

5. Crater Rim Uplift and Crater Wall Collapse



The basic processes involved in crater rim uplift are understood, but there is a lot of evidence at the crater that has not been fully explored and may eventually paint a better picture of the processes that occur at the margins of transient craters.

It is clear from almost all vantage points that the horizontal strata in the pre-impact target were uplifted and now have outward dipping orientations. Pre-impact dips are estimated to have generally been <3 or 4°. The regional dip of the underlying Supai is 0.7° to the northeast (Roddy, 1978). Strata in the crater walls, however, typically dip 30 to 40°. The unusual outward dipping strata were noted by all of the early geologic explorers (*e.g.*, Foote, 1891; Gilbert, 1896; Barringer, 1905; Tilghman, 1905).

The uplift in the crater walls is a continuation of the processes that excavated the crater. Within the crater cavity, that flow was sufficient to uplift and launch material, producing the cavity that we now observe. The capacity to eject material decreased with radial distance. Immediately beyond the margins of the transient cavity, there was sufficient energy to generate flow and, hence, uplift of material, but not sufficient energy to eject it. Thus, we see uplift in the crater walls. Similar uplift occurs in the walls of chemical and nuclear explosion craters.

The uplifted walls did not collapse into their pre-impact horizontal positions after the excavation flow ceased. The uplift is preserved for several reasons, including intense fracturing in the crater walls that “bulk up” the rock, the injection of breccia into the crater walls from the crater cavity, and fault-facilitated stratigraphic thickening within the crater walls.

Estimates for the amount of bulking in the walls of Barringer Crater are sketchy, but some insights are available from experimental explosion craters. For example, in the walls of a ~230 ft diameter crater produced by an 85 ton chemical explosion in volcanic rock (Pre-Schooner II; Frandsen, 1967), the bulk density declined by 27, 37, and 47% in three trenches cut through the crater wall. The average (37%) bulking factor measured in the crater walls is similar to the bulking factor measured in ejecta on the crater’s flanks (38%) and in fallback ejecta within the crater (37%). These are generally higher values than those used by investigators at Barringer Crater. Regan and Hinze (1975) estimated a 5% density decrease (*e.g.*, 2.18 vs. 2.30 g/cm³) in the crater breccia lens relative to pre-impact rock, based on a gravity study. This 5% bulking factor has been applied by others (Roddy *et al.*, 1975). A similar bulking value (6 to 10%) was obtained with a single direct density measurement of crater rim ejecta (Walters, 1966). If these bulking values for the breccia lens and ejecta are approximately the same as that in the crater wall, then part of the uplift at Barringer Crater is due to bulking. However, bulking is apparently a smaller component of rim uplift at Barringer Crater than it is around some experimental explosion craters.

The only other data point we have thus far for the amount of brecciation in the crater walls is an observation made by Haines (1966). In core recovered from one of the NASA-sponsored boreholes (MCC-4; Chapter 3), he logged 1,059 fractures in 107.4 m. These were horizontal fractures with an average spacing of 2 to 3 inches. Having examined material from other sites in that particular drilling campaign, he apparently believed the fractures were a property of the rock, rather than a drilling artifact.

In addition to this *in situ* brecciation and bulking of the crater walls, injected breccias from the crater cavity have also been proposed as a mechanism for maintaining crater rim uplift. Barringer (1905) was the first person to articulate the idea, suggesting that the crushed silica he observed beneath lake sediments and in ejecta was also propelled beneath the uplifted limestone and red sandstone walls. As

discussed in Chapter 3, a deep borehole into the crater wall from the south crater rim encountered injected material, including fragments of the asteroid.

Structural uplift has also been attributed to a variety of faults (*e.g.*, Shoemaker, 1960; Shoemaker and Kieffer, 1974; Roddy, 1977). They are often called “thrust” faults, to capture the idea that material is thrust into the crater walls or up the crater walls. The faults are not, however, always technically thrust faults. The term overthrust has also been used to describe structural features at craters, particularly around experimental explosion craters, but this term is applied to an overturned sequence of debris on the crater rim, not structure within the crater wall. The overturned sequence on the crater rim will be discussed in the following chapter.

