IMPACT BASIN FORMATION AND STRUCTURE FROM 3D SIMULATIONS. S. T. Stewart. Department of Earth and Planetary Sciences, 20 Oxford Street, Cambridge, MA 02138 (sstewart@eps.harvard.edu).

Introduction. Our understanding of the mechanics of impact basin formation has been handicapped by the difficulties in making robust comparisons between numerical simulations and present-day observable features. Basin-scale craters pose a particular challenge because of the expectation of significant post-impact modification resulting from the thermal and gravitational anomalies generated by the impact event. Cratering simulations are limited to studying the processes that occur in the first hours after an impact, after which the dominant physical processes are not included in the numerical models. And yet, we wish to make comparisons to features that are billions of years old.

Here, I investigate the formation of large impact basins, such as South Pole-Aitken (SP-A) on the Moon and the proposed Borealis basin on Mars, in order to identify features related to oblique impacts and structures to compare to observations.

Numerical Model. Basin formation is modeled using the CTH shock physics code with self-gravity in 3D [1]. The equations of state and rheological models are the same as described in [2, 3]. The planets were initialized in gravitational equilibrium with thermal profiles appropriate for post-magma ocean states in the early solar system [4, 5]. Computational expense limits the resolution to 10–40 km/cell in the crust and 5–10 km/cell in the projectile; adaptive meshing was utilized to decrease the resolution away from the impacted surface. A wide range of SP-A scale impact basin formation simulations were conducted in [3, 6]; here, I focus on the crater structures about 1 hour after the impact event. A few exploratory Borealis-scale simulations have been conducted in the range of impact energies suggested by [7].

South Pole-Aitken Results. At the current spatial resolution, excavation and deposition of crustal materials is broadly resolved (Fig. 1). With increasing impact angle from vertical, the annulus of thickened crust is focused in the downrange direction (similar to results in [8]). For the range of impact parameters explored, impact angles between 30 and 60° and 75 to 150-km radius projectiles, basin diameters at 1 hour are approximately circular (<5% ellipticity).

A region of the crust was completely excavated. The transient crater wall slopes are steep in the uprange direction, leading to collapse of significant amounts of crust from the uprange rim fold into the basin. The collapsing crust meets the uplifting molten mantle, which is offset downrange from the basin center. The numerical model does not allow mixing of the cold crust into the melt sheet, leading to an artificial concentration of crust in the uprange basin floor and an adjacent region devoid of crust. If the collapsed crust were evenly spread over the inner region, the crustal thickness in the basin floor would be 10-20 km.

For the nominal rheological parameters considered here, the 1-hour basin structure is defined by a central mass deficit, narrow terrace, and thickened crustal annulus. The amplitudes of the positive and negative mass anomalies are sensitive to the rheology. The rheological model assumes that the mantle rheology is dominated by rock friction lubricated by melts. Note that with increasing impact angle, the depth of melting decreases significantly [9]. In the 60° impacts, the depth of melting was shallower than the transient cavity (see also [8]). The rheological model for the mantle limits the extent of uplift and minimizes exposure of mantle phases [2]. Note that previous models that assumed a fluid rheology in the mantle during crater collapse produced significant flows of mantle materials onto the lunar surface, including over the basin rim [e.g., 10, 11], leading to a positive central mass anomaly.

Comparison to South Pole-Aitken Observations. The 1-hour shape of the modeled basins are nearly circular, in contrast to the elliptical shape derived by [12], implying either a combination of slower or more oblique impact conditions [13] or asymmetric post-formation modification. The combination of crustal thickening and magnetic anomalies to the north suggest an oblique impact from the south to north [3].

Exposure of mantle phases around SP-A are extremely scarce and concentrated on the southern rim [14]. If the collapsing crust is mixed into the melt sheet on the basin floor, then a thick crustal layer will eventually form over the uplifted mantle materials, effectively concealing their transient appearance on the lunar surface.

For the nominal rheology, the overall basin structure at 1 hour is remarkably similar to the broad topography and crustal thickness of the present-day SP-A. The transient topographic relief is larger than present day. Post-impact relaxation would reduce the topographic relief as the basin evolved to its present isostatic state.

The inner region of SP-A is characterized by a compositional anomaly [12]. The anomalies are asymmetric, with the most prominent features found in the northern half of the region, in alignment with the thermal anomaly and uplifted mantle melts for an impact from the south to north.

