GRAIL Gravity Observations of Lunar Volcanic Complexes

Walter S. Kiefer[1], Patrick J. McGovern[1], Jeffrey C. Andrews-Hanna[2], James W. Head III[3], James G. Williams[4], Maria T. Zuber[5], and the GRAIL Science Team, [1]Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston TX 77058, USA (kiefer@lpi.usra.edu), [2]Dept. of Geophysics, Colorado School of Mines, Golden CO 80401, USA, [3]Dept. of Geological Sciences, Brown University, Providence RI 02912, USA, [4]Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA 91109, USA, [5]Dept. of Earth, Atmospheric and Planetary Sciences, MIT, Cambridge MA 02139, USA.

Introduction

Lunar gravity observations provide our primary tool for understanding lateral variability in the structure of the Moon's crust and mantle. Over the last year, NASA's Gravity Recovery and Interior Laboratory (GRAIL) mission markedly sharpened our view of the Moon's gravity [1]. The current GRAIL gravity model has a resolution that is about a factor of 6 better than the best pre-GRAIL gravity models, and the resolution is expected to continue to improve as the full set of extended mission observations are analyzed [2]. These observations are leading to new constraints on the volume, thickness, and compensation state of lunar volcanic fields such as the Aristarchus Plateau, the Rümker Hills, Cauchy, Gardner, Hortensius, Tobias Mayer, Compton-Belkovich, and the Gruithuisen and Mairan Domes. Mapping of dense intrusive structures such as dike swarms and sills in some of these volcanic fields helps to define the magmatic plumbing that fed the volcanism.

Aristarchus Plateau

The Aristarchus Plateau is a geologically complex highland in northern Oceanus Procellarum, diamond shaped in map view and approximately 170 by 220 km across. It contains a high density of diverse volcanic landforms [3]. Much of the plateau is covered by a low-albedo unit, interpreted as deposits of volcanic glass produced in a series of pyroclastic eruptions [4, 5]. The unit covers 49,000 km^2, which is 5 times the size of the next largest lunar pyroclastic deposit [6]. Thirty-six sinuous rilles occur both within the Aristarchus Plateau and in the Prinz Crater/Harbinger Mountains area to the east of Aristarchus, demonstrating that effusive volcanism was also important in this region [3, 7-10].

Free-air gravity anomalies over the Aristarchus Plateau reach a maximum amplitude of 172 mGal [1], but most of the anomaly is caused by the topography. Assuming Airy isostasy, a typical crustal density of 2550 kg m^{-3}, and a crustal thickness of 40 km [11], the plateau is close to isostatic (Figure 1). Such a state is consistent with a high radioactive heating rate within the Procellarum KREEP Terrane [12, 13], which would lead to a very thin elastic lithosphere early in lunar history. East of the plateau, the large free-air gravity anomaly suggests the presence of thick surface flows and subsurface intrusions of high-density mare basalt extending to Prinz Crater and the Harbinger Mountains (Figure 1). The high-density material also wraps around the southeastern margin of the plateau but is not present within the plateau. Initial modeling indicates that the total mass of basalt is ~5×10^{16} kg, comparable to that present in the Marius Hills [14]. For a bulk density of 3150 kg m^{-3}, appropriate for lunar mare basalts with an intermediate TiO_2 abundance [15], the basalt layer is at least 6 km thick.

The approximately linear edges of the Aristarchus Plateau suggest that the plateau may be fault bounded. The plateau edges are essentially radial and concentric to the center of the Imbrium basin, and the northeast margin of the plateau lies on or very close to an Imbrium basin ring [3, 16, 17]. These observations suggest that the formation of the plateau may be related to the Imbrium impact. However, the gravity anomalies on the eastern side of the plateau are broad and do not contain the regions of high gravity gradient that one might expect to be associated with plateau-bounding faults. Ongoing modeling and gravity gradient mapping [18] will help to better define the role of faulting in producing the Aristarchus Plateau.

