

EXCAVATION OF MARTIAN LOWER CRUST AND MANTLE BY THE ISIDIS IMPACT AND IMPLICATIONS FOR THE MARS 2020 MISSION. A. J. Trowbridge¹, A. Boener¹, B. Horgan¹, J. Elliott¹, B. P. Weiss², and H. J. Melosh¹, Purdue University, West Lafayette, IN (atrowbr@purdue.edu), ²Massachusetts Institute of Technology, Cambridge, MA.

Introduction: Isidis Planitia (Figure 1) is a ~1500 km diameter basin centered at 13°N 87.0°E and is thought to be the last major impact basin that formed on Mars, approximately 3.9 billion years ago [1]. The Mars 2020 rover landing site has recently been selected to be Jezero crater, which lies between the inner and outer rings of Isidis (Figure 1). Thus, the circum-Isidis region represents a unique area for *in situ* investigations of basin-forming impact processes and their ejecta on Mars [2]. However, it is currently unknown how deeply the Isidis impact excavated, and thus it also unknown what types of materials the Mars 2020 rover will encounter and collect for possible future sample return.

A recent study [3] modeled the formation of the similarly-sized South Pole-Aitken basin on the Moon, showing that SPA ejecta should contain a large fraction of upper mantle material, which is consistent with the observed enrichment in such mafic phases as orthopyroxene (OPX) in likely ejecta materials in the lunar highlands. An upper OPX-rich mantle has major implications for the petrology of the Moon and how it formed from an early magma ocean. Recent spectral observations identified orthopyroxene in the ejecta blocks of Argyre Planitia, another large multi-ring basin on Mars [4] and is the dominant mineral detected in hypothesized ejecta materials from Isidis itself [5].

By implication, we hypothesize that Isidis may also be capable of excavating the upper mantle on Mars. If Mars also has an upper mantle rich in low-Ca pyroxene, it would imply that the olivine rich upper mantle of Earth is unique in our solar system. If upper mantle materials are expected to be present in the circum-Isidis region, these could be important targets for Mars 2020 and Mars sample return. In this study, we use hydrocode simulations to model the Isidis impact and to determine the depth of origin and shock state for materials in the rim and beyond.

Basin Size Constraints: Ref. [6] conducted a series of iSALE runs and admittance modeling of Isidis Planitia, varying the geothermal gradient, pre-impact crustal thickness, and projectile diameter. They concluded that the best-fit impact parameters for Isidis are a 120 km diameter dunite impactor striking a 60 km thick basalt crust with a 20 K/km geothermal gradient at 12 km/s. However, the diameter of the crustal collar formed from this size of impactor does not match the observed free air gravity anomaly of Isidis. Isidis, as a mascon basin, has a central free air gravity high

surrounded by a free air gravity negative annulus. A mascon basin's free air gravity low is associated with the location of its crustal collar, whose diameter does not change significantly with isostatic adjustment [7]. The diameter of the free air gravity annulus of Isidis is larger than the crustal collar produced by ref [6]'s best fit run. The diameter of the crustal collar is dependent on impact energy with a larger impact energy resulting in a larger diameter for the crustal collar. Therefore, in this work, we conducted a full parameter search of impactor parameters for impactors 120 km and larger.

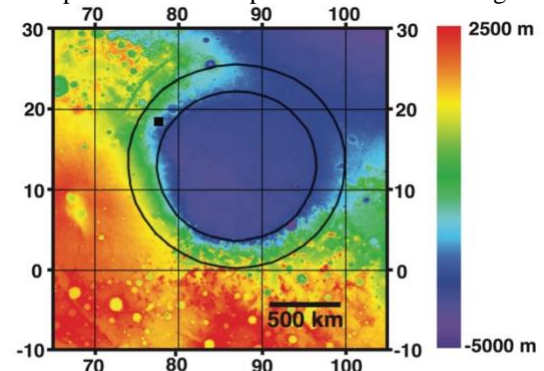


Figure 1. Topography map of Isidis Planitia. Black rings label the inner and outer rims. The black box shows the location of Jezero crater.

Modeling Approach: We used the iSALE shock physics code [8-10] for the hydrocode modeling. The runs were conducted in axisymmetric 2D. To save computation time, most of the runs were conducted with a planar Mars target; however, we conducted additional runs with a spherical target with a central gravity field to quantify the variation between a planar and spherical target. The crust was modeled with a basalt ANEOS equation of state, the core was modeled with an iron ANEOS equation of state while the mantle and impactors were modeled with the dunite ANEOS equation of state [11]. Our high-resolution zone contained cell sizes of 2 km and extended 800 cells from basin center and to a depth of 700 cells.

