Characterization of a mass movement site in Bennu's Bralgah Crater and implications for other asteroids

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Near-Earth asteroids such as Bennu and Ryugu have boulder-covered surfaces and latitude-dependent slope distributions, signifying that mass movements of boulders perform significant roles in the surface evolution of these small bodies. The OSIRIS-REx (Origins, Spectral Interpretation, Resource Identification, and Security–Regolith Explorer) mission [1] documented numerous locations on Bennu exhibiting evidence of mass movements of surface material, mostly towards the lower elevation equatorial region [2]. One such location, contained within Bralgah Crater, was considered (but not used) by the mission as a candidate site for sample collection; thus, high-resolution images collected during reconnaissance of this area allow a more detailed survey than would be possible elsewhere [3] [Fig. 1]. An apparent flow "wake" downhill from a 4.8-m-diameter central boulder in the area, where medium-sized boulders are much less prevalent than in the surrounding terrain, provides an opportunity to investigate the characteristics of mass flow on the asteroid. Through boulder mapping and topographic analysis, we found evidence of a pileup behind the central boulder, as well as a strong orientational preference of the boulders in this area [Fig. 2]. This preferential long-axis orientation exhibits the same westward deflection from the expected downslope direction that we observed at another mass movement site in Bennu's northern hemisphere [4], implying that a global mechanism with effects mirrored between the northern and southern hemispheres is affecting the mass flows.

We performed dynamical simulations of seismic shaking using the discrete-element N-body code PKDGRAV [5–8] to better constrain the conditions that may have formed the landscape. In these simulations, we used boulder sizes similar to those surveyed at the Bralgah Crater site and an environment with a similar 4.8-m-diameter central boulder. We were able to replicate the pileup of material uphill from the central boulder and the wake downhill from it, producing similar elevation profiles created by a lack of downflowing material in the wake area [Fig. 3].

Simulations also showed a preferential orientation emerging, with a strong possibility for preferential orientation parallel to direction of motion. Combined with the orientational preference observed in this and other studies of Bennu's landscape, this indicates that the Coriolis effect could be a major factor in the mass movement of boulders and would help to explain the westward deflection of the boulders' long-axis orientation. Numerical simulations show that the Coriolis effect is strong enough to induce an east-west displacement of the boulders, which can amount to 10% of the downslope displacement, which could lead to the observed orientational preferences. This effect would be expected to occur on other fast-spinning asteroids, such as Ryugu, where this hypothesis predicts a similar orientational preference, with eastward deviation from the poleward migration of the boulders.

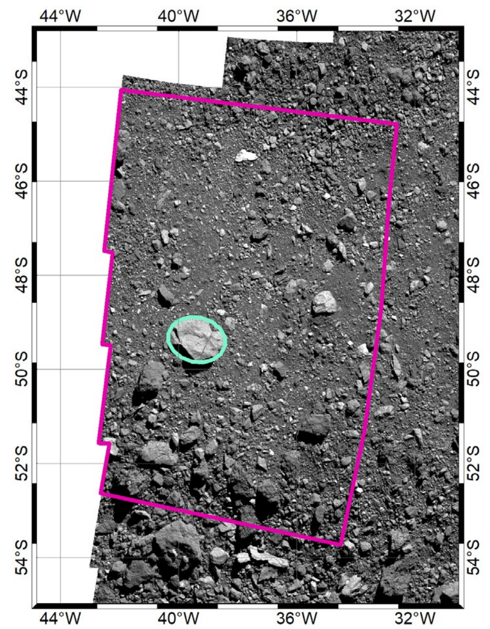

Figure 1. A map of the survey area (magenta outline) within Bralgah Crater, projected in ArcGIS, with the central boulder (long axis, 4.8 m) highlighted by the light blue best-fit ellipse. The downhill direction is north in this area.

