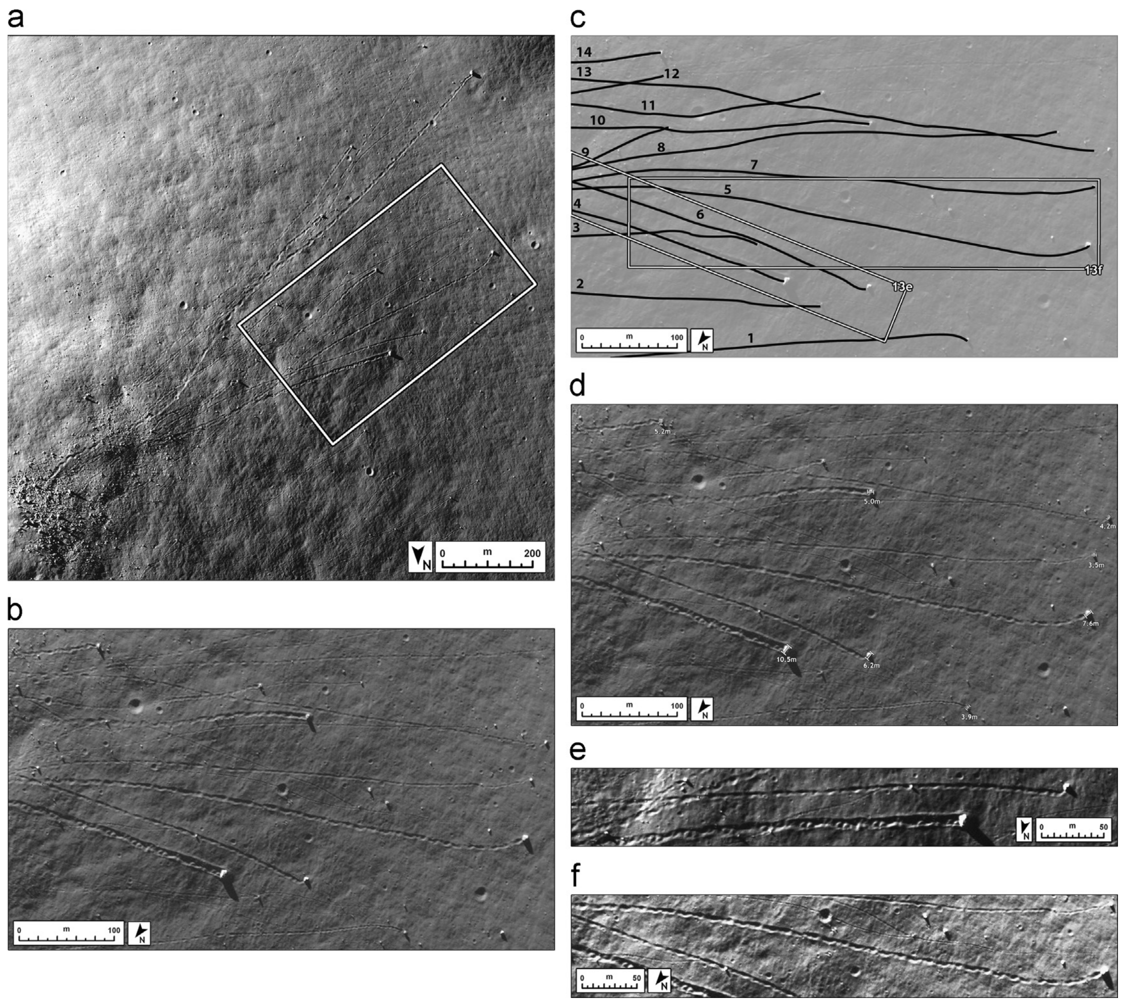

Fig. 13. Boulder tracks in the Montes Alpes region of the Moon (48.51°N, 1.69°E). (a) This image shows the source region of boulders (lower left), the hummocky nature of the downslope (i.e., to the upper right) topography, and the variable morphology of boulder tracks made before the boulders came to rest. Elevation difference between lower left (high) and upper right (low) is about 400 m and the average slope is ~14°. White rectangle shows location of inset map showing boulder track details (b and c). Lunar Reconnaissance Orbiter Camera (LROC) narrow angle camera (NAC) image M113947886R. (b) Location of boulder track examples showing different characteristics of orientation, morphology, and relation to boulders (area is rectangle in(a)). (c) Overlay on (b) showing boulder track numbering scheme; white rectangles show locations of (e) and (f). (d) Diameters of boulders at ends of boulder tracks, ranging from 3.5 to 10.5 m. (e) Details of boulder track cross-cutting relationships in tracks 2–7 (see (c) for location). (f) Details of boulder track relationships to pre-existing topography for tracks 3–7 (see (c) for location).

In addition, since the escape velocity from Phobos varies by more than a factor of two over its surface, the possibility of ejecta clasts leaving the surface even after they have already generated grooves 10–20 km long exists. In this latter case, a change in morphology from coalesced pits, to isolated pits (where the boulder bounced several times as it increased velocity), to no groove at all (downrange of its launch point), might be predicted. Many grooves on Phobos display discontinuous segments where the groove transitions into a row of individual, separate depressions (Thomas, 1978; Thomas et al., 1979; Murray and Iliffe, 2011), as might result from changes in velocity and local topography (Fig. 12). These features occur everywhere, but predominate near the area antipodal to Stickney where the grooves die out (near the zone of exclusion) (Thomas, 1978; Thomas et al., 1979; Murray and Iliffe, 2011) (Fig. 12).

It is in this latter area where we predict that some bouncing and rolling ejecta might gain sufficient velocity to leave Phobos (Fig. 12). For example, as shown in detail in Fig. 12b–d, the vast majority of grooves that approach the zone of avoidance undergo a gradual and distinct change in morphology. Here, grooves formed of overlapping pits (Fig. 12c and d) give way to isolated smaller pits (Fig. 12c), and then to isolated pits (often even smaller) along the strike of the groove (Fig. 12b and d), before the groove structure disappears entirely in the zone of avoidance. This observed behavior is consistent with the predictions described above (and shown in Fig. 2) that rolling boulders in the variable gravity field of Phobos can locally/regionally possess sufficient velocity to escape the surface of Phobos. In this case, as escape velocity is approached, a rolling boulder is predicted to transition from forming a beaded groove, to a beaded track, to a series of isolated pits (becoming progressively smaller as the boulder approaches local escape velocity), until it finally completely leaves the surface entirely, signifying the end of the groove. This strong correlation between theoretical predictions and observations provides additional support for the hypothesis that some types of grooves on Phobos originated through rolling and bouncing of blocks ejected from the Stickney impact.

f) *Groove linearity*: Grooves produced by the mechanism described here would be linear and would not be expected to deviate measurably from their path over the vast majority of their traverse. Even where preexisting topography was encountered (e.g., a preexisting impact crater) (Fig. 1b–e), a simple analysis shows that the combination