SAMPLING THE YOUNGEST AND OLDEST MARE BASALTS: IMPORTANT LUNAR REGIONS

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Introduction: The timing and duration of lunar mare volcanism is poorly constrained, because mare basalts are incompletely sampled. Radiometric analyses of existing basalt samples from the Moon—which include Apollo samples, Luna samples, and lunar meteorites—indicate mare volcanism occurred from ~4.3 Ga [e.g., 1] to ~2.8 Ga [2]. However, mare surface ages estimated from crater frequency measurements indicate mare volcanism may have persisted until ~1.0 Ga [3-5]. Resolving the duration of mare volcanism will greatly improve models for the thermal evolution of the Moon and has, thus, been identified by the National Research Council (NRC 2007; [6]) as a key scientific goal during the next phase of lunar exploration. Directly sampling and radiometrically dating mare basalt samples is currently the only unequivocal way to quantify their age. To determine where elements of the Constellation Program or complementary robotic programs should land for suitable samples, we evaluated the oldest and youngest mare deposits. Presented here is a brief summary of the current knowledge of mare basalt ages and a set of exploration targets where the youngest and oldest mare basalts may be found.

Youngest Mare Basalts: The youngest directly dated mare basalts obtained from the Apollo and Luna sample return missions have radiometric ages no younger than ~3.08 Ga [7]. The youngest basalt sample obtained from the Moon thus far is lunar meteorite Northwest Africa 032 (an unbrecciated basalt), which has a radiometric age of ~2.8 Ga [2]. However, model surface age estimates suggest that some mare basalt flows may be as young as ~1 Ga [3-5, 8].

Figure 1 shows the model ages for most of the visible mare basalt surfaces on the Moon, which have been compiled from the work of several investigators [3-5, 9-12]. According to these model ages, the very youngest mare basalt flow appears to embay the southernmost margin of the Aristarchus Plateau (AP in Fig. 1) and has an estimated surface age of ~1.2 Ga [4]. This locality lies in close proximity to volcanically complex locales (i.e., the Aristarchus Plateau and Harbinger Mtns.), and is, thus, in a region that can be used to address several other exploration objectives [e.g., 13].

A few small areas may have slightly younger mare basalts (e.g., the nearby and potentially ~0.9 Ga old mare embaying the eastern rim of the crater Lichtenberg, LC [8]), but these estimated ages are less certain. For that reason, these areas may be good secondary targets. Based on the crater-count work of [3-5]—which stands as the most thorough and comprehensive study of the relative ages of nearside mare basalts to date—and the crater-count work done on the lunar farside mare by other investigators represented in Fig. 1 [9, 10, 12], the basalt flow embaying the southern margin of the Aristarchus plateau is the least-densely cratered mare on the lunar surface and, thus, the best candidate for collecting samples of the youngest mare.

Oldest Mare Basalts: Basalt samples found among lunar meteorites and as clasts within Apollo impact breccias have radiometric ages as old as ~4.3 Ga [e.g., 1, 14]. In contrast, crater-frequency-based model ages of exposed mare surfaces do not appear to be greater than ~4.0 Ga (Fig. 1). It thus appears that the oldest mare basalts may be buried and relatively inaccessible. The buried mare basalts, termed *cryptomare*, are generally considered to be the oldest mare basalts [e.g., 8, 15], and, thus, their locations and accessibility on the lunar surface will be the focus here.

Most cryptomare have been identified by the presence of dark-halo impact craters (DHCs) and mafic geochemical anomalies in the highlands revealed by remote spectral data [8, 15-17]. Light plains topography has also been considered an indicator of cryptomare as their smooth texture might indicate buried mare basalt plains [15]. Figure 2 shows an overlay of the global distribution of DHCs, the Lunar Prospector Gamma Ray (LP-GRS) spectrometer Fe-abundance map (which reveals mafic geochemical anomalies in the highlands), and light plains across the lunar surface. Most regions where these features overlap (outlined in Fig. 2) are major regions of cryptomaria where the oldest mare basalts may occur.

DHCs are impact craters where low albedo material has been excavated from beneath higher albedo material by an impact event, producing a ring of dark ejecta material surrounding the impact crater [15], and have long been recognized to be indicators of buried mare deposits [18]. Because DHCs have excavated buried, potentially ancient basalts directly onto the lunar surface in the form of their dark haloes, the dark haloes are ideal locales for sampling such basalts.