Interpreting structure in crater walls is complicated, because the crater wall has been rotated during uplift, in addition to being faulted. The relative timing of faulting and rotation still needs to be examined along many of the faults now exposed in the crater walls. Some options include (Fig. 5.1): (a) An apparent thrust fault, produced by a normal fault along which the foot-wall moved up and outward from the crater, which was then rotated during crater wall uplift. (b) Reverse or thrust fault along which lower strata were moved down and outward from the crater and then rotated during crater wall uplift, possibly forming an anticline with a radially-directed plunge line at the top of the crater wall. (c) Thrust fault produced after crater wall uplift and outward dipping rotation; in this case there should be a rupture of the Moenkopi beneath the ejecta blanket. (d-e) High-angle thrust fault or reverse fault that essentially moves material up the crater wall, possibly forming an anticline with a radially-directed plunge line at the top of the crater wall. This type of fault would be produced during crater flow uplift, although it is unclear whether it would occur early, late, or throughout the uplift process. We (Thomas Kenkmann, Michael Poelchau, and I) have observed a fault within one ejected block of debris near the museum complex. Assuming the block was excavated during crater formation (rather than museum construction), the block indicates that thrusting occurs during the compression and excavation phases, not during a modification phase of crater formation.

Good structural descriptions of the most faults and their orientations relative to bedding do not yet exist. The best described fault occurs in the north-northeast wall of the crater, within the Kaibab-Alpha (Shoemaker and Kieffer, 1974). In this case, the fault dips about 45° , while the beds in the upper plate dip 30° . The sequence is thickened and forms a wedge that produces an anticline in the uppermost Kaibab, Moenkopi, and impact ejecta. This forms one of the highest uplifted points along the crater rim. (See Chapter 14 for a trail guide to this portion of the crater.) These observations are consistent with Fig. 5.1b. Two other options (a and c) do not satisfy observations, because they thin the sequence and also have faults with shallower dips than bedding. For this particular location, options (d-e) are also not appropriate, because the fault dips away from crater center, not towards crater center. However, Roddy (1977) indicates that (d-e) occur elsewhere in the crater. It is also possible that complex (multi-)fault systems were activated. For example, a wedge shaped block might be thrust into the expanding wall of the crater, bounded by a thrust fault on top and a normal fault on the base, that then maintains crater wall uplift after excavation flow has ceased.

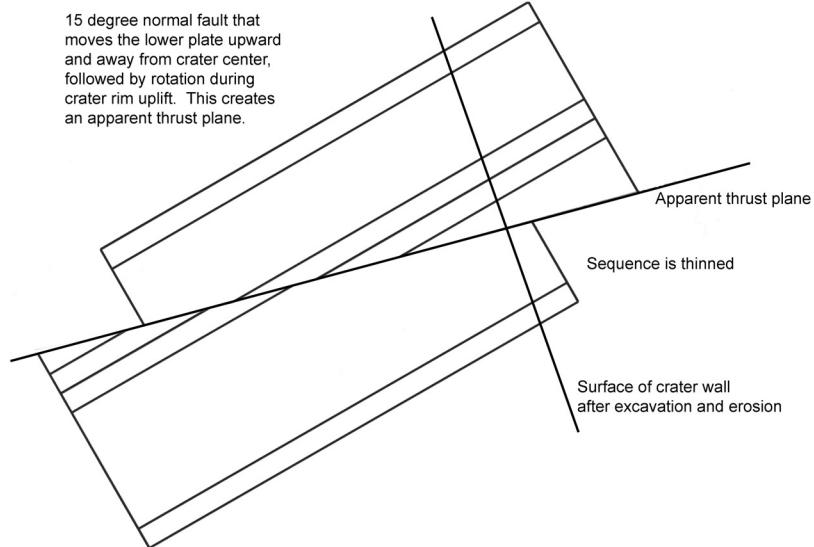
Thrust faulting is evident along the crater walls, with offsets of fractions of a meter to several meters. They cross-cut strata in both the Kaibab-Alpha and Kaibab-Beta. It is unknown if additional fault-bounded repetition of strata occurs in the lower crater walls of the covered Coconino. The faults, however, are poorly described and a much better structural description is needed. Qualitatively, a significant fraction of crater rim uplift is attributable to thrust faults. More work is needed to quantify this contribution.

One of the attributes of a fault-thickened section is an anticline in the overlying crater wall bedrock and overlying ejecta. These are particularly evident at Barringer Point and Moon Mountain, two of the

