The Potential Effect of Turbulence on the Bouguer Gravity Patterns of Mascons
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Introduction: The Bouguer anomaly map from GRAIL and LRO data [Wieczorek et al. 2012] show a typical pattern over large craters and basins. There is a large positive anomaly within a peak ring and a negative anomaly between the peak ring and the edge of the apparent crater (see Figure 1).

Figure 1: Typical Bouguer gravity pattern, less long wavelength orders, of the Mendel-Rydberg Basin. The pattern shows a large positive value within the peak ring, a neutral value at the peak ring, and a negative value between the peak ring and the edge of the apparent crater, where the Bouguer value is neutral. The rim is positive.

The magnitude of this pattern is measured as the Bouguer Anomaly Contrast (BAC) [Neumann et al., 2013]. BAC is the difference between the positive anomaly within the peak ring and the negative anomaly of the floor outside of that ring. The BAC is invariant of the Bouguer value of the general area. For craters less than 200 km, the BAC is very small and can be negative. For larger features (the mascons), the BAC value, in general, rises with the log of diameter above that value.

Figure 2 plots the BAC values of [Neumann et al., 2013] against the values of Rim Crest Diameter (RCD) taken from the radial profiles of the features [Byrne 2013]. Rim Crest, Apparent, and Peak Ring diameters are roughly proportional to each other and to the radius at which the impact shock wave is fully attenuated and transformed to an acoustic wave.

Figure 2 shows a main set of data with a few outliers: the Moscoviense (432 km, 647 mGal), Fecunditatis (850 km, 2.5 mGal), Nubium (872 km, 81 mGal), and Imbrium (1428 km, 307 mGal) basins. Additional outliers are very large features like the South Pole-Aitken Basin (not shown on Figure 2). There are at least two reasons why the typical Bouguer pattern may not be found associated with a large topographic feature:

1. The feature may not actually have resulted from an impact, especially if the topographic pattern is not clear. For example, Mare Fecunditatis or Mare Nubium might have been formed by pools of lava, not impact.

2. If the thermal state is sufficiently hot, separation by re-crystallization might reduce the BAC pattern.

Recent 2-D hydrocode simulations [Melosh et al. 2013, Freed et al., 2014] have emulated the major characteristics of large impact features suggested by 3-D simulations [Ivanov 2003, Stewart 2011]. These are formation of a deep melt pool, eruption and subsidence of mantle and crust, covering of mantle material with a crustal cap, and the distinctive Bouguer pattern revealed by GRAIL data.

A few features have positive Bouguer anomalies that appear to extend to the rim, such as the South Pole-Aitken Basin. In these cases, it is possible that the boundary ring is in fact a peak ring and a careful search should be done to see if there is a larger degraded rim.

Figure 2: This figure is similar to Figure 4 in [Neumann et al. 2013] but with the values of Rim Crest Diameter developed from radial profiles [Byrne 2013] and the Bouguer Anomaly Contrast (BAC) values found by Neumann. It shows that features with significant BAC values are larger than about 200 km in Rim Crest Diameters (RCD). For larger features (mascons), the BAC increases with the log of the RCD.
without mixing of the materials themselves. It is suggested here that the difference in turbulence is due to a loss of an energy term in the circularly symmetrical 2-D simulations.

**Proposed explanation of the turbulence:** In the speculative qualitative view here, the melt column is a chaotic mix of expanding melted and vaporized crust and basaltic mantle. Note that the phase change temperatures are different in the two materials.

The upward momentum of the melt column being lifted by rapid expansion could pull material from the rest of the subsurface shocked volume, also partly melted and vaporized (see Figure 3). This may draw down crust to mix with mantle in the chaotic conditions after shock. It might also produce a reduction in pressure there, encouraging vaporization and, after cooling, leave voids (vesicles) in cooled rock that increase porosity. Such vesicles are known to form in fusion crusts on lunar meteoroids [Thaisen and Taylor 2008]. Both crust and mantle material in these areas would be reduced in density by this effect (see Figure 4), producing the typical negative Bouguer anomaly there.

Figures 3 and 4 show only the subsurface process, not the ejection process or the collapsed apparent crater.

**Figure 3:** Proposed qualitative behavior of the material below the cavity of a future mascon. After the shock wave passes, energy stored in the material below the apparent crater forms a melt column whose circumference will form the peak ring. This conceptual figure shows how the rising column may draw material from the sides of the shocked area. The rising melt column erupts above the surface and then subsides, leaving the peak ring at its boundary.

Subsequent re-crystallization and partial separation restores some of the crust to the surface but if that process is incomplete as the material cools, a column of variable density (greater than that of crust) would be created below the area within the peak ring. Thus the positive Bouguer anomaly within the peak ring may be due not only to a raised lunar moho but also to a column of crust mixed with raised mantle material. The proportion of mantle would increase with depth until there is pure mantle. The negative Bouguer anomaly outside of the peak ring may be partly due to the voids in the crust and upper mantle there. This conforms to the qualitative pattern that is observed in the majority of the mascons.

**Discussion:** Turbulent mixing of crust and mantle may contribute to the Bouguer pattern. It would be very desirable to produce 3-D simulations with the same or similar state models and environmental parameters (such as the pre-impact thermal gradient) to see if the parameter constraints required to match the simulations with the observations are modified in the 3-D case.