ANCIENT LUNAR MARE VOLCANISM: IDENTIFICATION, DISTRIBUTION, AND COMPOSITION OF CRYPTOMARE DEPOSITS.
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Introduction: Cryptomaria [1] are defined as ancient basaltic volcanic deposits on the Moon hidden from direct surface exposure by burial or dusting by high-albedo material, such as feldspathic impact ejecta. Although young craters can produce cryptomaria (e.g., Copernicus impact ejecta covers Imbrian-aged mare deposits), the term more commonly refers to ancient mare deposits that predate the latest impact basins, such as Orientale and Imbrium. Typically, ancient cryptomare deposits are characterized as relatively bright smooth plains and can be confused with Cayley Formation plains deposits, which are often interpreted to be ponded impact basin ejecta [2]. As first outlined in the 1970s, cryptomare deposits were confirmed by the presence of dark-halo craters [e.g., 3], craters that have impacted into a high-albedo surface and excavated low-albedo basaltic material. Concentrations of dark-halo craters on high-albedo smooth plains deposits indicate the existence of a buried volcanic deposit. Additionally, the occurrence of bright, but basalt-rich soils in the absence of an exposed mare deposit is another indication that a buried volcanic deposit is present [e.g., 4, 5].

Currently there are approximately 21 proposed cryptomare regions (Fig. 1) located across the Moon [e.g., 3-8]. Typically cryptomare deposits occur on the boundary between a large mare basalt deposit and the lunar highlands, such as Oceanus Procellarum and Humorum [5], or within a large crater or basin like Mendel-Rydberg [8]. Additionally, there are several identified cryptomare deposits located near more ancient degraded basins, such as Australe [4] and Schiller-Zucchius basins [4, 6]. Finally, some cryptomaria occur beneath ejecta from large Imbrian-aged (and even younger) craters, such as Tsiolkovskiy (Fig. 2).

Critical questions being addressed in this study include: When and where did “mare” volcanism start? What was its areal distribution and mode of occurrence? Did it change in mineralogy and composition with time? When is the end of the early cryptomaria period (e.g., is it the Orientale basin-forming impact?)? How can an increased knowledge of cryptomaria help to understand early volcanism on Mercury and the origin of intercrater plains? To address these questions we are evaluating each of the 21 proposed lunar cryptomare locations and mapping the distribution of ancient cryptomare deposits across the rest of the lunar surface.

Methods: Several datasets were used to identify and map out the distribution of cryptomare deposits, including the Lunar Reconnaissance Orbiter Camera (LROC) visible images [9], Lunar Orbiter Laser Altimeter (LOLA) topography [10] and surface roughness [11] data and the Moon Mineralogy Mapper (M^3) spectroscopic data [12]. Several different surface roughness baselines (e.g., 0.5, 0.8 and 1.8 km) were analyzed to investigate deposit smoothness on a variety of scales.

Initially, those regions previously identified as cryptomare deposits [e.g., 3-8] were surveyed using LROC visible images to identify dark-halo craters and basalt-rich soils by looking for variations in the surface albedo. LOLA surface roughness data were analyzed in these proposed cryptomare regions to identify the smoothest deposits and try to distinguish between ponded ejecta deposits and ejecta overlying volcanic deposits. M^3 spectroscopic data were used to identify

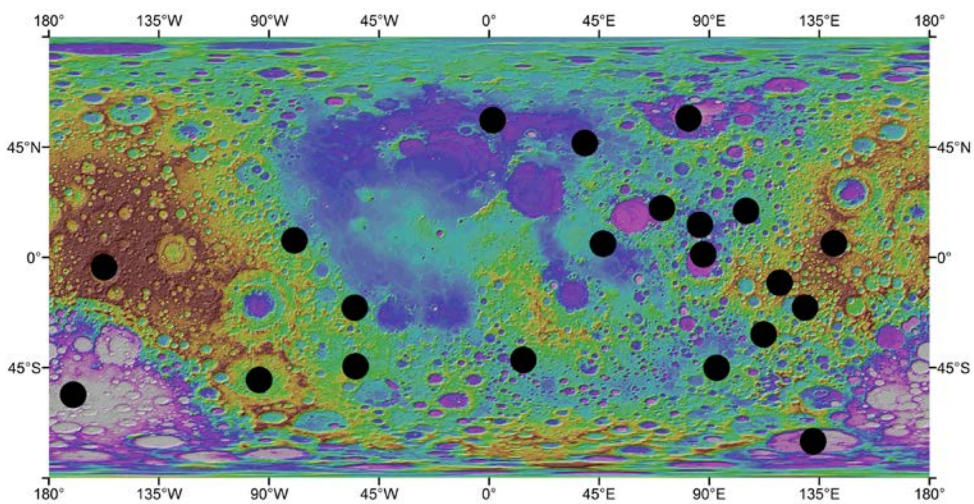

Figure 1. Location of the proposed sites of cryptomare deposits [e.g., 3-8] (black dots). Warm colors represent high-standing topography and cooler colors represent low-lying topography. LOLA 128 pixels/degree topography overlaying hillshade.

