

EARHART: A LARGE, PREVIOUSLY UNKNOWN LUNAR NEARSIDE CRATER REVEALED BY GRAIL GRADIOMETRY. R. Sood¹, L. Chappaz¹, C. Milbury², D. M. Blair², H. J. Melosh^{1,2}, and K. C. Howell¹.

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Introduction: As a part of NASA's Discovery Program, the Gravity Recovery and Interior Laboratory (GRAIL) vehicles were launched in September 2011. The sister spacecraft, Ebb and Flow, mapped lunar gravity to an unprecedented precision [1]. High resolution data is currently being utilized to gain a greater understanding of the Moon's interior. Through gravitational analysis of the Moon, subsurface features are also detected. In the current investigation, gravity mapping data collected at different altitudes is applied to detect, characterize, and validate the presence of buried craters. The free-air gravity coupled with Bouguer gravity (corrected for topography and terrain) aids in recognizing gravitational footprints that may correspond to subsurface density anomalies. Detection of buried features is further supported by individually analyzing free-air and Bouguer gravity maps. Furthermore, forward modeling supports the detection and validates the existence of buried craters.

Detection Strategy: Previous work done by Chappaz *et al.*, (2014) makes use of two detection strategies based on gradiometry and cross-correlation to detect subsurface features. Gradiometry technique encompasses the calculation of the gravitational potential from a spherical harmonics data set. Specific truncation and tapering are applied to amplify the signal corresponding to the wavelength of the structures. By calculating the second partial derivatives of the potential function, the Hessian of the gravitational field is formulated. The largest eigenvalue and corresponding eigenvector associated with the Hessian determine the direction of maximum gradient. A secondary detection strategy, cross-correlation, utilizes the individual track data based on the relative acceleration between the two spacecraft as they move along their respective orbits.

Detection of Buried Craters: The apparent features investigated in this study are a completely buried anomaly within northern Mare Tranquillitatis and a partially buried rim of a speculated crater lying in the northwestern region of Lacus Somniorum (northeast of Mare Serenitatis). For reference, the Lacus Somniorum anomaly is designated as "Earhart", a provisional name selected by authors to honor a female explorer and early aviatrix. The vicinity around Earhart is filled with lava basalt with post mare formation impacts as shown in Fig. 1(a) using topography data collected by LOLA. Based on visual analysis of Fig. 1(a), a partially buried, discontinuous ring structure appears as illustrated by a black circle in Fig. 1(b). In order to confirm the presen-

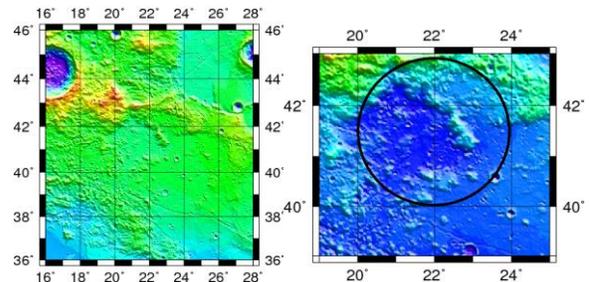


Fig. 1: (a) Topography near Earhart crater (left). (b) Earhart crater depicted by black circle (right).

ce of a subsurface anomaly, free-air and Bouguer gravitational data is exploited and employed in the detection process.

Gradiometry and Cross-Correlation: The gradiometry and cross-correlation detection techniques are applied to localized regions. Gravity models up to degree and order 900 with predetermined truncation and tapers are utilized. The top row of Fig. 2 illustrates the corresponding local averaged maximum eigenvalues for the free-air, Bouguer potentials, and the correlation between the two. The maps overlay local topography,

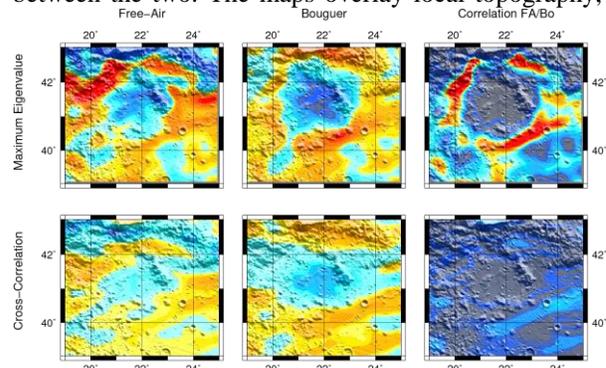


Fig. 2: Local gradiometry (top), cross-correlation (bottom) maps for free-air (left), Bouguer (center), and free-air/Bouguer correlation (right) for Earhart crater.

and the color represents the signed magnitude corresponding to the largest eigenvalue of the Hessian derived from the gravitational potential. The first row depicts a subsurface circular anomaly about 120 km in diameter, centered at 41.2° N and 21.8° E. As Earhart is a partially buried crater, both free-air and Bouguer eigenvalue maps show a circular anomaly. Thus, the correlation distinctively outlines the partially buried crater rim. The cross-correlation technique applied is shown in the second row of Fig. 2. The schematic

shows that for both free-air and Bouguer maps, the anomaly is detected, though not as pronounced as via the gradiometry technique. Both techniques provide evidence of a partially buried crater.

