We have estimated the planform of the overturned flap hinge of Endurance Crater (Fig. 1) which formed in layered sedimentary rocks, using (a) digital elevation models derived from stereo imagery acquired by MER-B and (b) Pancam panoramas of the Endurance Crater walls. Using these data we measured layer thicknesses and bedding orientations, so that a 2D model of the stratigraphy (Fig. 2) could be used to estimate the path (“trace”) in three dimensions of the flap hinge. We find that the planform of the hinge trace is concave [1]. That is, the hinge resides inside the walls at [some] of the corners of Endurance Crater, and outside the walls (i.e., has been removed) between the corners.

The same pattern occurs in other craters at Meridiani Planum as well as Meteor Crater. We propose that this implies a transient crater that was concave in planform (Fig. 3) because crater growth was carried farther in some directions [1], instead of an excess of stratigraphic uplift at the corners [2]. This produces a pattern of “open smiles” or lenses between corners of a polygonal crater, observed at Meridiani and Meteor Crater. The reason for the asymmetry in planform is likely the same as for the case in Meteor Crater: i.e., that excavation was carried farther along the direction of pre-existing planes of weakness [3,4]. Like Meteor Crater, modes in the length-weighted fracture azimuth...
planform is mimicked by the trace of the flap hinge. B. Crater walls between vertices slump, forming a polygonal planform. C. Because hinge trace mimics the walls of the transient, layering is expressed as “open smiles” or lenses between vertices of the polygonal crater (here, the 2D stratigraphic model in Fig. 2 has been assumed).

distribution outside the crater (Fig. 4) align with extrema of the fourth harmonic of the rim planform (i.e., with the square component of the planform) of Endurance Crater. We have also confirmed this relationship for Tswaing Crater in South Africa using the observations of [5]. The reason that crater growth is carried farther in the direction of dominant fracture orientations is that shear strength is smallest in this direction, so that columns of aligned blocks are easily displaced and ejected. This is illustrated in the simulation of a layer of cubes (initially at rest on a rigid surface) to which a radial impulse has been applied (which decays with increasing radius), shown in Fig. 5. (Accomplished using a rigid-body motion dynamics engine with elastic collisions and surface friction.) The result is a highly concave transient void. The concavity of transient craters will be greatest in targets where the anisotropy in shear strength is greatest: i.e., where fractures are not hairline but have finite width, as occurs across Meridiani Planum where a rare set of conjugate tension fractures has formed.


Fig. 4: Length-weighted fracture azimuth distribution (within two radii of Endurance Crater), indicating a conjugate set of [orthogonal] fractures. The fourth harmonic amplitude (A4) and the folded radius (Rf) of the rim crest outline are also shown (deviation from mean radius, normalized by maximum radial deviation, and folded onto the domain [-90°, 90°]). As in the case of Meteor and Tswaing craters, the fractures are aligned (to within 5-10°) with the “diagonals” of the square component of the crater planform.

Fig. 5: Model of a plane of aligned cubes responding to an impulse that decays linearly with the square of radial distance. Symmetry is broken by the anisotropy in shear strength, which allows columns of blocks to be ejected along the direction of fracture alignments. The results is a highly concave void, analogous to a concave transient crater.