GRAIL SEARCH FOR CRYPTOMARIA. Michael M. Sori[1], Maria T. Zuber[1], James W. Head[2], and Walter S. Kiefer[3]. [1]Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139, USA (mms18@mit.edu); [2]Department of Geological Sciences, Brown University, Providence, RI 02912, USA; [3]Lunar and Planetary Institute, Houston, TX 77058, USA.

Introduction: Observations from the Gravity Recovery and Interior Laboratory (GRAIL) mission [1] have provided the most accurate and highest resolved gravity data of any planetary body to date from orbit [2]. Data from the Lunar Orbiter Laser Altimeter (LOLA) instrument [3] aboard the Lunar Reconnaissance Orbiter (LRO) [4] are providing the most accurate and spatially dense topographic map of the Moon. Combination of these two data sets has allowed for construction of a global map of lunar Bouguer anomalies [2]. Positive Bouguer anomalies must be associated with mass excesses relative to the reference density [5], such as mantle uplift associated with large impact basins. In this study, we use a positive Bouguer anomaly map, such as that seen in Fig. 1, to investigate potential cryptomaria deposits.

Cryptomaria: Lunar maria are basaltic extrusions found on the Moon's surface and characterized by lower albedo than the anorthositic highlands. Cryptomaria are similar volcanic deposits, but are overlain by higher albedo material (such as impact ejecta) and thus hidden from direct visual observation [6]. Since cryptomare deposits are believed to be generally older than 3.8 Ga, understanding their volume and spatial distribution is crucial to understanding the Moon's early volcanic (and thus thermal) history.

Previous studies have used a variety of geological and remote sensing evidence to infer the existence of deposits of cryptomaria, particularly the presence of dark-haloed impact craters [7–9]. Such craters excavate through the surficial deposits and into the underlying low-albedo basaltic material, producing a dark circular emplacement of ejecta. Constraints on the thickness of the cryptomaria unit and the high-albedo cover can be inferred from the dimensions of the crater. The global distribution of cryptomaria known to date is shown in Fig. 3 [10].

Procedure: Since cryptomaria are composed of basalts that are of higher density than the anorthositic crust, they should exhibit positive Bouguer anomalies. The highest resolution map that we use here is a spherical harmonic model of the gravitational field to degree and order 660 [11]. However, we also study maps that contain different degrees and orders of the field to ensure that features of interest are not artificially produced by our choice of filter. One such map is shown in Fig. 1.

Once we have a map that reveals the Moon's positive Bouguer features, we identify those features that can be attributed to impact basins [12], igneous vertical tabular intrusions [13], or surface mare deposits [14]. We use a database of lunar impact features [15] and Lunar Reconnaissance Orbiter Camera (LROC) [16] images to assist in these identifications (Fig. 2). These features are eliminated as candidates for cryptomaria, and the remaining features are considered as being possibly attributable to such deposits.

For a given region of potential cryptomaria, we use estimates of the density of lunar igneous rocks [17] and equations as derived in [18] to produce constraints on the thickness of the deposit. This method assumes a density between 3100 and 3350 kg/m^3 for the deposits, a density of 2550 kg/m^3 for the lunar crust [5], and that the deposit of cryptomaria can be approximated as a rectangular prism. We also assume the cryptomaria deposits are close to the surface, or equivalently that the overlying high-albedo layers are thin.

Results: The most prominent positive feature in the GRAIL Bouguer anomaly maps that cannot be easily attributed to an impact basin, known region of surface maria, or vertical tabular intrusion is a largely continuous east-west feature that extends along most of the lunar nearside, centered approximately at a latitude of 50 degrees south. It can be seen in Fig. 1 and is the focus of this investigation.

The western end of this feature lies near the Schiller-Schickard area, which has previously been identified as a potential region of cryptomaria (Fig. 3). Previous study has yielded an average layer thickness of 1100 m on the basis of dark-haloed craters (DHCs) in the area, but this was suggested to be a minimum, as the largest DHCs may not be reaching the base of the deposits [19]. The largest DHC in this study suggested a local thickness estimate of 1942 m. Our method yields a thickness of between 1800 m and 2600 m, depending on the density chosen for the deposits.

The eastern end of the positive Bouguer feature overlaps with Mare Australe on the eastern limb of the Moon. The Bouguer anomaly there suggests a thickness of between 1500 m and 2200 m, again depending on the density chosen for the cryptomare deposits. Previous study has suggested the presence of cryptomaria in and near Australe, and proposed a thickness for mare materials between 500 m and 3500 m [20].

Most of the area of the positive Bouguer feature that lies between Mare Australe and the Schiller-Schickard region has not previously been identified with maria or cryptomaria. A small portion of it does overlap with the proposed Maurolycus deposit [10, 19, 21]. If it is associated with a near-surface region of cryptomaria, the Bouguer anomaly suggests an average thickness between 1000 m and 1500 m.

Discussion: We have identified areas of positive Bouguer anomalies that are both associated with and not associated with known cryptomaria sources. We consider the large positive Bouguer feature described in the previous section to be a strong candidate for association with a region of cryptomaria, in large part because the western and eastern ends of the feature, and the area near Maurolycus crater, contain geological evidence for such deposits. If this is the case, lunar volcanism was more prevalent than indicated by previous studies of mapped cryptomaria [10].

