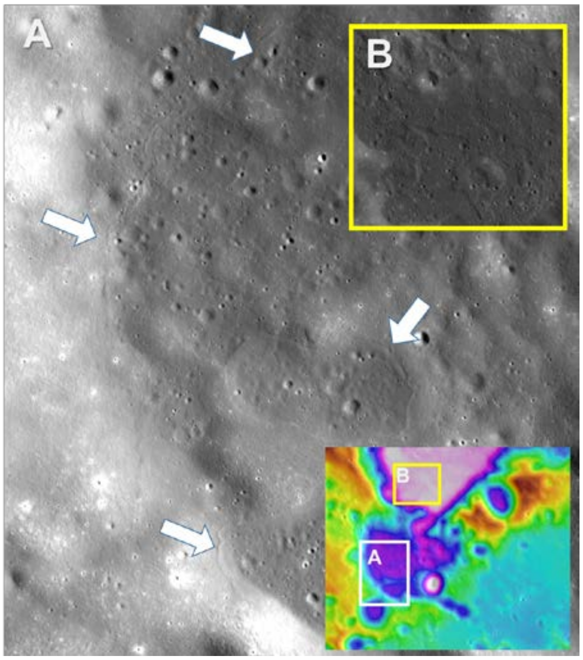

Fig 2. *A) Bathtub-ring-like texture S of Barnard D (arrows, image ~12 km across) and FeO-enhancement ~10 wt.% (FeO=15 wt.% in maria and surrounding terra ~5 wt.%). B) Atypical flow textures in Barnard D (image ~12 km across). Inset: GLD100 elevations (red=high, purple=low).*