DATING YOUNG MARE FLOWS: LICTHENBERG AND FLAMSTEED REGIONS. E. Hon[1,2] and J. Stopar[1], [1]Lunar and Planetary Institute, Universities Space Research Association, 3600 Bay Area Blvd, Houston TX 77058. [2]Department of Geology and Geophysics, University of Hawaii at Mānoa, 2500 Campus Rd, Honolulu, HI 96822, (ehon@hawaii,edu)

Introduction: The objective of this research is to investigate the ages and stratigraphy of two potentially very young mare deposits: the Flamsteed ring mare (FRM) and a mare deposit to the southeast of Lichtenberg crater (LCM), both located in Oceanus Procellarum. Schultz and Spudis (1983) estimated the FRM to be 900±400 Ma and the LCM to be 900±300 Ma [1], potentially making them some of the youngest known mare flows on the Moon. Improved knowledge of the timing, stratigraphy, and extent of the youngest mare deposits is critical to understanding the end stages of lunar volcanism. Thus, the FRM and LCM flows can help put into perspective not only the longevity of volcanic activity on the Moon, but also the volume of late-stage activity. This can lead to a deeper understanding of the Moon's thermal history and composition.

Background: Hiesinger et al. [2, 3] mapped numerous nearside mare units using primarily Clementine and Lunar Orbiter images, deriving young ages (<2 Ga) for several mare deposits. One of those is a deposit near Lichtenberg crater with a derived age of ~1.7 Ga (P53 unit [2, 3]); another is near Flamsteed crater, which has a derived age of ~1.3 Ga (P57 unit [2, 3]). The youngest derived age from Hiesinger et al.'s work is ~1.2 Ga for the P60 unit south of Aristarchus plateau [3].

Table 1. *Reported model ages of Lichtenberg and Flamsteed blue mare deposits and maria south of Aristarchus crater [1, 3-5].*

Mare name (unit label)	**1983 [1]**	**2011 [3]**	**2011 [5]**	**2018 [4]**
FRM (P35)	900±400 Myr	2.54 Ga	1.5 Ga	N/A
Lichtenberg (P53)	900±300 Myr	1.68/ 3.18 Ga	2.1 Ga	N/A
Aristarchus (P60)	N/A	1.2 Ga	1.73 Ga	~1.0 -2.7 Ga

New data and images have since been gathered, such as from the Lunar Reconnaissance Orbiter Camera (LROC) and Kaguya's Terrain Camera (TC). An investigation by Stadermann et al. (2018) using LROC data showed that the P60 unit south of the Aristarchus plateau can be interpreted as a series of deposits spanning ~1 Ga to 2.7 Ga, getting older from west to east [4]. Morota et al. (2011) used Kaguya data to redate many of the units defined earlier by Hiesinger et al. (2011), finding that FRM (P35) and LCM (P53) to be ~1.5 Ga and ~2.1 Ga in age, respectively [5]. The FRM (P35) unit was assigned a much older age by Hiesinger et al. of ~2.45 Ga. Constraining ages reported by Hiesinger et al. [3] and Morota et al. [5], as well as the wide range of ages found by Stadermann et al. [4] (**Table 1**), suggest that many compositionally uniform mare units are, in fact, composed of deposits of differing ages. Alternatively, we might be at the limits of our current ability to accurately date young mare deposits by these methods.

Methods: The definition of mare units for age determinations here is based on LROC and TC images, as well as Kaguya Multiband Imager (MI) and Clementine UVVIS color ratio, FeO, and TiO_2 maps [6, 7]. Mare deposits of similar FeO and TiO_2 compositions were identified and grouped for CSFD analyses. Mapping was guided by previous geologic maps [8] and Hiesinger et al.'s units [2, 3]; however, our unit boundaries differ as a result of higher resolution data now available. Three compositional units are mapped: blue mare (high FeO and TiO_2), red mare (high FeO and lower TiO_2), and crater ejecta (low FeO and TiO_2). Topographic indicators, such as embayment of crater ejecta, also guide our maps and unit definition.

We use the standard Neukum et al. [9] methodology of determining model ages from crater size frequency distributions (CSFDs). We follow Stadermann et al.'s (2018) method for excluding crater ray material and secondary craters from the count regions [4]. Using ArcGIS [10], the primary craters in the chosen area were mapped with CraterTools [11] and their diameters recorded. Only craters 400 m or larger in diameter have been used to determine model ages to avoid the effects of crater scaling and degradation as a function of target strength [12].

Secondary craters were created by both Flamsteed and Lichtenberg craters, as well as other large craters near the study areas. When the secondary craters are close to their crater of origin, they are asymmetric in shape and have v-shaped ejecta [4]. We excluded obvious close-range secondary craters, as well densely clustered craters (probable secondary craters). Other areas of potential resurfacing were also excluded from the CSFD areas, including wrinkle ridges.

