THE THICKNESS OF THE LUNAR CRUST: HOW LOW CAN YOU GO? Mark A. Wieczorek, Département de Géophysique Spatiale et Planétaire, Institut de Physique du Globe de Paris, 4 Avenue de Neptune, 94107 Saint Maur des Fossés Cedex, France (wieczor@ipgp.jussieu.fr).

Introduction: Seismometers were placed on the lunar surface during the Apollo missions that allowed the seismic velocity of the lunar interior to be crudely determined. One of the major results from these analyses was the existence of a crust that was approximately 60 km thick at the Apollo 12 and 14 landing sites [e.g., 1, 2]. Recent inversions of the same dataset using a more robust Monte Carlo inversion scheme, however, have cast some doubt on these Apollo-era conclusions. In particular, *Khan et al*. [3] found that the lunar crust beneath the Apollo seismic network is most likely thinner than previously believed, possessing a thickness of 45±5 km. Using Bayesian hypothesis testing, *Khan and Mosegaard* [4] further showed that a crustal thickness of 38±3 km was to be highly favored over a crustal thickness between 50 and 70 km.

A complete independent reanalysis and inversion of the Apollo seismic arrival times by the IPGP group [5, 6] further supports the notion that the lunar crust is thinner than believed, possessing a thickness of 30±2.5 km. Using a receiver function analysis, *Lognonné et al.* [5] further suggest that the crustal thickness beneath the Apollo 12 site is about 27 km, or marginally lower than their average value.

While these recent crustal thickness estimates represent an average over all the raypaths that were modeled in these studies (excluding the receiver function analysis), the artificial impact data place the most stringent constraints on the seismic velocity of the crust and upper mantle. As the artificial impacts mostly sample the region of the Apollo 12 and 14 sites, these estimates are thus most representative of this region. In this abstract I assess whether geophysical models using the known lunar gravity and topography data are compatible with these new seismic constraints.

Geoid-to-Topography Ratios: In a study by *Wieczorek and Phillips* [7], geoid-to-topography-ratios (GTRs) were used to constrain the structure and compensation state of the nearside highland crust. I have redone these calculations here using an improved gravity model [8], and find that if the lunar crust is compensated by an Airy mechanism, then the average predicted crustal thickness is 49±16 km. In comparing this value to the seismically constrained crustal thickness of the Apollo 12 and 14 sites, though, the fact that these sites are not located at the mean planetary radius must be taken into consideration. Assuming that the degree-2 portion of the lunar topography is entirely the result of rotational and tidal flattening, and using reasonable values for the density of the crust (2710–2885 kg m^{-3}) and mantle (3200–3335 kg m^{-3}), the crustal thickness of the Apollo 12/14 site is predicted to lie between 16 and 56 km.

As the Apollo-era crustal thickness beneath the Apollo 12 and 14 sites is greater than this range, it was originally suggested that the highland crust was most consistent with being layered, with partial compensation occurring at an intra-crustal interface. The new seismic constraints suggest that such an appeal to a dual-layered crustal structure is no longer required. A dual-layered crustal structure, however, can not be excluded from these data. In particular, it is found that a model of the lunar crust which possesses a constant thickness lower crust, and a variable thickness low-density upper crust is equally consistent with the GTR constraints. Such a dual layered model is appealing, as large impact events would largely redistribute upper crustal materials, leaving the lower crust untouched.

Crustal Thickness Constraints: If one assumes that the density of the crust and mantle are constant, then it is straightforward to use the lunar gravity field and topography to create a crustal thickness map. The first step is to remove the gravitational attraction of the topography from the free-air gravity, and then to interpret the remaining Bouguer anomaly as being the result of relief along the crust-mantle interface [9]. However, as gravity modeling is non-unique (even after assuming constant density layers) the model must be anchored to a known value at a single location.

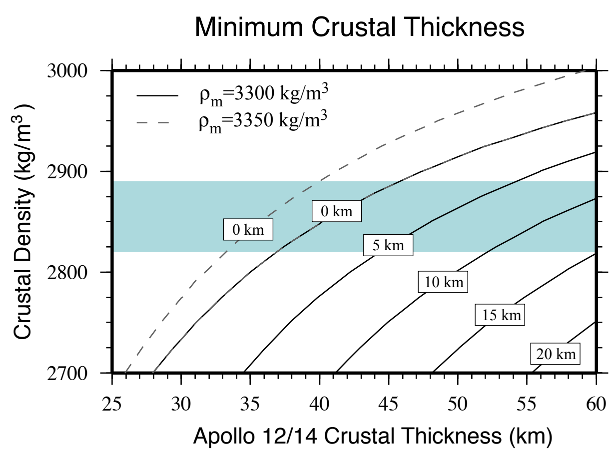

Figure 1. Contours of the minimum crustal thickness (excluding mare fill) obtained from a set of crustal thickness models as a function of the assumed crustal and mantle densities and thickness of the crust at the Apollo 12 and 14 sites. The blue shaded region shows the most plausible range of crustal densities.

Crustal thickness maps which are constructed in this way thus depend upon three parameters: (1) the density of the crust, (2) the density of the mantle, and (3) the thickness of the crust at the Apollo 12 and 14 sites. One additional constraint that can be employed is that the thickness of the crust should everywhere be greater than zero.

