ORIGIN OF SUPERISOSTATIC GRAVITY ANOMALIES IN LUNAR BASINS. H. J. Melosh[1] D. M. Blair[1] and A. M. Freed, [1]Dept. Earth and Atmospheric Sciences, Purdue University, 550 Stadium Mall Drive, West Lafayette, IN 47907 USA (jmelosh@purdue.edu).

Introduction: One of the enduring puzzles of lunar geophysics is the observation of positive free-air gravity anomalies in the centers of large lunar basins that lack substantial infillings of mare basalt. The presence of such gravity anomalies in lava-filled basins has been known since 1968, when "lunar mascons" were first discovered [1]. It is now accepted that most of these anomalies are created by an uncompensated mass of mare basalt that flooded these basins long after their formation, supported out of isostatic equilibrium by the strength of the thick lunar lithosphere [2]. This mascon model seems to make good geologic sense. It was therefore a great surprise when analysis of Clementine gravity and topography data [3] revealed that at least 9 lunar basins ranging from 200 to 600 km in radius possess positive anomalies in excess of that attributable to lava filling. Ranging in size from 200 to 500 mGal, these excess positive anomalies are encircled by annuli of anomalously low gravitational acceleration. Such superisostatic anomalies occur in both mare-filled nearside and nearly mare-free farside basins. Orientale basin is one of the most prominent examples. They have been attributed to frozen mantle rebound during crater collapse [3] or to uplift by flexure under external loads [4].

Melt Cooling Model: This abstract proposes a new origin for superisostatic anomalies in lunar basins. It is motivated by advances during the past decade in computer modeling of impact crater formation and collapse. Hydrocode programs such as CTH and iSALE successfully reproduce observations of small and mid-sized craters, up to diameters of several hundred km. More recently, even larger craters have been modeled [5,6]. One common but surprising feature of these simulations is the formation of a deep pool of hot impact melt underlying the center of the basin following collapse. Older treatments of basin subsidence by cooling neglected the possibility of large melt regions [7]. Figure 1 illustrates two stages in the formation of a 15 km radius, 40 km deep pool in a 150 km diameter transient crater on the Earth [8]. Deep melt pools form beneath large craters in a relatively hot target, such as the mantle of the Moon during the LHB. The size of the melt pool as a function of crater size is not well understood: Future modeling should address this .

The melt in the pool is typically about 10% less dense than the mantle from which it forms. Crustal material typically overlies the melt, derived either from surrounding material that collapsed laterally onto the melt pocket or from later differentiation of the melt into new crust. Because of its high temperature, the basin center lacks strength and the free-air gravity anomaly over the basin is initially zero: the hot melt supports the crust on the floor of the basin, which floats in isostatic equilibrium, shown in the left panel of Fig. 2.

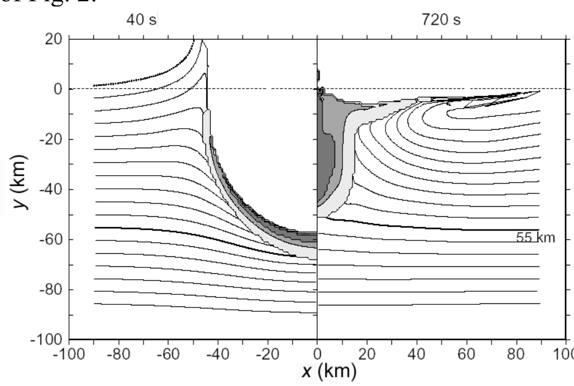

Fig. 1 Formation of a deep melt pool subsequent to the collapse of a large impact crater on Earth formed by a 20 km diameter asteroid striking at 15 km/sec. From Fig. 3 of [8]. Dark tones indicate complete melt.

However, the top of the melt pool cools rapidly to space. When its temperature drops below about half of its melting temperature it responds elastically to long-term stresses, forming a new lithosphere welded to the surrounding older, cooler lithosphere. If it remained strengthless, the center of the basin would subside as the melt pocket cooled by an amount w_{iso}

$$w_{iso} = \left(\frac{\rho_m - \rho_c}{\rho_m} \right) (t_c - t_b)$$

where t_c is the thickness of the surrounding crust and t_b the thickness of the crust over the basin center and ρ_c is the density of the crust. The basin remains in isostatic equilibrium in this case and does not develop a superisostatic gravity anomaly. At the opposite extreme, if the basin floor were rigid, preventing any subsidence, as the density of the melt rises from ρ_l to the ambient mantle density of ρ_m, (the decreasing volume is compensated by inflow of the surrounding warm mantle), a strong positive anomaly would develop of magnitude:

$$\Delta g_{rigid} = 2\pi G(\rho_m - \rho_l)(t_c - t_b)$$

This would lead to enormous superisostatic anomalies, equal to about 21 mGal/km of crustal thickness difference between the basin center and surrounding crust. For Orientale, this would produce a positive anomaly of 970 mGal, about twice the observed anomaly.