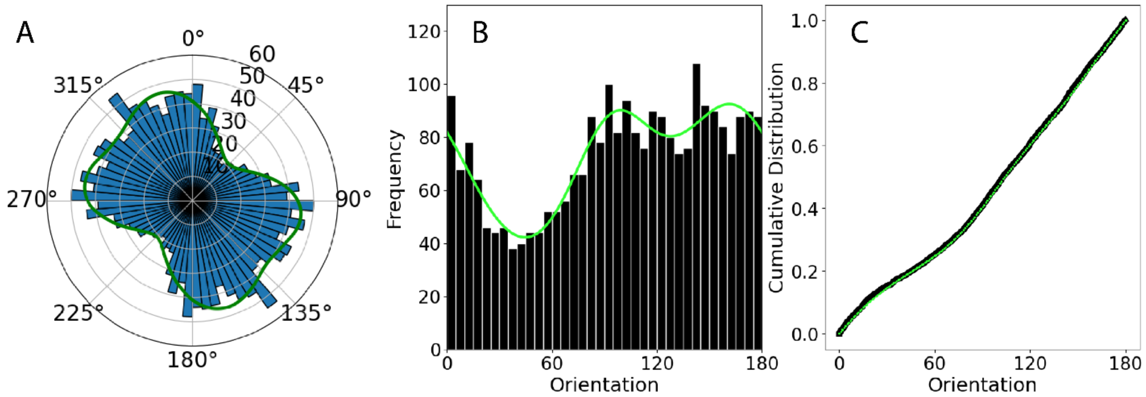

Figure 2. Orientations of the surveyed boulders as a rose diagram (A) and histogram (B), with the data best fitted by a bimodal von Mises distribution (green) with peaks at 94.1° and 164.2° (p-value = 0.839). (C) The empirical distribution function (black line) and cumulative distribution function (green line) of the orientations, used for the K-S tests to derive the p-values.

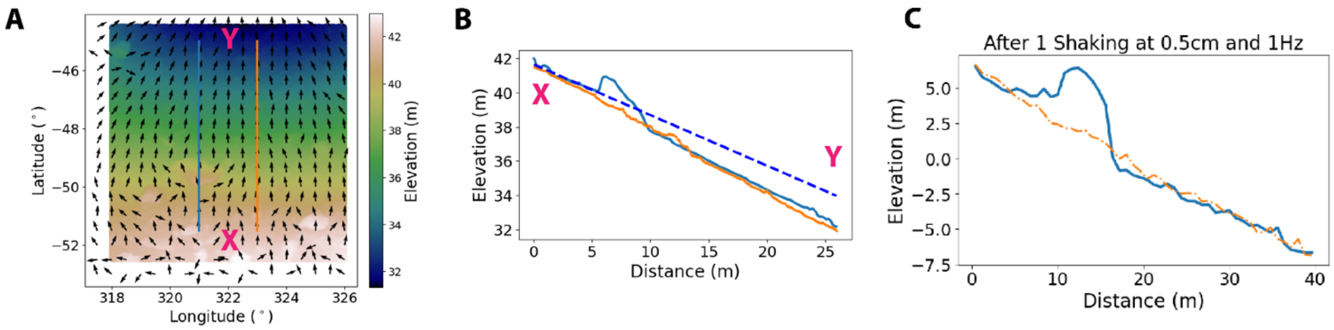

Figure 3. (A) Elevation map of the study site, overlayed with arrows indicating the direction of greatest slope, with the locations of the elevation profiles along longitudes 321°E and 323°E marked in cyan and orange, respectively. (B) The elevation profiles indicated in (A), with the 321°E line profile (cyan) crossing the middle of the central boulder. The blue dashed line represents the best-fit slope of the pileup area uphill from the central boulder, extrapolated across the entire mass movement length. The extrapolated profile ranges from 0.8 to 1.6 m above the actual elevation profile downhill from the central boulder, with greater differences further north (downhill). (C) Elevation profile of simulations after one shaking. The cyan solid line shows elevation along the center of the wake, and the orange dashed-dot line shows the elevation along a parallel transect away from the wake.

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