HYDROCODE MODELING OF THE SOUTH POLE AITKEN BASIN-FORMING IMPACT. N. P. Hammond[1], F. Nimmo[1], and D. Korycansky[1] [1]Department of Earth & Planetary Sciences, University of California Santa Cruz (nphammon@ucsc.edu).

Introduction: The South Pole Aitken Basin (SPA; probably the largest in the solar system) is about 2500 km in diameter and up to 13 km deep [1]. Simple scaling arguments suggest that this basin should have excavated the entire lunar crust [2]. However, remote-sensing observations indicate the floor of the SPA basin is predominantly lower crustal in origin [3-5], while gravitational and topographic data likewise suggest the presence of a ~40 km thick lower crust [6]. This discrepancy might be due to either a low velocity impact [7] or less likely, nonproportional scaling [6]. Here we build on previous investigations [8,9] and use a high resolution, two dimensional hydrocode (Zeus [10]) to model vertical lunar impacts and test these hypotheses. We also suggest that regions external to the basin are more likely to contain ejected lunar mantle material.

Methods: The model contains 200 grid points in the radial direction and 300 grid points in the azimuthal direction. The moon has a radius of 1760 km and a core of radius 350 km. The silicate and metallic portions of the model have Tillotson equations of state for dunite and iron, respectively [11]. Gravity varies in the radial direction but remains constant with respect to time. Zeus is an axisymmetric model, making it incapable of simulating oblique impacts. However this geometry allows for higher spatial resolution, useful in determining whether the entirety of the lunar crust was excavated during the SPA basin-forming impact.

Impactors range from 60 to 300 km in diameter and 5 to 28 km/s in velocity. Massless tracer particles are used to track and locate excavation cavity depth and diameter [10]. The excavation cavity diameter is defined as the distance over which at least half of the lunar crust (assumed 60 km thick) has been removed.

Excavation depth is tracked by determining the shallowest tracer particle beneath the impact point which is not vaporized. Unlike the excavation diameter, the excavation depth does not reach a steady value (see Fig 1). This behavior appears to result from the unrealistic focusing and reflection of shock waves which occurs due to the 2D symmetry of the model. In these preliminary results, we determine the excavation depth at a time which is a constant multiple of the time to reach maximum transient crater depth.

Figure 1a-c show snapshots of density at different times for a typical impact. The black and white circles are solid and vaporized crustal particles, respectively, showing the evolution of the excavation cavity with time. By the time of Fig 1c reflected shock waves from the antipode are causing likely unphysical behavior beneath the impact site. Fig 1d shows the initial depth of particles (open circles – vaporized, solid circles – unexpanded material) and demonstrates that at this time the excavation depth is roughly 350 km. Fig 1e shows how the excavation depth and diameter evolve as a function of time, and Fig 1f plots the final crustal thickness as a function of distance from the impact point. The antipodal thinning is an artifact of the 2D geometry employed; crustal thickening results from the re-impact of ejected crustal and mantle material.

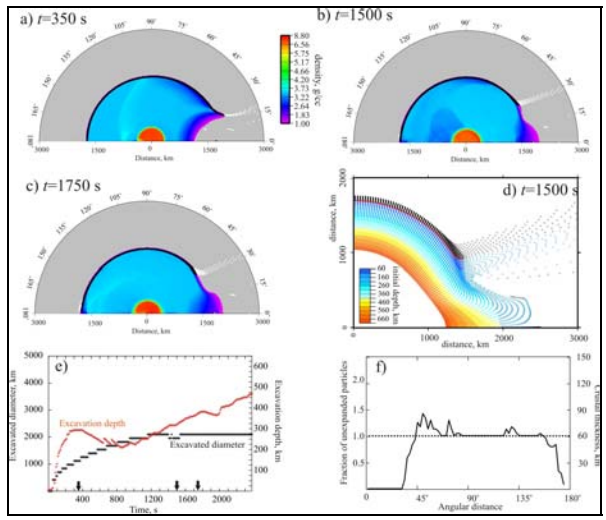

Figure 1: a-c) Density of target after collision with impactor 100km in radius, 20km/s in velocity. Maximum transient cavity depth and determination of excavation diameter occur in a and b, respectively. d) Provenance of crustal particles. Open and closed circles represent vaporized and unexpanded material, respectively, while black particles represent lunar crust. e) Excavation depth and diameter over time. f) Crustal thickness as a function of angular distance from the impact.

Results: Excavation cavity diameter scales as kinetic energy of the impactor to the 0.28 power, in agreement with previous studies [10,12]. An energy of ~2.5×10^{27} J is required to form an SPA-sized basin. An impactor with a radius of 100 km and a velocity of 20km/s forms a crater with an excavation diameter of 2500 km and an excavation depth of 350-380 km (Fig 1). For constant kinetic energies, lower velocities result in shallower excavation depths (Fig 2). However even at a minimum velocity of 3 km/s, the excavation depth for an SPA-sized impact always exceeds 150 km, greater than likely crustal thickness. Thus, the low-velocity impact hypothesis [7] is unlikely to be correct.

Excavation depth: diameter ratios remain relatively constant at 0.17 +/- 0.03 over basin diameters ranging from 500 to 2600 km in diameter (Fig 3). Hence, non-proportional scaling [6] can also be ruled out.