For a range of assumed crustal and mantle densities and Apollo 12/14 crustal thicknesses, I have computed a set of global crustal thickness maps, and have determined the minimum crustal thickness for each model. These results are shown in Figure 1 where the minimum crustal thickness is contoured for an assumed mantle density of 3300 kg/m^3. Models where the minimum crustal thickness was less than zero are unphysical and hence are not displayed. In addition, the zero minimum crustal thickness is contoured for an assumed mantle density of 3350 kg/m^3. The minimum crustal thickness in these models always occurred beneath the Crisium basin.

Following *Wieczorek and Zuber* [10], the most plausible density range for the upper portion of the crust is 2855±35 kg/m^3. Though the density of the crust may be somewhat lower if it is substantially fractured, the average density of the crust is likely to be somewhat larger if the lower portion of the crust is more mafic. Considering these two factors, the upper crustal (unfractured) density range is probably acceptable as a lower bound for the average crustal density. It is thus seen in Figure 1 that the thickness of the crust at the Apollo 12 and 14 sites must be greater than 33 km. As it is probable that at least one of the large lunar impact basins excavated into the lunar mantle, if we assume that the minimum crustal thickness is exactly zero, then the Apollo 12 and 14 crustal thickness must lie between 33 and 46 km.

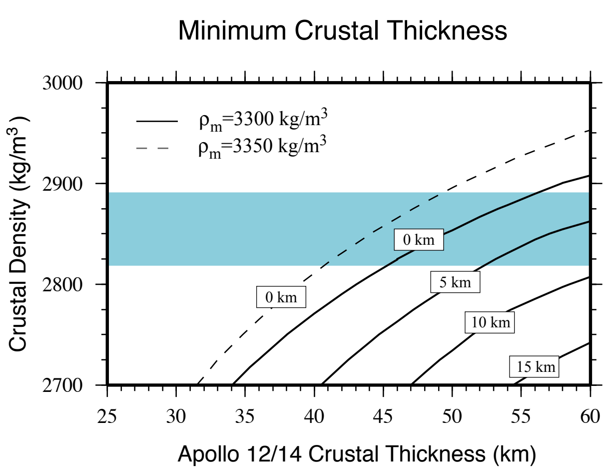

Figure 2. Same as for Figure 1, except that the degree-1 Bouguer anomaly is assumed to have a mantle origin.

The most probable crustal thickness of the Apollo 12 and 14 sites of *Khan and Mosegaard* [4] (38±3 km) is consistent with these crustal thickness models. The minimum allowable crustal thickness of 33 km is also marginally consistent with the crustal thickness determination of *Lognonné et al.* [5] (30±2.5 km). While the IPGP dataset [5, 6] seems to demand extreme values of the mantle and crustal density, the crustal thickness modeling here may possess systematic errors because of the poor spectral representation of the gravity field above spherical harmonic degree 15 [8].

In contrast to the standard crustal thickness model above in which the entire Bouguer anomaly is interpreted as relief along the crust-mantle interface, it is possible that some portion of the Bouguer anomaly may result from density anomalies within the mantle. In particular, if ilmenite-rich magma-ocean cumulates only sank beneath the lunar nearside, then it is possible that the nearside mantle is denser than that of the farside. As an extreme model, I assume that the entire degree-1 Bouguer anomaly is a result of a denser nearside mantle. The results of this end-member model are presented in Figure 2. If the crust is assumed to have a zero minimum thickness, then the crustal thickness of the Apollo 12 and 14 sites is constrained to lie between 41 and 56. While this range is barely consistent with the crustal thickness model of *Khan and Mosegaard* [4], it is inconsistent with the model of *Lognonné et al.* [5]. Even though this end-member model might be considered a bit unrealistic, it demonstrates that if any portion of the degree-1 Bouguer anomaly has a mantle origin, that the minimum Apollo 12 and 14 crustal thickness must be larger than those derived from Figure 1. In these models, the minimum crustal thickness always occured beneath the Apollo basin which resides within the larger South Pole-Aitken basin.

New Crustal Thickness Models: Given the liklihood of a thinner lunar crust, new crustal thicknes models will be constructed and their implications discussed. In particular, is it likely that the lunar mantle is exposed at the lunar surface? What is the average thickness of the crust? What are the implications for the bulk composition of the Moon? Are asymmetries visible in any on the large impact basins?

References: [1] Toksöz et al., Rev. Geophys. 12, 539, 1974; [2] Nakamura et al., PLPSC, 13th, Part 1, JGR, suppl. 87, A117, 1982; [3] Khan et al., GRL, 27, 1591, 2000; [4] Khan and Mosegaard, JGR, 107(E6), 2002; [5] Lognonné et al. EPSL, submitted, 2002; [6] Chenet et al., LPSC XXXIII (CD-ROM), 1684, 2002; [7] Wieczorek and Phillips, JGR, 102, 10,933, 1997; [8] Konopliv et al., Icarus 150, 1, 2001; [9] Wieczorek and Phillips, JGR, 103, 1715, 1998; [10] Wieczorek and Zuber, GRL, 28, 4023, 2001.