A POSSIBLE LINK BETWEEN PROCELLARUM AND THE SOUTH-POLE-AITKEN BASIN. P. H. Schultz, Brown University, Department of Geological Sciences, Box 1846, 324 Brook Street, Providence, RI 02912-1846 (peter_schultz@brown.edu).

Introduction: The recognition of regions on the Moon that have been modified endogenically over the last 10Myr [1] creates a dilemma. Because widespread basaltic effusions ceased 3Ga with minor effusions extending to 1Ga [2,3], the presence of degassing events requires tapping the deep interior where phase transitions may still occur [4]. This is consistent with their association with a system of rilles (graben) that crosscut radial structures from the Imbrium basin. A closer look reveals that degassing sites occur along a system of grabens radiating from the putative 2300km in diameter "Procellarum Basin (PB)" first proposed by Whitaker [5]. The precise origin of the PB, however, remains enigmatic [6,7]. It is delineated by a radial and concentric system of ridges and faults (as well as boundaries of irregular maria), but the remaining evidence of a massif ring, gravity anomaly, or topographic depression is absent [e.g., 8]. The impact origin of PB, however, is attractive due to its unique association with a region of high-Th due to crustal thinning [e.g., 8]. Here it is proposed instead that the PB represents offset antipodal effects from the formation of South-Pole-Aitken Basin (SPAB), a process that could account for its scale, placement, and association with sites of the inferred deep degassing site.

Antipodal effects from the SPAB impact: The center of the 2300 km diameter SPAB occurs at about 60S, 20E [9] on the lunar farside, with the corresponding antipode at +60, 20W. There is no obvious modification from antipodal focusing of shock waves at this location, which is significantly offset from the center of the PB (+23, 15W). As result, any connection between SPAB and PB has been logically ignored. Instead, other processes have been proposed for Procellarum and the related enhancement in Th, such as asymmetric crystallization of a magma ocean [10,11] or offset structural effects from an oblique Imbrium impact [12]. The first mechanism accounts for the observed geochemistry but begs the question of origin. The second accounts for structural patterns (graben and ridges) but would not account for the deep-seated pathways resulting in Ina-like degassing sites [1].

SPA represents scars from a collision that must have had generated significant antipodal shock effects. Because SPA was formed only 0.2-0.3Ga after lunar formation, the absence of any evidence on the nearside can be simply attributed to overprinting by later impacts, mare emplacement, and the Imbrium basin. Nevertheless, massifs associated with SPA curiously have survived (13) and the basin retains 12 km in relief. The gravitational binding energy of the Moon is ~$1.2x10^{29}$J , whereas an impact by an asteroid 800km in diameter (at 10 km/s) is ~$4.4x10^{26}$J, which approaches 0.35% of the energy that holds the Moon together. An even larger body is possible for an oblique (<45º) trajectory due to decoupling prior to complete penetration for a spherical target [14]. Consequently, a series of experiments were designed to address the pattern of shock effects on a sphere.

Laboratory Impact Experiments: Numerous studies have addressed the threshold for catastrophic disruption of asteroids [e.g., see 15]. The present study, however, assesses failure patterns well below this threshold. A range of projectile sizes (1/8" to ¼" aluminum and Pyrex) impacted two different sizes of clear acrylic spheres (4" and 3") at various impact angles (surface tangent at the point of impact). The properties of such a target obviously is totally unlike a planetary body, but it does record failure patterns due to strong shocks that can be applied qualitatively. The experiments were performed at the NASA Ames Vertical Gun Range (AVGR) at the NASA Ames Research Center. Direct impacts (normal to the surface) with energies near the disruption limit produce extensive antipodal spallation similar to previous studies using acrylics [16]. With decreasing energies, however, antipodal spallation does not occur; instead, antipodal failure occurs near the center of sphere as rarefactions converge from the free surface (Figure 1 and [17]). More importantly, antipodal effects from oblique impacts is offset in direction of the incoming trajectory (Figure 1). The crater center and surface spallation are also offset downrange from first contact, corresponding to asymmetry in shock strength [18]. The net result is an offset in antipodal effects. High-speed imaging reveals that in addition, the strong downrange shock compression induces localized failure before the development of shallow spallation. Failure in the uprange is notably absent since the uprange shock is much weaker.

Implications: The experiments provide a relatively simple explanation for the absence of obvious SPA antipodal effects and PB. PB represents crustal failure due to SPA but is offset by about 900km to the southwest of the predicted antipode due to the trajectory of the collision that formed SPA (Figure 2). Deep-seated stresses within the Moon (extending to near the core) would also have been offset toward what is now the nearside, thereby concentrating layered igneous intrusions and subsequent mare volcanism on the nearside as well as deep seismic activity. Conversely, crustal weaknesses uprange from the SPA trajectory are poorly developed and would not result in extensive conduits for magma sources on the farside.