In reality, the newly-formed lithosphere is neither strengthless nor rigid, but subsides some fraction of the full isostatic distance and ends up supporting a superisostatic load whose magnitude depends on the relative rate of thickening of new lithosphere formed by cooling and the thermal contraction of the underlying melt pocket, shown schematically in the right of Fig. 2.

For this mechanism to operate, the depth of the melt pool must be greater than a minimum *H*, large enough so that its volume contraction can accommodate the isostatic subsidence w_{iso}. This requires:

$$H \geq \left(\frac{\rho_m - \rho_c}{\rho_m - \rho_l} \right) (t_c - t_b)$$

For the Orientale basin the minimum *H* is 70 km. This mechanism requires a deep melt pocket and cannot function for small impact craters with thin melt sheets.

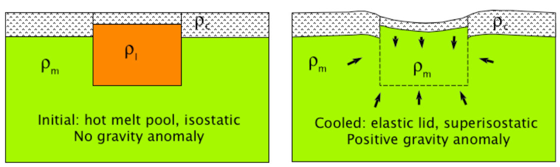

Fig. 2 Schematic illustration of the melt cooling model. After the impact melt pocket forms, a lithosphere is re-established over the pool that supports the weight of the actively cooling, denser crystallized melt pool.

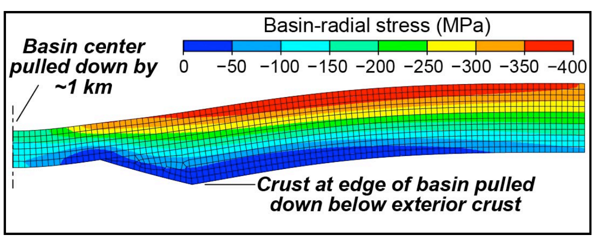

Fig. 3 ABACUS finite element model showing exaggerated deformation (x20) of the crust following cooling of a subcrustal melt pool 100 km in radius. The basin center is drawn down ~1 km by the cooling melt, while isostatic equilibrium requires 4 km subsidence. A superisostatic anomaly is thus present. Deflection of thick crust at the basin edge produces a negative anomaly surrounding the basin.

Analytic Model: Ideally, further work requires numerical modeling that can account for the different rates of lithosphere formation, melt cooling, mantle flow and surface subsidence, including realistic rheologies for all parts. Figure 3 shows a preliminary computation of this type. However, an idea of the likely success of this proposal is provided by a simple analytic model based on the flexure of an axisymmetric elastic sheet [9] of uniform thickness.

This analytic model assumes that the hot melt pool is a vertical cylinder of uniform density overlain by a lithosphere with the same thickness both over the hot cylinder and outside in the cooler crust. These simplifying assumptions are unrealistic: In particular, the sharp corners of the cylinder lead to the sudden jump in gravity anomaly seen in Figure 4 and the uniform thickness lithosphere does not spread the negative anomaly outside the load over a broad enough area. Nevertheless, the results shown in Figure 4 are in qualitative agreement with the observed magnitudes of the central superisostatic anomalies in lunar basins. Furthermore, the observed negative anomaly surrounding the central high is explained as the natural response of the cool surrounding lithosphere to the superisostatic load in the center of the basin.

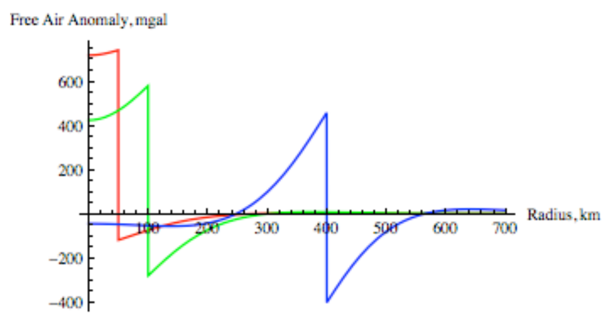

Fig. 4 Analytic model of gravity anomalies over a cooled melt pool. The radii of the melt pools under the basin are 50 km (red), 100 km (green) and 400 km (blue). The lithosphere is 30 km thick in all cases. Crustal density is 2800 kg/m^3, mantle density 3300 kg/m^3. Crust is 60 km thick outside the basin and 20 km thick in the basin center. The sharp reversal in gravity at the edge of the pool is an artifact of the sharp-edged melt pool in this analytic model. This model predicts that the anomaly is large for moderate size basins but small for very large ones, as observed.

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