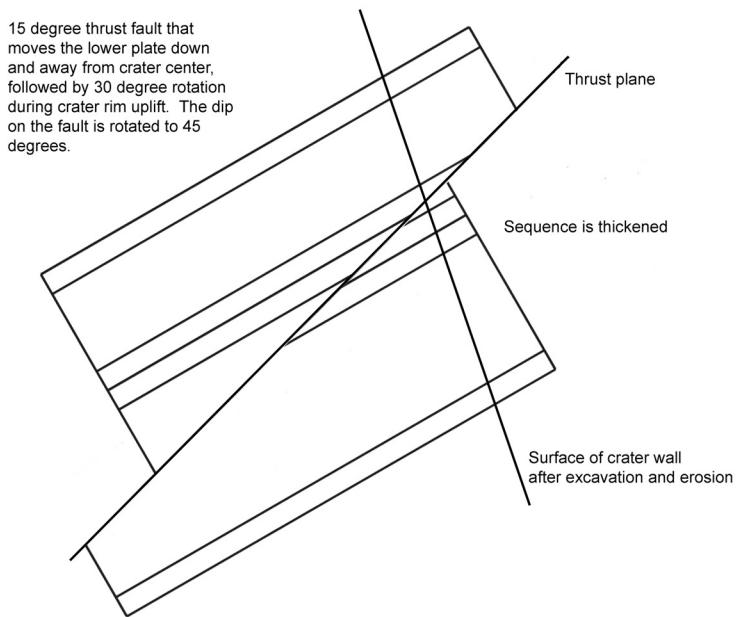
highest topographic points around the rim of the crater. Both are illustrated in the trail guides to the crater (Chapters 14 and 15). The thrust wedges created a circumferentially-distributed series of alternating anticlines and synclines. These structures were also cross-cut by tear faults in some portions of the crater walls. Drag folds along those tear faults accentuated the anticline-syncline structure (*e.g.*, in the northwest corner of the crater).

All of these structures were produced during the excavation phase of crater formation, which moved material upward along the crater wall. In contrast, the subsequent modification stage provided an opportunity for material to begin moving down along the crater wall. This is the source of the breccia lens on the crater floor. Large slabs of bedrock also slumped down the crater walls. Drilling revealed that at least one large slab of Coconino was incorporated into the breccia lens. Other fragments of slumped rock were left hanging on the crater walls, bounded by authigenic breccias that were created by shear while they moved. Neither the blocks or the authigenic breccias exposed in the crater walls are well-documented. (To be clear, some authigenic breccias were produced during the thrusting described above. Thus, there are two generations of authigenic breccias.)

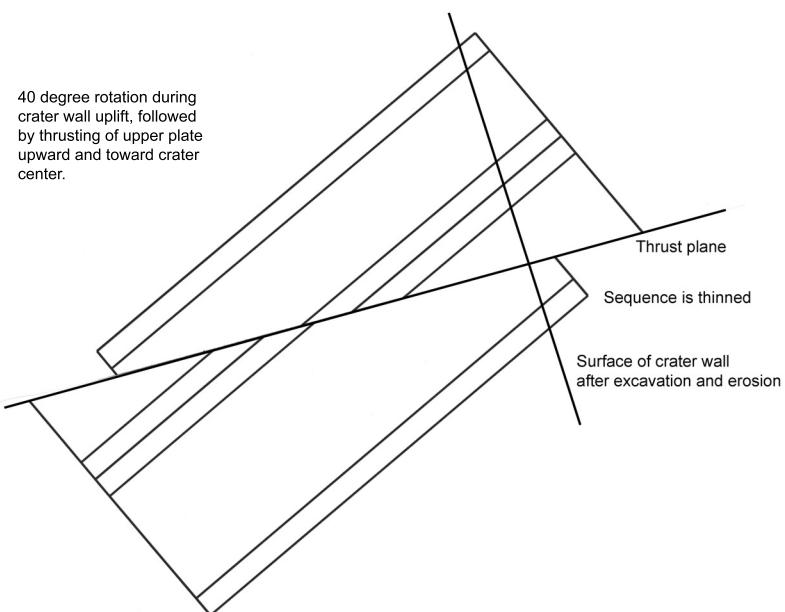
Other types of shear within and between strata generated during crater excavation and modification are preserved in blocks that bound the crater wall. “Chatter” marks are found within blocks of Kaibab (Fig. 5.2). These chatter marks may be small drag folds that were created along a shear plane; they have been observed at other craters in sedimentary targets (Thomas Kenkmann, personal communication, 2007). Slippage lineations created when rock broke along shear planes have also been found (with Michael Poelchau and Thomas Kenkmann). The direction of shear is indicated by a sharp leading edge where the rock popped apart (Fig. 5.2). After further study, it is hoped that these newly identified structures will assist with an enhanced description of crater flow.



