CASCADING BOULDER AND BOULDER TRACK EXPERIMENT AT BARRINGER METEORITE CRATER (AKA METEOR CRATER), ARIZONA.

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Introduction: The bearing capacity of lunar regolith can affect crew traverses and trafficability of mobile assets. Low bearing capacities, for example, may require more energy for crew and mobility assets to traverse terrain. Bearing capacities may also affect the effort needed for trenching and coring, which may, in turn, be required for sample return, *in situ* scientific analyses, and *in situ* resource utilization (ISRU) recovery and processing technologies. To address that geotechnical property in advance of surface missions, boulders and boulder tracks visible in Lunar Reconnaissance Orbiter Camera (LROC) images have been used to estimate bearing capacities in pyroclastic deposits [1], permanently shadowed regions [2], and throughout the Artemis exploration zone [3]. Those orbitally-determined estimates need to be tested. One way to test and calibrate those values is to build measurements into astronauts' extravehicular activities (EVA) traverses [4]. A second way to test the methodology is to conduct experiments on Earth. While gravity and surface conditions differ between the Earth and Moon, insights may be gleaned from an experiment in a suitable analogue terrain. Here we report a (dramatic) boulder rolling experiment at Barringer Meteorite Crater (aka Meteor Crater), which is a 1.2 km-diameter, ~180 m-deep simple crater [5-7] similar in size to Apollo 16's North Ray Crater and >100 craters within the Artemis exploration zone.

Experimental Conditions: A sandy carbonate (Kaibab) boulder that was ejected during the crater-forming process and sitting on the rim of the crater became unstable due to erosion of finer-grained ejecta around it. Because the block was a potential hazard for visitors, owners and operators of the crater determined it needed to be displaced. We used that September 28, 2022, opportunity to evaluate falling boulder processes. A series of eighteen video cameras were distributed around the anticipated boulder path to record the displacement. Physical conditions of the boulder and boulder track were evaluated after the displacement.

Results: The original mass of the boulder is unclear, because it was partially buried before rolling and, once rolling began, it split into several fragments that were incompletely recovered after rolling stopped. Nonetheless, the boulder's mass was roughly 60,000 kg and its potential energy 79 ± 16 MJ.

The falling boulder's path (**Fig. 1**) was initially bounded by the walls of a fault zone and eventually by gully at the base of the crater wall. When the boulder entered the gully, it bounced from one side of the gully to the other, but did not escape the gully.

The bearing capacity of the crater wall along the rolling path varied from that of hard rock to that of an organic-poor soil that formed a thin veneer over boulder-rich colluvium. Penetration depths in colluvium along the boulder track were measured in 18 locations, ranging from 12 to 74 cm. Cone penetrometer and vane shear device measurements were made in those locations. While we are still evaluating those data, preliminary analyses indicate the bearing capacity of the slope is ~50 kNm^{-2}, about 5 times greater than that recommended for rovers on the lunar surface [8].

Figure 1. Compiled images showing (top) the boulder rolling down the crater wall and (b) a close-up view of its descent over a cliff in the upper crater wall.

Figure 2. Figure 3. Images of (upper left) main mass of fractured boulder at the bottom of the crater, (upper right) second largest fragment that was stranded on the upper crater wall, and (bottom) 3D renderings of the boulder before rolling (left) and the two largest fragments (right) generated using iPhone lidar depth-scanning sensors and the 3D Scanner App. Longest boulder dimension is ~3.3 m.

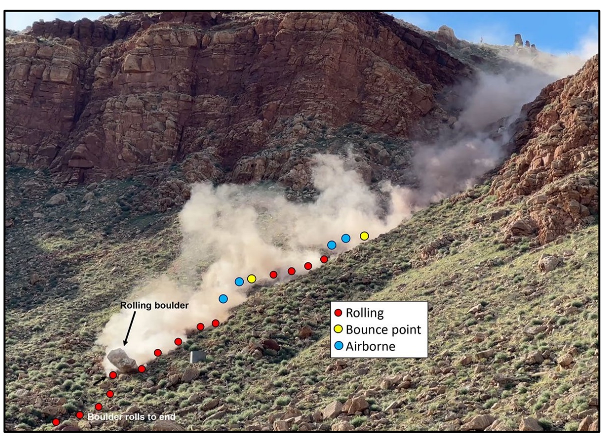

Figure 3. Illustration of rolling and bouncing portions of the downhill path of boulder and the dust plume it generated.

The boulder's fall down the crater wall was complex. The boulder split into fragments (**Fig. 2**), producing a new population of higher-albedo angular rock fragments, the largest of which was 80 to 85% the original mass and was stopped near the bottom of the slope by another boulder that had fallen previously in geologic time.

The largest fragment rolled, slid, and bounced downslope (**Fig. 3**). Because the boulder was angular (**Fig. 2**), it rolled by bouncing from corner to corner, with intermittent contact, unlike a rolling sphere with continuous surface contact. Along the way, the boulder dislodged other boulders, producing a cascading event. The boulder (and subsequent main mass) also cracked boulders into multiple fragments and, in some cases, crushed rock it hit, producing an explosive spray of rock flour that coated nearby rocks and vegetation. Glancing blows by the falling boulder produced scrape marks along the crater wall. When the boulder fragmented, it sometimes did so via shear that produced slickensides (**Fig. 4**) on its surface. In general, the devastation witnessed along the boulder's path is not something that is easy to appreciate from orbital images.

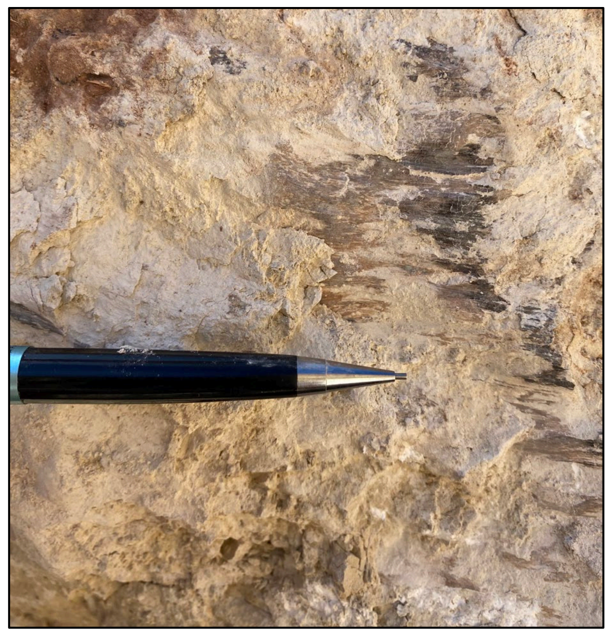

Figure 4. Cm-scale slickensides on the surface of the largest fragment of the boulder where a portion of the boulder was removed by shear fragmentation during the fall.

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