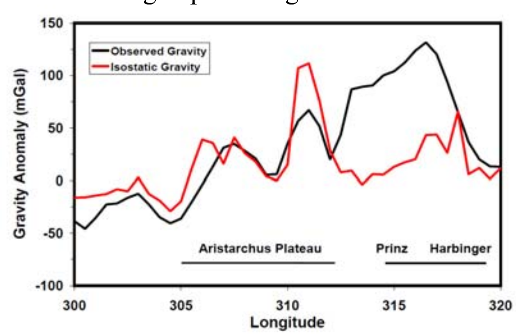

Figure 1: The free-air gravity anomaly (black) and gravity due to isostatically compensated topography (red) across the Aristarchus Plateau, Prinz Crater, and the Harbinger Mountains at 26°N. The profile is from gravity model GRAIL660C6A to spherical harmonic degree and order 450 (block size resolution 12 km).

Rümker Hills

The Rümker Hills in northern Oceanus Procellarum are an elevated volcanic dome complex that is

80 km across. It contains more than 30 domes up to 9 km in diameter, some of which have summit pits [8, 19]. Spectral evidence indicates that the volcanic field has a basaltic composition [20]. The free-air gravity anomaly has a maximum amplitude of 76 mGal and the area is close to isostatic equilibrium, implying that dense intrusive material is not present beneath Rümker.

Cauchy and Hortensius

The Cauchy region of eastern Mare Tranquillitatis contains many low-relief volcanic domes, up to 20 km across and with low flank slopes, scattered across a region about 500 km across [21-23]. Spectral observations indicate that the region consists of high-titanium basalts [22, 24]. The Hortensius and Tobias Mayer volcanic fields, located in Mare Insularum west of Copernicus crater, have ~20 low-relief volcanic domes in an area about 350 km across, along with collapse pits and chains of spatter cones [21, 22]. Several prominent long, young lava flows in Mare Imbrium originate just north of the Tobias Mayer volcanic field [25], and several small pyroclastic deposits (total area 1600 km^2) occur there [6, 26]. Spectral observations indicate that the region consists of low-titanium basalts [22].

The free-air anomaly is negative in both Cauchy and Hortensius/Tobias Mayer, reflecting the occurrence of these volcanic fields in topographic basins. The gravity anomaly due to isostatically supported topography is similar in amplitude to the free-air anomaly, indicating that dense intrusive material is not required in the subsurface of either region. On the north flank of Cauchy, the Gardner volcanic field's large free-air anomaly (300 mGal) may require the presence of dense subsurface material.

Compton-Belkovich

Compton-Belkovich is 25 by 35 km across and 300-500 m high and is located just east of Mare Humboldtianum. It is interpreted as a volcanic edifice, with a central depression and several small domes with steep flank slopes on its surface. Remote sensing observations suggest that Compton-Belkovich formed from a silica-rich or alkali feldspar-rich magma. One possible interpretation is that magma stalled in a shallow crustal magma chamber, resulting in chemical fractionation of the magma prior to eruption onto the Moon's surface [27]. Compton-Belkovich is a weak positive free-air gravity anomaly. However, the dome is similar in size to the resolution of the current gravity model. Ongoing improvements in the resolution of the gravity field will improve our ability both to separate Compton-Belkovich from other nearby anomalies and to quantitatively model the dome's structure.

Gruithuisen and Mairan Domes

The Gruithuisen and Mairan domes are located in northeastern Oceanus Procellarum near the Imbrium basin rim. The domes have steep flank slopes and are up to 30 km across and 1.6 km high, although most are substantially smaller. A variety of geomorphologic and spectral observations indicate that these domes consist of silica-rich, highly evolved magma [28-31]. The two largest domes, Gruithuisen γ and Gruithuisen δ, are weak positive free-air anomalies. However, these domes are close to the limit of the resolution of the current gravity model and detailed modeling will benefit from ongoing improvements in resolution of the gravity field.

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