EXCAVATION OF APOLLO SAMPLES 76535 AND 78235 DURING THE FORMATION OF THE SERENITATIS BASIN: IMPLICATIONS FOR THE FORMATION AGE OF THE BASIN.

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Introduction: Impact events are some of the most energetic processes to affect planetary surfaces. Conventionally, impact excavation occurs early in the cratering process and describes the acceleration of predominantly near-surface material away from the point of impact. This response is due to the passing shock and rarefaction waves formed immediately after contact between a projectile and target surface [1]. Within this framework, most ejected material is likely to have shock features (e. g. planar deformation features, mineral twinning) indicating the degree of shock experienced by the mineral grain, with ejecta originating nearest the point of impact experiencing the highest shock levels.

The presence of initially deep, lightly shocked material along the peak-rings of impact basins is predicted from hydrocode models of basin forming impacts [e. g. 2]. Although remote sensing observations of Orientale basin confirm that its peak-ring has crystalline anorthosite and is therefore compositionally similar to lunar crustal composition [3], the degree of shock has not been directly tested. Shock metamorphism remains one of the key measurements for understanding the scale of impact processes and often anchors geologic interpretation of impact structures.

Apollo 17 samples 76535 and 78235 from Serenitatis may provide the link between models and observations. We explore here how formation of the Serenitatis impact basin may have ejected these two samples of the deep lunar crust. Troctolite 76535 and norite 78235 were both collected along the Serenitatis basin rim during Apollo 17. 76535 is coarse-grained and unzoned, indicating a high degree of thermal equilibrium [4], and symplectite assemblages indicate that it formed at a depth of 45 – 65 km in the crust [5,6]. A period of rapid cooling at low temperature [7, 8] suggests that the ^{40}Ar/^{39}Ar age of 4249±12 Ma dates the time of impact ejection from the deep crust [9]. However, 76535 is unbrecciated and shows no evidence of experiencing shocks above 6 GPa [4, 6, 7], seemingly inconsistent with the sample having been excavated during a basin-scale impact event. Norite 78235 originated at depths between 8 and 30 km [10]. Although unbrecciated, it shows maskelynite and other features consistent with shock pressures of up to 50 GPa [11,12]. Pb-Pb dating of phosphate grains give an age of 4210±14 Ma that has recently been interpreted as the age of the Serenitatis impact event [13].

It has previously been suggested that the Serenitatis impact event cannot explain the characteristics of 76535. An alternatively proposed model involved both the South Pole-Aitken basin impact and a second large, low shock impact to transport 76535 from near the South Pole to the Apollo 17 landing site [6]. However, the need to excavate two different rock types from large depths and deposit them in close proximity along the Serenitatis basin rim suggests that it is valuable to reconsider the possibility of the Serenitatis impact ejecting both 76535 and 78235, specifically focusing on the effect of the central uplift bringing deep material to the surface during the crater collapse stage. This mechanism would be relevant to understanding the genesis and geologic history of material found along the basin floor and inside the rim of impact basins, having strong implications for the interpretation of such material potentially collected during upcoming lunar missions.

Methods: We use the shock-physics hydrocode iSALE-2D [14–18] to test the hypothesis that significant amounts of material are displaced during crater collapse of large impact events, using Serenitatis basin as our test case. We structure a lunar-like curved target with either 35- or 40-km-thick granite crust (a reasonable average crustal thickness surrounding Serenitatis basin [19]) with gabbroic rheology overlying a dunite mantle and 350-km radius iron core. The model resolution is 1 km, high enough to resolve ejecta distribution. Impacts strike vertically with a 100-km diameter dunite impactor moving at 12 km/s. Given the strong influence of temperature on material strength and the range of thermal gradients inferred at the time of 76535's excavation (8-17 K/km) [6], we test lithospheric thermal gradients from 10 – 30 K/km; all temperature profiles transition to an adiabat at 1300 K. As we are focusing on replicating Serenitatis basin and the exhumation of samples 76535 and 78235, we evaluate our models on how well they match observed structure and crustal thickness of Serenitatis basin while displacing 76535- and 78235-like material to the surface.

Preliminary Results: We seek to understand the role of crater collapse in redistributing material during an impact by modeling the Serenitatis impact and determining if material like samples 76535 and 78235 are displaced to the surface. Our model with 20 K/km thermal gradient and 35-km crustal thickness best replicate the crustal thickness profile and fault locations of the Serenitatis basin. Our models are ~10% wider than observations and we are continuing to refine the parameter space to better match Serenitatis' diameter.

When considering the geophysical constraints, material with similar geologic histories of 76535 and 78235 is displaced to the surface with our fiducial impact simulation (Figure 1). There is less material matching troctolite 76535 at the surface compared to material matching norite 78235; we attribute this to the significantly deeper origin depth of 76535 (45 – 65 km vs 8 – 30 km). Importantly, troctolite-like material is deposited on the surface under all preimpact conditions tested, supporting our hypothesis that deep material is likely to be exhumed without being subjected to high shock pressures. Models show that lower thermal gradients facilitate displacement of a higher volume of lightly-shocked material to the surface.

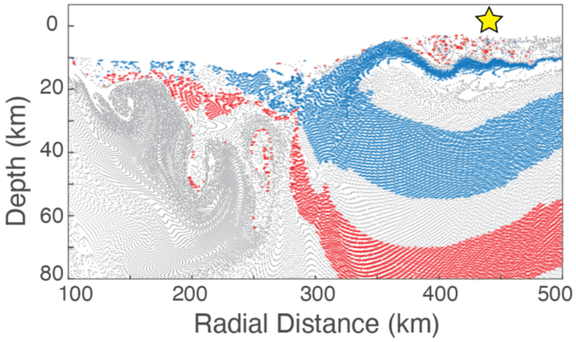

Figure 1: Distribution of post-impact tracer particles in model with 35 km thick crust and 20 K/km thermal gradient. Tracer particles are colored according to if they meet the geologic constraints of 76535 (45 – 65 km depth, < 6 GPa shock; red) or 78235 (8 – 30 km depth, < 50 GPa; blue). Tracers which meet neither sample are shaded gray. Star approximately denotes the landing site of Apollo 17.

Implications for the Age of the Serenitatis Basin Impact: Because of the likelihood of overprinting by younger Imbrium basin ejecta, it has been recognized that it is difficult to date the age of the Serenitatis impact from radiometric ages of Apollo 17 impact melt breccias [20]. Based on the success of our hydrocode models in explaining the excavation of both 76535 and 78235, we suggest that the radiometric ages of the impact events recorded in these samples dates the Serenitatis impact at 4.25 to 4.20 Ga [9,13]. This is consistent with a recent estimate of 4.22±0.03 Ga from crater counting with a buffered non-sparseness correction [21], although other estimates require a stratigraphically younger age for Serenitatis [e.g. 22].

Conclusions: These results support our hypothesis that a significant volume of material is exhumed to the surface during the crater collapse stage of basin-forming impacts. Sample 76535 specifically highlights how important it is to understand this process in the context of lunar exploration; this sample has been a confounding data point in the Apollo sample suite for decades as it necessitated an excavation from great depth while avoiding the high shock pressures traditionally associated with impact excavation. However, our results show that this rock could have been displaced to the surface during the Serenitatis impact event under a variety of pre-impact conditions.

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