CONSEQUENCES OF FORMING THE SOUTH-POLE-AITKEN BASIN. P. H. Schultz[1] and D. A. Crawford[2], [1]Brown University, Department of Geological Sciences, 324 Brook Street, Providence, RI 02912-1846 (peter_schultz@brown.edu); [2]Sandia National Laboratories, Albuquerque, NM.

Introduction: The diameter of the South-Pole-Aitken (SPA) Basin exceeds the radius of the Moon [1,2]. While scaling relations at this scale are highly uncertain, the impactor producing this basin approached 500-800 km in diameter. Intersecting shocks and rarefactions off the free surface of a spherical body induces multiple failure planes deep inside the opposite side (antipodal). While antipodal effects have been modeled for smaller impact basins on the Moon [3,4] and elsewhere [5], the possible effects of the SPA impact have not been previously fully modeled.

Approach: Computations using three-dimensional hydrocodes allow testing the extrapolations inferred from the small-scale experiments. An improved version of the CTH [7] hydrocode includes self-gravity with adaptive mesh refinement (40 km for the finest mesh). The calculations used ANEOS equations-of-state [8] for the dunite impactor, a lunar mantle, and molten iron core (350 km radius) with a temperature profile based on theoretical models [9].

The computations explored the effect of impacts on the degree of fracturing of the Moon not only at a given impact angle (90°, different sizes at 10 km/s) but also at different impact angles (different sizes at 20km/s). The impact kinetic energy (KE) for the largest body represents a significant fraction (up to about 30%) of the total gravitational potential (binding) energy of the Moon. For vertical impacts (90° to the surface tangent), objects larger than 400km in diameter 10km/s fracture more than 50% of the total lunar mass (7.35 $x10^{22}$ kg) as shown in Figure 1. Converging shocks at the antipode become strong enough to overcome the lithostatic overburden at depth. Here, fracturing is defined where/when the tensile stress exceeds 250 MPa.

Results: Figure 2 shows the consequences of impact angle as it decreases from vertical to oblique (30°). In this case, the total damage to the Moon is kept nearly constant (~65%) for the different impact angles. An impact at 20 km/s by an asteroid 260 km (9.2 $x10^{21}$ ergs) in diameter at 90° would induce the same amount of damage as an asteroid 700 km (1.8 $x10^{23}$ kg) in diameter at 30° but this damage would be distributed differently (Figure 2). Even though the latter collision has ~ 20 times more KE than the latter, its effect is about the same. This dramatic contrast in damage efficiency is not due to reduced peak pressures at a low impact angle. Rather, a significant fraction of the impacting body decouples from the collision due to its decapitation. This process has been documented experimentally for both planar [10] and spherical targets [11]. Nevertheless, the large-diameter body will still result in an SPA-diameter crater since the shock decays from the projectile/target interface. The degree of damage below the crater, however, is reduced and directed downrange.

Implications: Results from the hydrocode closely resemble the laboratory experiments where an oblique impact into a spherical body induced significant internal failure offset from the antipode [12]. This should be expected since the process is controlled by geometry. The calculation demonstrates, however, that such failure also applies to a differentiated Moon with self-gravity (lithostatic overpressure). The SPA collision should have induced failure extending from below the surface to the lunar core. The resulting fracturing occurred in several long-lasting episodes due to repeated convergent, reinforcing shocks. Increasing lithostatic pressure would have forced magma into the developing fractures at different depths over the 14 minutes after the SPA impact. Deep-seated intrusions would have been concentrated in a broad oval below the nearside, encompassing present-day Oceanus Procellarum and Imbrium (Fig. 3). Evolving magma reaching the lower crust would account for the localization of the source regions for KREEP and high-Th anomalies [13]. The Imbrium collision subsequently excavated such pre-Imbrium magma bodies asymmetrically over the nearside [14-16]. Radial and concentric tensile failure inherited from the SPA collision controlled later mare volcanism (Imbrium Period), thereby forming the Procellarum System of ridges, vents, and fractures first described by Whittaker [17]. This new theory, therefore, provides a possible cause for the nearside concentration of Imbrian volcanism, paucity on the farside (except in SPA), and pathways for deep-seated venting [18].