Borealis Results. Initial calculations find similar volumes of excavated crust as in [8]. As with SP-A, collapse of the transient cavity incorporates crust from the uprange rim. The rheological model significantly reduces the amplitude of global oscillations seen in the hydrodynamic code used in [8]. The goal of the investigation of Borealis is to identify features to test the impact-formation hypothesis for the global crustal dichotomy on Mars [7, 15].

Implications and Conclusions. Three-dimensional simulations of the formation of large impact basins using a pressure, temperature and strain-rate dependent rheological model generates structures in excellent agreement with the broad characteristics of SP-A. The model basins presented here represent one possible evolutionary path for SP-A. If correct, it implies a stronger rheological response for the mantle and more limited post-impact modification than previously considered.

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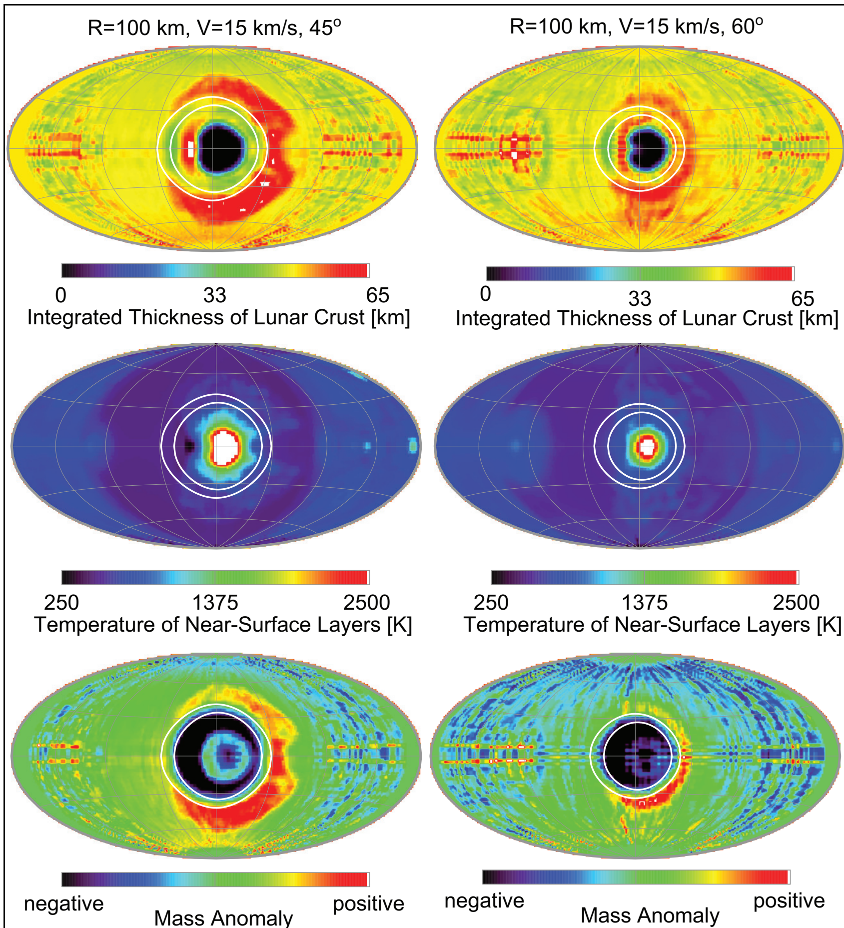

Fig. 1. Results of numerical simulations of basin formation on the Moon. The projectile was differentiated with a kinetic energy of 1.9×10^{27} J and formed a structure comparable in size to South Pole-Aitken basin. Integrated crustal thicknesses, near-surface temperatures, and mass anomalies shown on a Hammer projection at ~1 hour after impact. Example 45 and 60° from vertical impacts, moving from left to right, had 10 and 20-km resolution in the crust, respectively. Outer contours identify the basin diameter, defined as the inner edge of the annulus of thickened crust. Inner contours are defined by the negative mass anomaly, which is slightly offset downrange from the outer contour center. The thermal anomaly and uplifted mantle are offset downrage within the inner region. The thick deposit of crust in the uprange inner region is an artifact; the crust that collapses into the basin should mix into the melt pool. The magnitude of the mass anomaly is sensitive to the rheological parameters. For the nominal values used here, the 1-hour topographic relief is larger than the present-day SP-A.