INDICATION OF THE THICKNESS OF THE SOUTH-POLE AITKEN IMPACT EJECTA ON THE LUNAR FAR SIDE FROM CRATER EQUILIBRIUM PROBLEM.

Masatoshi Hirabayashi[1], H. Jay Melosh[1], Jason M. Soderblom[2], and David A. Minton[1], [1]Purdue University, West Lafayette, IN 47907-2051, USA, (thirabayashi@purdue.edu), [2]Massachusetts Institute of Technology, Cambridge, MA 02139, USA.

Introduction: Gravity field maps derived from Gravity Recovery and Interior Laboratory (GRAIL) observations [1] show that the crustal porosity of the lunar farside crust is higher than that of the lunar nearside crust (see Figure 1 [2]). Recently, Soderblom et al. [3] investigated the Bouguer Anomalies (BAs) of lunar highland craters (most of which are located on the lunar far side) and found that craters with diameters ranging between 30 km and 200 km have negative BAs that trend towards zero BA at smaller diameters. They proposed that the upper ~8 km of the lunar highlands crust is in a state of equilibrium for impact-generated porosity due to craters smaller than 30 km in diameter.

The ~8-km-thick porous layer cannot be the result of impact-induced porosity: We use the LOLA crater database [4] to compute the cumulative size-frequency distribution (CSFD). We choose craters with diameters larger than 20 km in a region with a BA less than -300 mGal, which corresponds to the highland on the lunar far side (Figure 1). These craters are a subset of the dataset considered by Soderblom et al. [3]. The CSFD in Figure 2 shows that craters smaller than 55 km in diameter are in a state of crater equilibrium. Considering the steep slope in Figure 2 to be the production function and using a stochastic evolution model by Hirabayashi et al. [5], we conclude that if the target surface is initially bedrock, only 30 % of the surface will have a porous layer at least 8 km thick. This comes from the fact that the cross-section of the transient crater becomes smaller at greater depth because the transient crater has a bowl shape.

A thick porous layer must have existed before cratering bombardment: We explore the possibility that the porosity in the upper 8 km resulted from a source other than primary impact cratering. We use the Cratered Terrain Evolution Model (CTEM), a Monte-Carlo simulation code computing the surface evolution due to multiple impact events [6, 7]. The present study newly considers that the initial target surface consists of an 8-km-thick high-porosity layer on the top of the low-porosity bedrock layer. With this initial condition, CTEM models emplacement of impact craters based on the production function. CTEM also tracks the locations of impact lenses, crater rims, and ejecta blankets to compute impact-induced porosity.

We simulate the crater evolution on a flat surface with a size of 320 X 320 km. Here, to recover the residual BAs, the relative BA of a crater interior to a crater exterior, obtained by Soderblom et al. [3] numerically, we only generate craters with diameters ranging from 1 km to 80 km. Milbury et al. [8] showed that a mantle uplift would cause a high BA at a crater interior, and Soderblom et al. [3] argued that such a high BA would happen to craters with diameters larger than 200 km. Therefore, the mantle uplift should not affect our model. In our model, craters larger than 27 km in diameter will penetrate through the 8-km highly porous layer to the low-porosity layer. Figure 3 shows the surface elevation computed by CTEM.

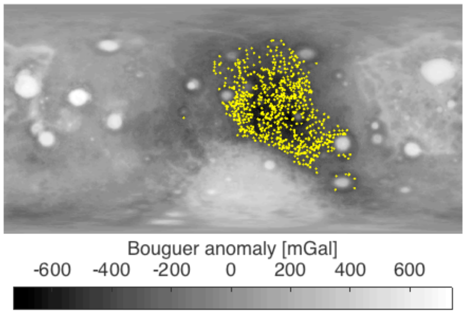

Figure 1. The BA of the Moon [2]. The crustal bulk density is assumed to be 2500 kg/m^3 [2]. The yellow dots are craters with diameters larger than 20 km that are in the region with a BA less than -300 mGa [3].

Figure 4 describes the BA distribution for the case discussed above. In this calculation, the crustal bulk density is assumed to be 2560 kg/m3 [9]. To yield a BA distribution comparable to the observed residual BA, we describe the BA distribution relative to the maximum value in the target area. We find that while the BAs of small craters that do not reach the underlying low-porosity layer remain similar to those of the non-cratered regions, large craters that intersect the top of the higher-density layer have negative BAs. In this simulation, two craters with diameters of ~ 80 km are emplaced. We obtain the residual BAs of these craters as - 20 mGal, which is consistent with Soderblom [3]. By the present analysis, we show that the surface on the lunar far side would have consisted of a high-porosity layer on the top of a low-porosity layer before the impact bombardment event.

The upper porous layer would indicate the ejecta thickness of the SPA impact: Soderblom et al. [3] concluded that the upper 8-km-thick layer might be in a state of equilibrium for crustal porosity, which was supported by Besserer et al. [10]. In this study, conducting CTEM simulations, we recovered the gravity features due to impact craters demonstrated by Soderblom et al. [3]. We found that the number of smaller (<55 km) craters could not have brought the crust to a state of equilibrium for crustal porosity. This 8-km-thick low-porosity layer must have existed before impact bombardment. Here, we propose that the highly porous layer on the lunar far side having a low BA (Figure 1) is the ejecta blanket of the SPA impact.