In our ongoing work, we are relaxing our assumption that the deposits can be approximated by a layer of constant thickness to get a more accurate picture of the three-dimensional geometry of cryptomaria and correlating the results with other approaches to the identification of cryptomaria using remote sensing data. We are also studying other smaller regions with positive Bouguer anomalies that do not have an obvious association with a previously known lunar feature, and correlating with ongoing geological analyses [10] as well as flooding experiments that can help in modeling cryptomare deposit geometry [22].

References: [1] Zuber M. T. et al. (2012) *Space Sci. Rev.,* doi: 10.1007/s11214-012-9952-7. [2] Zuber M. T. et al. (2012) *Science,* doi: 10.1126/science.1231507. [3] Smith D. E. et al. (2010) *Space Sci. Rev., 150,* 209-241. [4] Chin G. et al. (2007) *Space Sci. Rev., 129,* 391-419. [5] Wieczorek M. A. et al. (2012) *Science,* doi: 10.1126/science.1231530. [6] Head J. W. and Wilson L. (1992) *Geochim. Et Cosmochim. Acta. 56*, 2144-2175. [7] Schultz P. H. and Spudis P. D. (1979) *Proc. Lunar Planet. Sci. Conf., 10th*, 2899-2918. [8] Hawke B. R., and Bell J. F. (1981), *Proc. Lunar Planet. Sci. Conf., 12th*, 665-678. [9] Antonenko I. et al. (1995) *Earth, Moon, Planets,* 69, 141-172. [10] Whitten J. L. and Head J. W. III (2013) *LPSC XLIV*, 1247. [11] Zuber M. T. et al. (2013) *LPSC XLIV,* this issue. [12] Fassett C. I. et al. (2012) *J. Geophys. Res.,* 117, doi: 10.1029/2011JE003951. [13] Andrews-Hanna J. C. et al. (2012) *Science,* doi: 10.1126/science.1231753. [14] Hiesinger H. et al. (2011) *Recent Advances and Current Research Issues in Lunar Stratigraphy*, pp 1-51. [15] Head J.W. III et al. (2010) *Science*, doi: 10.1126/science.1195050. [16] Robinson M. S. et al. (2010) *Space Sci. Rev.,* 150, 81-124. [17] Kiefer W. S. et al. (2012) *Geophys. Res. Lett.* 39. [18] Blakeley R. J. (1995) *Potential theory in gravity and magnetic applications,* pg 441. [19] Antonenko I. (1999) Thesis. [20] Whitford-Stark J. R. (1979) *Proc. Lunar Planet. Sci. Conf., 10th*, 2975-2994. [21] Giguere T. A. et al. (1998) *LPSC XXIX*, 1782. [22] Whitten, J. L. et al. (2012) *LPSC XLIII,*1470.

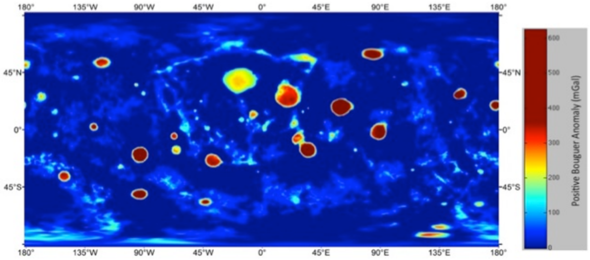

Figure 1. Global positive Bouguer anomaly map of the Moon from the GRAIL Primary Mission. The map is a cylindrical projection centered on the near side, plotting degrees and orders 7 through 340. It assumes a reference density of 2550 kg/m^3 [5] for the crust. All negative Bouguer anomalies are set to zero in this map in order to highlight the positive features.

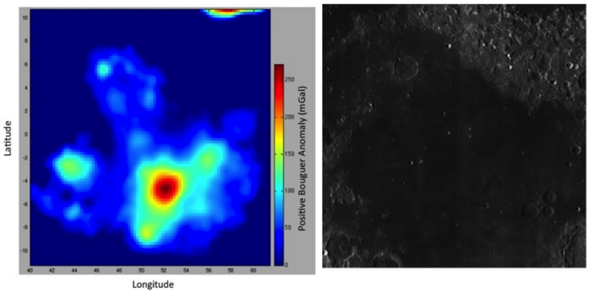

Figure 2. Example of a positive Bouguer anomaly that corresponds to a region of maria, in this case Mare Fecunditatis. The Bouguer map is in mGal (left) and is derived from GRAIL data [2], and the image is from LROC [16].

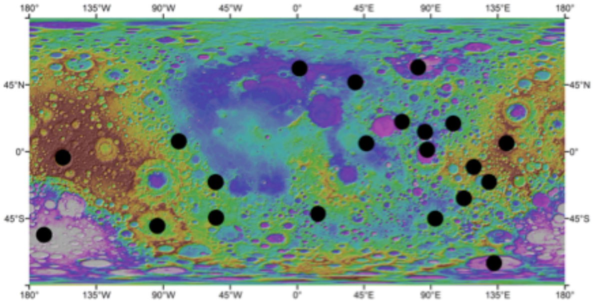

Figure 3. Location of the proposed sites of cryptomare deposits [e.g., 7-9] (black dots). Warm colors represent high-standing topography and cooler colors represent low-lying topography. LOLA 128 pixels/degree topography overlaying hillshade. From [10].