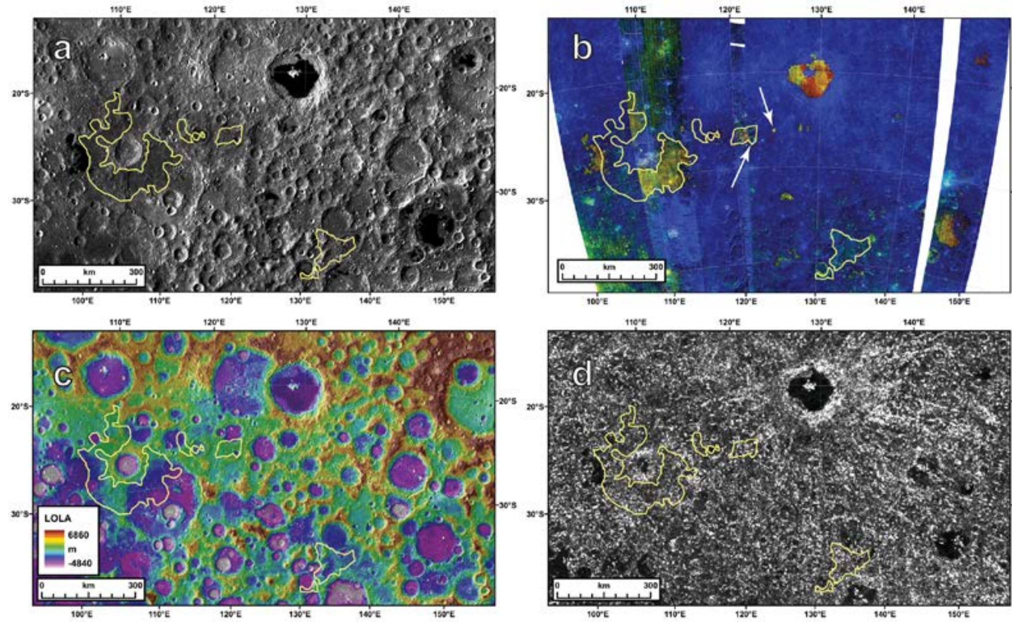

Figure 2. Tsiolkovskiy cryptomare study region. a) LROC image data; b) M^3 mafic composite of optical periods 2C1 and 2C2. White arrows point out craters excavating mare basalts (R: 1 µm integrated band depth, G: 2 µm integrated band depth, B: Reflectance at 1489 nm); c) LOLA topography and; d) LOLA surface roughness, baseline ~1.8 km. Yellow polygons are the outlines for the mafic-rich soil regions defined in this study.

regions of mafic-rich soil, by looking for non-mare soil regions with the largest 1 and 2 µm absorptions (Fig. 2, yellow polygons), and to compare the composition of dark-halo craters to exposed mare basalts. Two different methods, the Modified Gaussian Model (MGM) [e.g., 13] and a parabola fitting routine, were used in order to determine the mineralogy of these volcanic deposits.

Discussion: Most of the identified cryptomare deposits (Fig. 1) are located in the eastern hemisphere in regions of low topography, either around the edge of exposed mare basalt deposits or in large craters and basins. The compositions of the exposed mare basalts and dark-halo craters examined thus far are not distinguishable using the MGM model, suggesting very similar mineralogies between the older (cryptomaria) and younger (exposed) basalt deposits. The ability to detect mafic-rich soils is strongly controlled by the number and proximity of large impacts in the cryptomare region. Cryptomaria deposits closer to primary craters or basins are covered by thicker ejecta deposits, increasing the non-mare component in ejecta/substrate mixtures [2] and, therefore, reducing the mafic signature.

Among our cryptomare analyses is the Tsiolkovskiy region (Fig. 2), an area that enables us to explore further the nearside/farside mare basalt dichotomy. We have mapped (M^3) mafic-rich soil regions southwest of Tsiolkovskiy crater indicating the presence of a cryptomare deposit. Additional evidence confirms the existence of a cryptomare deposit, including basaltic spectral signatures in a dark-halo crater in Neujmin crater and exposed as layers in the wall of Neujmin T crater (arrows, Fig. 2b). The proximal Tsiolkovskiy ejecta deposit is too young and too thick to have been subjected to enough vertical mixing to produce a strong mafic soil signature derived from pre-Tsiolkovskiy mare deposits, making identification of other cryptomare deposits more difficult unless features such as dark-halo craters (right arrow, Fig. 2b) are present. The exposed maria have been dated as Early Imbrian [14] and Neujmin T crater is even earlier Imbrian, predating the Orientale basin.

In summary, farside basaltic signatures in craters and soils indicate that there is a greater abundance of ancient mare basalt deposits in the Tsiolkovskiy region than previously known. The stratigraphic position of the cryptomare indicate that it is older than both Tsiolkovskiy and Neujmin T craters [15], suggesting a pre-Orientale age for the cryptomare. These detections increase the known area of mare basalt deposits on the lunar surface and suggest a more volcanically active farside in early mare history.

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