The South-Pole Aitken (SPA) basin has been thought to result from an oblique impact. Kendall [11] conducted 3D iSALE simulations for the SPA impact crater formation, proposing that this impact could create a multi-kilometer-thick ejecta blanket covering the lunar far side. He predicted that the ejecta would spread over the northern part of this basin [10], which is consistent with the location where craters exhibit low BAs [2].

We note that our current study does not take into account the fact that an impact increases porosity in a low-porosity target and decreases porosity beneath the crater in a high-porosity target [8]. The compressive effect might not create a distinct bulk density contrast between the cratered region and the underlying layer, implying that the high-porosity layer might be shallower than the 8-km thickness to achieve the observed residual BA [3]. Therefore, we infer that the ejecta thickness of the SPA impact on the considered area should be up to 8 km. With further investigations, this project will be able to shed light on the ejecta thickness distribution of the SPA impact, allowing for better scientific and engineering of the MoonRise mission.

Acknowledgements: This research was supported by NASA LDAP, NNH15ZDA001N-LDAP.

References: [1] M. T. Zuber et al. (2013) *Science 339*, p.668-671. [2] *NASA PDS Geophysics Node*, http://pds-geosciences.wustl.edu/grail/grail-l-lgrs-5-rdr-v1/grail_1001/rsdmap/gggrx_0900c_boug_l600.lbl [3] J. M. Soderblom et al. (2013) *GRL 42*, p. 6939-6944. [4] J. W. Head et al. (2010) *Science 329*, p.1504-1507. [5] Hirabayashi et al. (2016) *AGU*, P53C-2235. [6] D. A. Minton et al. (2015) *Icarus 247*, p.172-190 [7] J. C. Richardson (2009) *Icarus 204*, p.697-715. [8] C. Milbury et al. (2015) *GRL 42*. [9] M. A. Wieczorek et al. (2013) *Science 339*, p.671-675. [10] J. Besserer et al. (2014) GRL 41, p.5771-5777. [11] J. D. Kendall (2016), *Ph.D. thesis*.

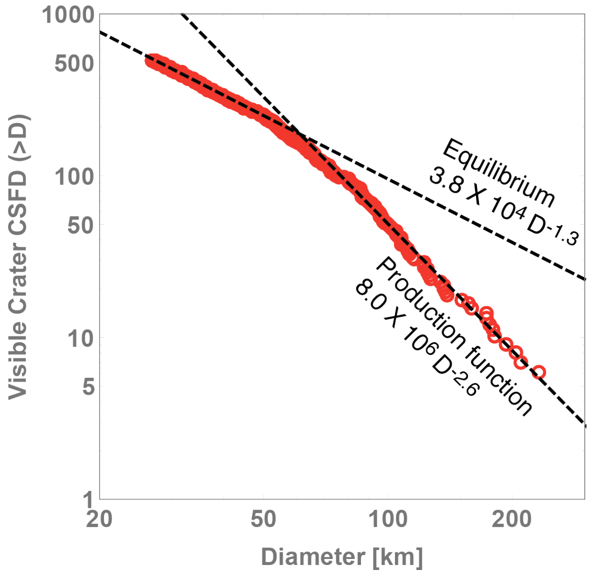

Figure 2. The crater cumulative size frequency distribution of the craters described in Figure 1.

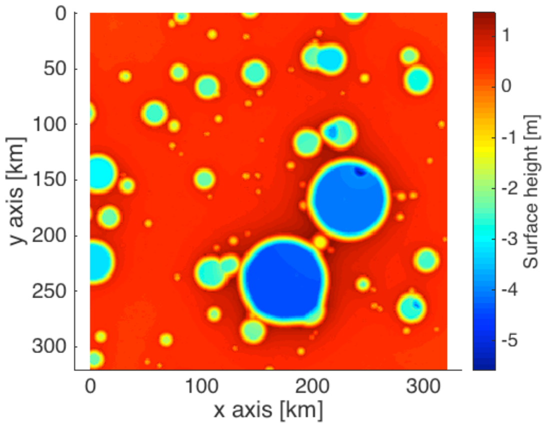

Figure 3. The surface height obtained from CTEM. For this simulation, the area size is 320 km by 320 km.

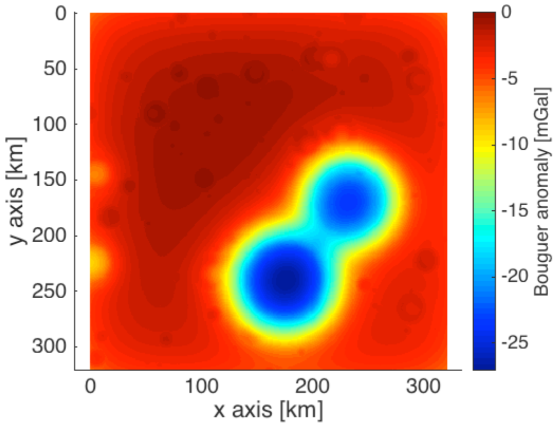

Figure 4. The computed relative BA to the maximum BA in the test area.