Lichtenberg Crater Mare: Deposits in the LCM group are composed of blue mare (high TiO_2 and FeO), which are stratigraphically the youngest deposits present. The western edge of the mare deposits embay Lichtenberg crater (diam. 20 km). We performed CSFD analyses across the blue mare deposits (P53 unit). The oldest derived age within the blue mare deposit is adjacent to Lichtenberg crater, with younger ages to the east. Color data suggest multiple flows within the blue mare deposits (**Fig 1.** and [13]). The blue mare deposits overlie older red mare deposits with ages ~3.5 Ga. Intermediate mare and blue mare were emplaced ≥ 1 billion years after the red mare. Source vents are not obvious within the blue mare, but these flows could have been sourced from the Aristarchus plateau.

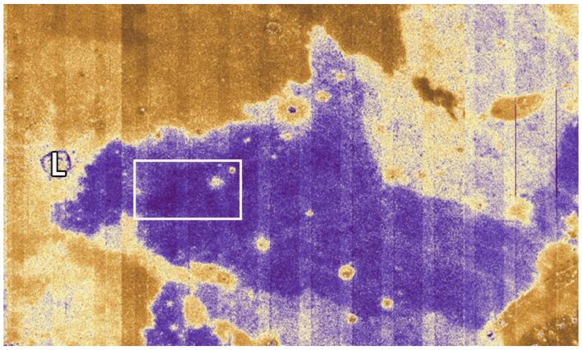

Fig. 1: *Kaguya MI 415/750 nm ratio image. Blue mare deposits have a high ratio (shown as purple-blue); red mare have a low ratio (orange-red). Lichtenberg crater (L) is 20 km in diameter; Lichtenberg crater is embayed by blue mare flows. The white box indicates a color variation within the blue mare group.*

Flamsteed Ring Mare: The FRM is located within an ancient crater rim bounded by Flamsteed crater (diam. 21 km) to the south. The FRM is composed of blue mare deposits (**Fig. 2**). The P57 unit is located to the northwest. Blue mare deposits extend northeast of the crater; these deposits also have the highest TiO_2 and FeO contents in the vicinity. The red mare deposits surrounding the region have an age ~3 Ga and underlie at least part of the blue mare. We found that the youngest CSFD-derived ages are associated with the areas of highest TiO_2 and FeO contents; these flows were emplaced ≥ 1.5 billion years later. The youngest areas do not correlate well with the areas previously selected for CSFD age-determinations (i.e., P35 unit).

Discussion: Our CSFD-derived ages for the red mare deposits near Lichtenberg and Flamsteed craters are similar to those found by Heisinger et al. [3] in the same regions. However, for the younger blue mare deposits, we found some age discrepancies. Nonetheless, we did confirm the presence of young mare deposits (< 2 Ga) near both Lichtenberg and Flamsteed craters. In both regions, the blue mare deposits were emplaced ≥ 1 billion years after the earlier red mare flows. Variations in CSFDs within both the LCM and FRM deposits suggest that the deposits may represent different eruptions spanning >500 million years, as suggested by possible observed flow boundaries.

The areas we selected for the blue mare CSFD analyses are complex and reflect both apparent geologic/compositional units and also the exclusion of ray material and secondary craters. Exact flow boundaries are difficult to map from orbital datasets because compositional variations can be gradational even in the new higher resolution data.

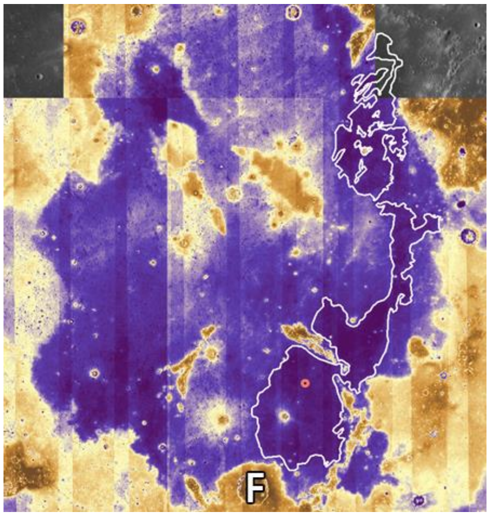

Fig. 2: *Kaguya MI 415/750 nm ratio image. Blue mare deposits have a high ratio (purple-blue); red mare have a low ratio (orange-red). Flamsteed crater (F) is 21 km in diameter. Deposits with the highest TiO_2 and FeO content outlined in white.*

Conclusion: We have derived a range of relatively young ages < 2 Ga for the FRM and LCM flows. These, combined with Stadermann et al.'s [4] ages for the maria south of Aristarchus, suggest that the definition of geologic unit plays a critical role in determining representative surface ages. Further work is still needed to determine whether the range we observed in derived ages across the blue mare deposits is a function of the ability of current CSFD techniques to resolve young ages, or if it reflects individual eruptive events.

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