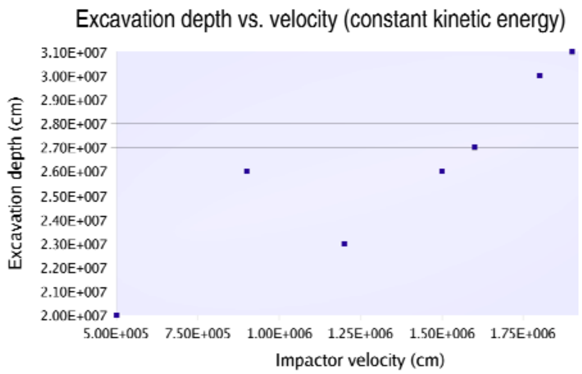

Figure 2. Excavation depth:diameter ratio as a function of impact velocity for a constant impactor kinetic energy of 2.67e26 J

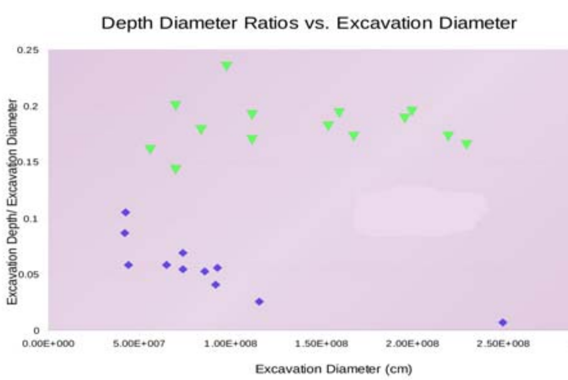

Figure 3. Excavation depth:diameter ratio as a function of basin diameter**.** Green triangles represent impact simulations. Blue diamonds represent gravitational modeling done by Wieczorek and Philips [6].

Discussion: Gravity and topography observations have been used to infer the excavation depths of large lunar impact basins [6]. The inferred excavation depth:diameter ratio decreases as diameter increases, in contrast to our numerical models (Fig 3). The most likely explanation for this discrepancy is that the entire pre-existing crust is removed during the impact process, but impact-generated melt ponds in the impact basin [8,13], re-solidifies and forms a layer of a similar density to the original crust. This new layer could not be distinguished from the original crust by gravity observations. Fractional crystallization of the melt sheet during the solidification process [13] probably accounts for the non-detection of strong mantle mineralogy signatures by remote sensing [3-5]. Thus, the floor of the SPA basin is unlikely to be a good place to recover samples of the lunar mantle, a high priority for future spacecraft missions [14].

A more plausible place to find lunar mantle material is in the ejecta blanket adjacent to the basin. Fig 1d demonstrates that the bulk of the ejecta material is of mantle origin, and that the last-deposited material tends to come from the greatest depths, resulting in an inverted stratigraphy [11]. We caution, however, that most of this mantle material is likely to have undergone melting and refreezing, leading to potentially confounding geochemical effects.

Figure 4 plots the normalized ejecta thickness as a function of distance from the impact, compared with both laboratory experiments [15] and the results of [6]. The agreement is quite good, and suggests that the thickest ejecta will be found within 1.5 basin radii.

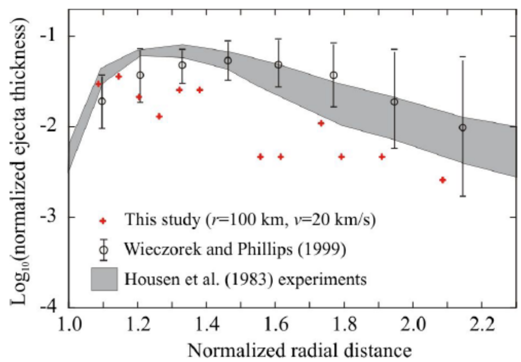

Figure 4. Ejecta thickness, normalized to crustal thickness, as a function of radial distance, compared with experimental results [15] and lunar observations [6].

Conclusions: An SPA-forming impact almost certainly excavated the entire lunar crust. The relative absence of mantle signatures within the basin, and the apparent presence of lower crustal material inferred by gravity, are both likely the result of recrystallization of a thick impact-melt sheet. Mantle material is most likely to be found in the ejecta blanket adjacent to the basin. Although our models are limited to vertical impacts, oblique impacts are unlikely to significantly change these conclusions, although the impact direction will certainly influence the location of the thickest ejecta deposits.

References: 1] Spudis et al. Science 1994 [2] P. G. Lucey et al. (1998) JGR 103, 3701-3708[3] C. M. Pieters et al. (2001) JGR 24, 1903-1906 [4] B. L. Jolliff et al. 2000 *LPS XXX* 1670 [5] Lucey (2004) GRL [6] M. A. Wieczorek and R. J. Phillips (1999) Icarus 139 246-259 [7] P. H. Schultz (1986) LPI 17, 777-778 [8] G. S. Collins and H. J. Melosh (2004) *LPS XXXIV* [9] Ivanov (2007), *LPS XXXIX*, 2003. [10] Nimmo et al. (2008) *Nature* 453, 1220-1224 [11] Melosh (1989) *Impact Cratering.* [12] Housen et al. (1979) *Icarus*. [13] Morrison (1998) *LPS XXIX*, 1657. [14] *Opening New Frontiers in Space*, NRC, 2008. [15] Housen et al. (1983) JGR 88, 2486-2499.