Figure 4 also demonstrates that about 80% of the initial KE is lost through decapitation of the impacting body. Experiments reveal that this process not only induces catastrophic disruption but also results in large surviving masses due to shear [8, 11]. Consequently, nearly half of the original mass by this 700 km-diameter asteroid leaves the Moon close to the original impact velocity. Such debris leaves in an earth-crossing orbit and will be on a future collision course with the Earth-Moon system. One implication is that each large, oblique basin-forming collision (SPA, Imbrium, Nectaris, and Orientale) during the delayed

Late Heavy Bombardment (LHB) or Lunar Cataclysm [19] will contribute to the subsequent cratering record (craters <100km). If the LHB was initiated by dynamic dispersal of large bodies elsewhere in the solar system [20], then its expression in the statistics of Nectaran craters (such as the "Population II" [21]) may represent returning decapitated relicts from large, basin-forming oblique collisions.

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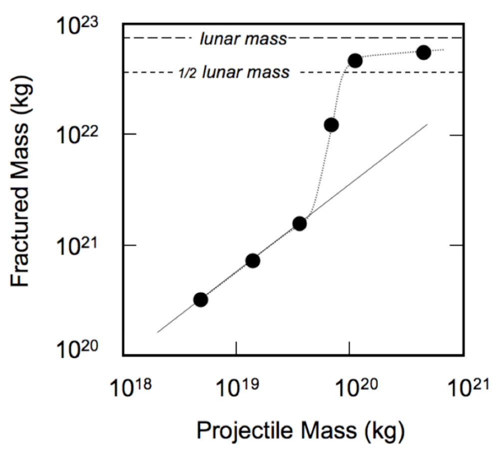

Figure 1: The effect of different mass impactors on the degree of fracturing of the Moon. Fracturing is defined where the tensile stress at any depth exceeds 250 MPa.

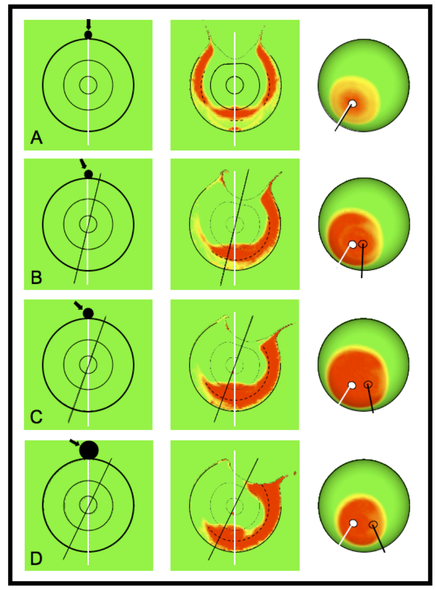

Figure 2: The effect of impact angle on crustal failure (tensile stress > 250 MPa) for an SPA-scale collision. Coupled energy is kept nearly constant in order to produce the same-size crater with an impact speed of 20km/s. Impactor diameters and angles correspond to: 260 km at 90° (A); 300km at 60° (B); 380km at 45° (C); and 700km at 30°.

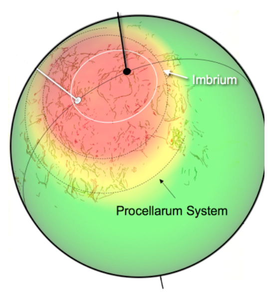

Figure 3: Effect of large (700km diameter) impact on the distribution of failure on the opposite side of the Moon. Black "pole" corresponds to the SPA center antipode where the white "pole" indicates the approximate center of the Procellarum System [17] defined in part by a system of arcuate and radial graben and ridges.

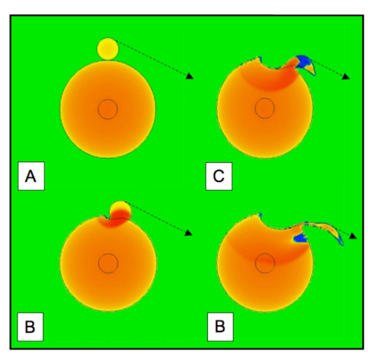

Figure 4: Survival of 700km impactor after a 30° impact at 20km/s. A significant fraction (~50%) of the impacting mass decouples from the collision and produces large debris with a velocity similar to the orignal.