Most regions outlined in Fig. 2 contain abundant DHCs. Examples of DHCs that might have excavated the oldest cryptomare may be found in the Balmer-Kapteyn (B-K) and Lomonosov-Fleming (L-F) regions. These DHCs include the craters named Kapteyn-B in B-K [17] and the craters named 3 and 11 by

[16] in L-F. Kapteyn-B is by far the largest DHC (diameter=39km) in the B-K region [17], and because craters with larger diameters excavate material from greater depths, the dark halo around Kapteyn B might contain some of the deepest (and, thus, oldest) cryptomare in the region. Craters named 3 and 11 in the L-F region excavate material from beneath Nectarian-pre-Nectarian aged terra mantling material [16], excavating basalt material older than any exposed mare surfaces.

Summary: The youngest mare basalt on the lunar surface appears to embay the southern margin of the Aristarchus Plateau, which is a good target for a mission that obtains samples for radiometric age determinations. The buried cryptomare appear to be the oldest basalts on the lunar surface and are best exposed at the surface via DHCs. Thus, a dark halo surrounding a DHC is another good target for a mission that samples material for radiometric age determiniations. Examples of the oldest cryptomare may be around DHCs in the Mendel-Rydberg and Lomonosov-Fleming regions of the Moon.

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References: [1] Terada K. et al. (2007) *Nature 450*, 849-852. [2] Fagan T. J. et al. (2002) *MAPS 37*, 371-394. [3] Hiesinger H. et al. (2000) *JGR 105*(E12), 29239-29276. [4] Hiesinger H. et al. (2003) *JGR 108*(E7), 5065. [5] Hiesinger H. et al. (2008), *LPSC 39*, #1269. [6] NRC (2007) The Scientific Context for Exploration of the Moon: Final Report, 120pp. [7] BVSP (1981) 1286 pp., Pergamon, New York, NY. [8] Schultz P.H. and Spudis P.D. (1983) *Nature*, *302*, 233-236. [9] Tyrie A. (1988) *EM&P 42*, 245-264. [10] Greeley, R. et al. (1993) *JGR 98*(E9), 17183-17206. [11] Neukum G. and Ivanov B.A. (1994) in *Haz. Due to Comets and Asteroids*, 359-416, Univ. of Ariz. Press, Tucson, AZ. [12] Haruyama, J. et al. (2009) *Science, 323,* 905-908. [13] Korteniemi J. et al. (2010) *LPSC 41,* #1339. [14] Taylor L.A. et al. (1983) *EPSL 66*, 33-47. [15] Antonenko I. et al. (1995) *EM&P 69*, 141-172. [16] Giguere, T. A. et al. (2003) *J.G.R., 108*(E11), 5118. [17] Hawke, B.R. et al. (2005) *J.G.R., 110*, E06004. [18] Schultz P.H. and Spudis P.D. (1979) *Proc. LPSC 10*, 2899-2918.

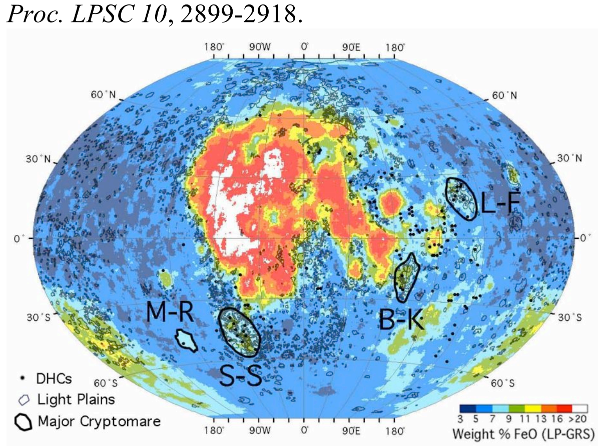

Figure 2 (above). The global distribution of DHCs (black dots, [18]), light plains (faint grey outlines, [15]), and mafic geochemical anomalies in the highlands (revealed by the LP-GRS Fe-abundance map). Major cryptomare regions are darkly outlined (after [17]): M-R= Mendel-Rydberg, S-S= Schiller-Schickard, B-K= Balmer-Kapteyn, L-F= Lomonosov-Fleming.

Figure 1 (below). Clementine UV-VIS mosaic map showing the surface model ages (ranging from 1 Ga, red, to 4 Ga, fuchsia) of most major mare basalts on the lunar surface, compiled using the work of [3-5, 9-12].