To simulate the rheology of dunite and basalt, we incorporated a rock-like strength model [9], a damage model [12], and thermal weakening model [13] corresponding to the temperature- and pressure-dependence of the material.

We conducted a parameter sweep of runs varying the geothermal gradient, pre-impact crustal thickness, projectile diameter, and melt viscosity while keeping

the impact velocity constant. We used an impact velocity of 12 km/s to be consistent with previous work [6]; however, the mean impact velocity of Mars is 9.4 km/s [14].

Results: Using the best-fit run of the previous work [6], the iSALE simulations show that the impact forming Isidis Planitia excavated deep enough to deposit mantle material at Jezero crater. Figure 2 shows the Lagrangian tracer particles for a slightly larger impactor run (132 km diameter impactor). The gray dots in Figure 2b indicate mantle tracer particles and the dotted line shows the radial location of Jezero crater. The top 10 km material that would be deposited at the location of Jezero crater consists of a mixture of material with variable depth of provenance, but the predominant percentage of material comes from >30 km depth, which includes mantle material. This deep crust/mantle material is deposited as a result of the collapse of the central peak, similar to the process that forms peak rings [15]. Since the central peak collapse is the last major step in the impact process, the central peak material is deposited at the top of the stratigraphy at Jezero, just above the ejected material. Our runs with larger impactor sizes yield more mantle material deposited at Jezero crater.

The tracer peak shock pressure plotted in Figure 2a shows that the top 10 km at the Jezero landing site consists of a mixture of material shocked to a variable peak pressure. The predominant percentage of material has been shocked above 10 GPa with higher shock pressure corresponding with deeper depth of provenance. Using the texture and characteristic shock effects for the progressive stages of shock metamorphism of basaltic achondrites, illustrated in Table 2 of [16], the Mars 2020 rover should be able to determine the peak pressure of material present in the observed megabreccia, and the results presented in Figure 2 could be used to determine the depth of provenance.

Conclusions: Based on the results presented here, the Mars 2020 rover could encounter a mix of upper crustal, lower crust, and mantle materials in the hypothesized Isidis ejecta deposits that form the basement unit outside of Jezero crater. The actual exposed cross section of Figure 2 depends on how much erosion has taken place in the subsequent 3.9 By after emplacement. It is therefore crucial to identify how much erosion has occurred at Jezero crater. Orbital imagery shows a diverse suite of layered ejecta as well as large megabreccia blocks in this area, which dominantly exhibit an orthopyroxene spectral signature and variable alteration signatures [17]. We hypothesize that data from the Mars 2020 rover can be used to determine the peak pressure of material in the ejecta

and thus its depth of provenance. Thereby, the results of this study can be used as a guide for the Mars 2020 team to identify in-situ the composition of the lower crust/mantle at the time of the Isidis impact. This result will further enable ejecta composition/alteration to be linked to depth of provenance and better constrain early crustal modification processes.

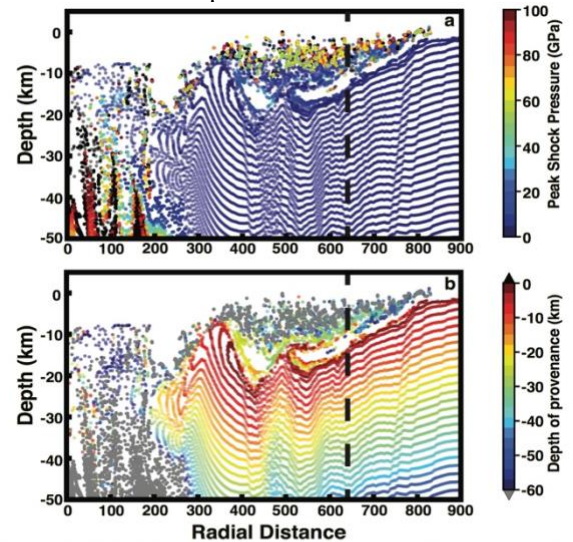


Figure 2. iSALE lagrangian tracer particle results for a 132 km diameter dunite impactor with an impact velocity of 12 km/s, a geothermal gradient of 20 K/km, and a pre-impact crustal thickness of 60 km: (a) peak shock pressure; and (b) depth of provenance. Black dotted line illustrates the location of Jezero crater. Tracers from >60 km depth are plotted on top of other tracers to emphasize mantle material.

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