The Imbrium impact later occurred to the northeast of the SPA-antipode. It is intriguing to note that the "High-Th Oval" region [19] could represent asymmetric excavation of intrusions related to the SPA antipode offset from Imbium.

Clementine LIDAR topography is consistent with the proposed oblique trajectory where the greatest amount of ejecta is to either side of the trajectory axis. Such a distribution would account for both the thickened farside crust and the nearside Southern Highlands. Conversely, it would contribute little ejecta across Procellarum and Imbrium, which would ensure deeper excavation into the crust by Imbrium and Serenitatis.

The radial and concentric grabens comprising PB represent reactivation of SPA-related failure and extend deeper into the lunar crust than superimposed basins, such as Humorum and Grimaldi. Consequently, such basins reactivate and deflect SPA-antipode faults but do not fully erase them. These also would be sites of the last effusions of high-Ti mare basalts [e.g., 2,3]. Of particular note is the occurrence of Ina (and other regions of possible degassing) along the NNW-SSE systems of grabens that cut across the radial and concentric weaknesses of Imbrium [1]. Offset antipodal fractures from SPA could have provided deep conduits throughout lunar history (see Fig. 1).

Future tests: Upcoming lunar missions should be able to test this hypothesis through detailed gravity of the SPAB, higher resolution topography, higher resolution geochemical mapping, more detailed mapping of the Procellarum system, and location of additional degassing regions.

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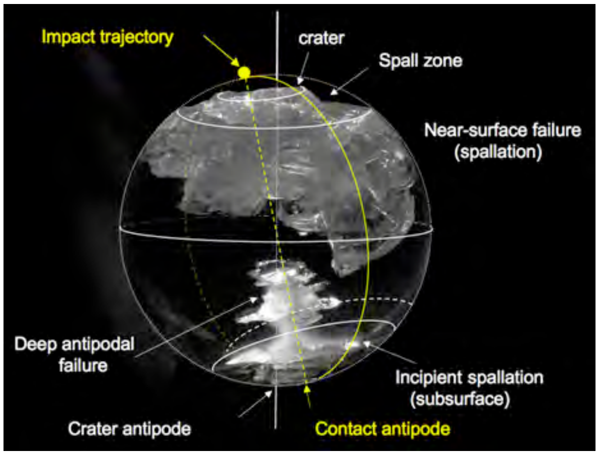

Figure 1. Oblique impact into acrylic sphere (45º) at 5.4km/s. Oblique trajectory results in higher peak pressures downrange (yellow line). Failure is initiated at the center and progresses toward antipode. Antipodal deformation is offset from the crater but coincides more closely with the first contact. Incipient spallation below the surface is further offset back toward the crater.

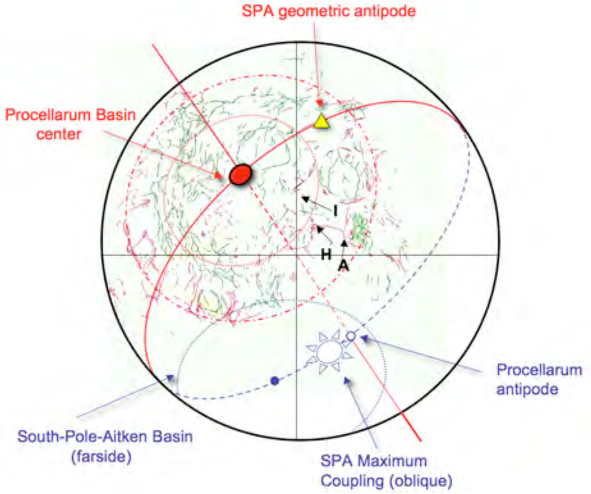

Figure 2. Implications of offset antipodal effects due to the formation of South-Pole-Aitken (SPA) Basin. A southeast (farside) would produce antipodal effects offset from the SPA antipode based on center of the basin. Maximum coupling occurs ~ 900km uprange from the crater center. The resulting offset antipode closely corresponds to the center of the "Procellarum Basin PB" delineated by radial/concentric grabens (red) and mare ridges (greeen). Inferred gas release from Ina (I), Hyginus (H), and south of Arago (A) are along reactivated structure radial to PB that superimpose Imbrium [1]. Dotted red lines indicate strikes of radial graben/ridges.