Free-air and Bouguer Gravity: Continuing the validation of Earhart crater, regional free-air and Bouguer gravity maps are generated. Fig. 3 illustrates local maps for the free-air gravity on the left and Bouguer gravity on the right. The two gravity maps

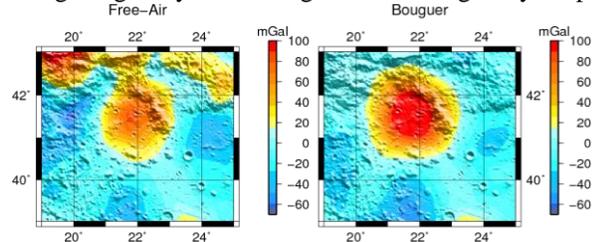


Fig. 3: Local free-air (left) and Bouguer (right) gravity map of Earhart crater with overlay of topography.

clearly outline the presence of a subsurface anomaly in addition to a partial rim structure seen in the topography. The central bulls-eye pattern illustrated in the two maps along with a circular rim-like structure suggests the presence of Earhart crater.

Forward Modeling: The gradiometry strategy relies on the gravity models derived from the GRAIL data to detect features of interest. The basis is a model that describes the gravitational signature of an anomaly and estimates the required parameters from the gradiometry maps. The objective is the development of a simple and computationally inexpensive strategy to describe the gravitational anomaly associated with a buried crater. A simple geometric shape model is constructed in terms of elementary blocks. Any crater feature in the forward model is a ring or a disk. It is assumed that the crater is buried in a mare emplacement with no topographical expression. Thus, the gravity anomaly for a given crater arises from the density contrast between crust, mare, and mantle materials. Then, the gravitational potential, anomaly, and hessian are computed for the forward model and compared with the initial simulation. The performance of the forward model is assessed by its ability to match the observed signatures that correspond to the features of interest on the gradiometry maps. To enable this comparison, an azimuthal average profile of the gravity anomalies is computed.

The forward model strategy is applied to Earhart crater. Several forward models are constructed as the potential crater size is unknown. One model that seems to capture the anomaly is a complex crater morphology with a pronounced mantle uplift; the corresponding shape model is illustrated in Fig. 4. The gravity anomaly and the eigenvalue for the forward model are computed and displayed in black on the left and right plots,

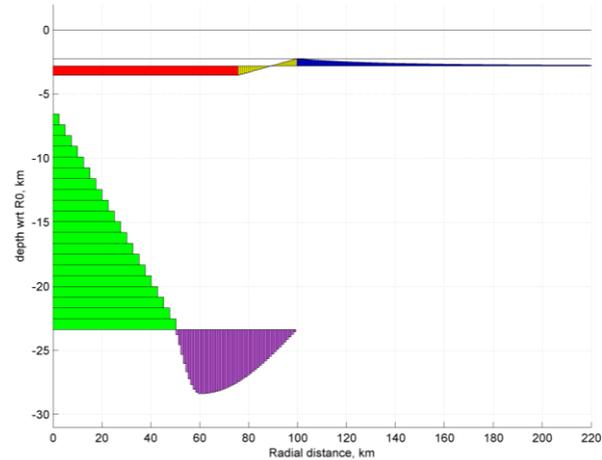


Fig. 4: Shape model for Earhart crater including lava fill (red), rim (blue), rim/floor transition (yellow), mantle uplift (green), and crustal bulge (purple).

respectively, in Fig. 5. For comparison, the profiles from the GRAIL data are also overlaid in blue, and

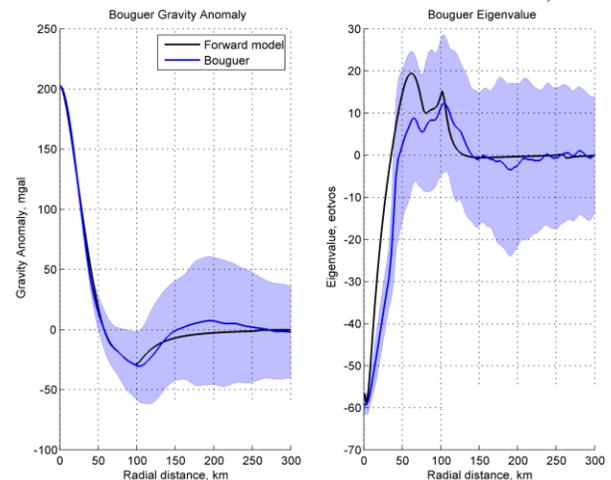


Fig. 5: Bouguer gravity (left) and eigenvalue (right) azimuthal profiles for Earhart crater with GRAIL data (blue) with 1- σ envelope and forward model (black)

although the agreement between the data and the forward model is not complete, the initial fit is satisfying.

Conclusions: Lunar gravitational analysis using gradiometry and cross-correlation techniques lead to the detection of buried craters. As a part of the validation process, both partially and completely buried structures are investigated. Gravitational footprints corresponding to Earhart crater are confirmed from free-air and Bouguer gravity maps. Forward modeling further supports the detection and validated the presence of partially buried Earhart crater.

References: [1] Zuber *et al.* (2013) SSR 178, 1. [2] Chappaz *et al.* (2014) AIAA DOI:10.2514/6.2014-4371.