(a)



(b)



(c)

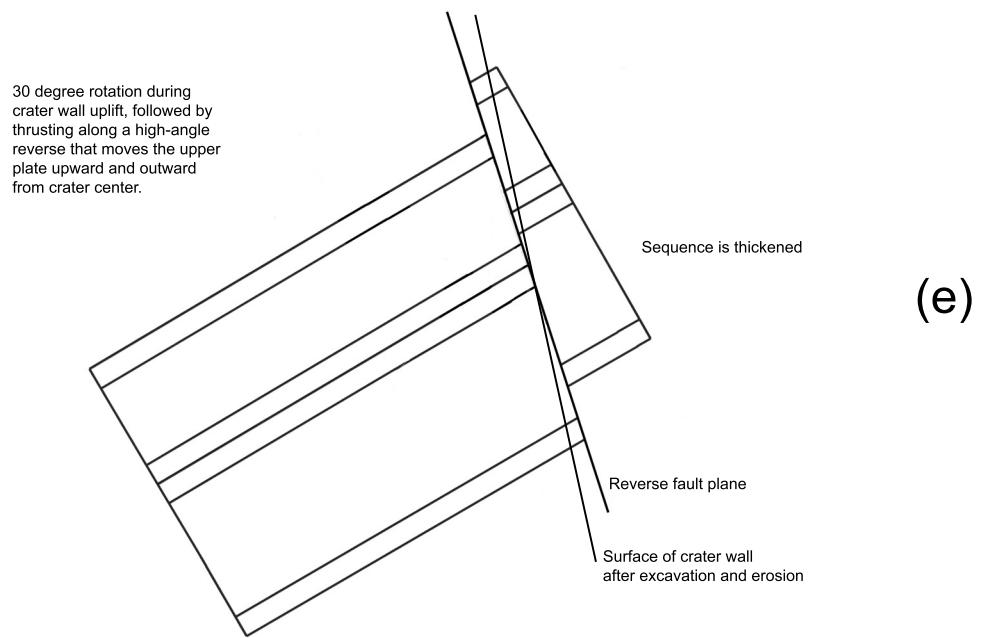
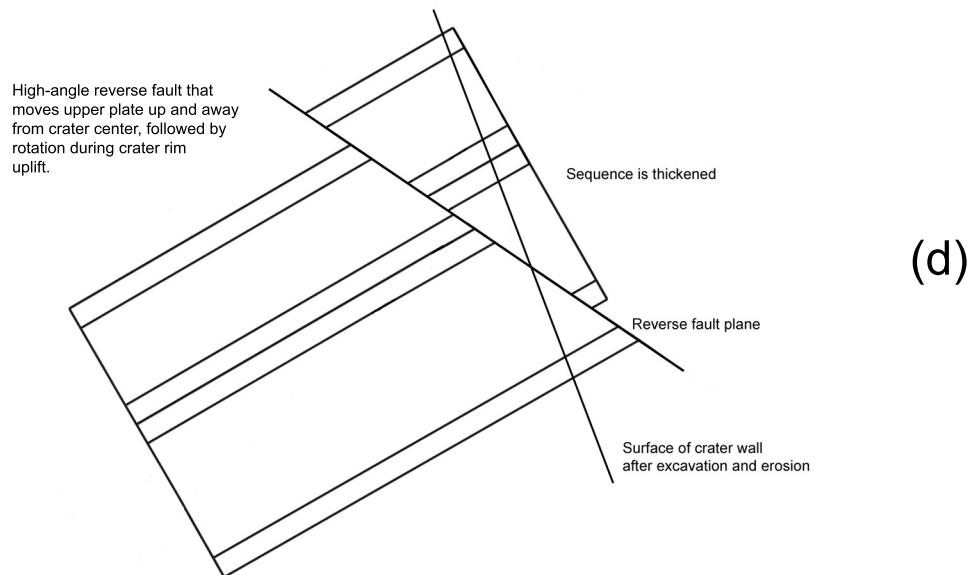


Fig. 5.1. Schematic block diagrams of possible fault movements and rotation during crater excavation and rim uplift (a-c, previous page; d-e, this page). A thrust fault (b) that moves the lower plate down and away from crater center, followed by rotation during rim uplift, is consistent with observations in the north-northeast crater wall. High-angle thrusts or reverse faults (d-e) that move the upper plate up and away from crater center have also been proposed for some of the features at the crater (Roddy, 1977).

Fig. 5.2. Elements of shear in blocks of Kaibab dolomite. "Chatter" marks are visible on some surfaces. In the upper right panel, the marks occur on top of an outcrop. They are located between and are oriented perpendicular to the arrows. In the middle panel (below), the marks are visible on a near-vertical block of dolomite along the crater wall; the chatter marks trend horizontally across the image. Slippage lineations also occur along shear planes (lower right panel), in this case indicating upward shear.

