AMOUNTS AND STYLES OF EJECTA EROSION AT METEOR CRATER, ARIZONA;

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INTRODUCTION: Two independent studies constrain average erosion from much of the ejecta surrounding the 50,000 year old (1,2) Meteor Crater, thereby supporting our preliminary contention (3) that the majority of the ejecta retains a largely pristine morphology. Most erosion occurred during a brief period following impact and under wetter conditions ~24,000–12,000 years ago. Preserved morphology indicates that fluvial run-off and eolian processes have dominated denudation with insignificant erosion by groundwater sapping processes and mass-wasting. Our conclusions are supported by the scale of preserved primary ejecta features.

AMOUNT OF EROSION: Average erosion of ejecta (comprised of predominantly Kaibab fragments) beyond ~0.25R from the rim crest is 60 +/−30 cm based on: A) the relative coarsening of ejecta surface lag deposits at various grain scales as compared to unweathered ejecta drainage systems/densities; B) the volume of locally eroded sediments within a semi-enclosed drainage basin west of the crater; and C) the persistence of small distal ejecta blocks on pre-impact surfaces and distal ejecta deposits in exposed locations on top of, and a ballistic shadow downrange of a pre-existing ridge located ~1 km from the crater rim (3). Less resistant and areally limited outcrops of ejecta dominated by Coconino debris fragments are estimated to have been eroded an average 1.5–3.0 m.

In contrast with processes responsible for formation of coarse-grained surface lag deposits in most arid environments (4,5), lag-forming processes on the widespread Kaibab ejecta at Meteor Crater are dominated by unconfined run-off, deflation, and weathering. Upward clast migration and downslope creep of saturated soils were most active during the early history of the crater, but have played only minor roles. Because lag-forming processes on the ejecta result primarily in downwasting, we can assume that the lags formed largely by differential transport of the finer matrix and *in situ* accumulation of coarse-grains. Hence, their development provides a measure of erosion after correcting for losses due to *in situ* weathering processes. Thirty samples from a variety of locations and depths demonstrate that the grainsize characteristics of the unweathered ejecta are fairly uniform (for the Kaibab and Coconino ejecta, respectively). Erosion estimates based on comparison of coarse-grained lag deposit and unweathered ejecta grainsize characteristics were made using ~50 samples in pairs/trios from around the crater. Analyses of sediments in alluvium eroded from the ejecta reveals that blocks >20 cm are infrequently carried. Blocks larger than 20 cm therefore, collect *in situ* on gully floors as finer material is removed. Because block densities per channel volume preserved on gully floors are indistinguishable from block concentrations in unweathered ejecta, only minor amounts of erosion in addition to that required for gully formation can have occurred overall (3).

Mapping of depositional environment and trenching were used to constrain the initial volume of sediments within the semi-enclosed basin. These initial volumes were then corrected for five other contributions and losses. First, deposits adjacent to the basin were included in order to account for sediments transported outside through minor divide breaches. Second, corrections were made for sediments lost by eolian deflation from the exposed ejecta and the various deposits using: the degree of coarsening relative to subsurface alluvium in lag deposits on alluvial fans; the height of phreatophyte mounds in areas of distal, diffuse drainage; and comparison of these results with amounts of erosion indicated by the present windstreak northeast of the crater. Third, volumes were modified to account for material deflated from surfaces prior to burial by the observed deposits. Fourth, a similar adjustment was made to account for buried colluvium. Finally, corrections were made to account for losses due to chemical dissolution.

STYLES OF EROSION: Fluvial run-off and eolian processes have dominated ejecta denudation with fluvial activity controlling erosion of the higher gradient upper rim (<0.5R). Overall, the two processes have operated at about equal intensities on the lower rim and distal ejecta (>0.5R). Dissection of the ejecta has occurred along ~75 small gullies incised into the outer crater flanks. Gullies are generally incised to depths of less than 1 to 2 m and merge with alluvial fans and areas of diffuse drainage near the base of the outer rim. The drainage density around the crater out to 0.6R from the rim is 8.6 km/km^2 (3) and associated drainage basins have an average relief ratio of 0.7, indicating the ejecta is well drained and adjusted to low frequency, high magnitude events. Divides between adjacent drainage basins are typically delineated by topographic variations in the primary ejecta. Many of the alluvial fans around the crater are presently inactive as demonstrated by: A) headward fan incisement by Holocene activity resulting in only minor, more distal deposition; B) little variability between proximal and distal fan/diffuse drainage grainsize distributions; C) coarse-grained lag accumulations on fan surfaces and an absence of small scale (5–10 cm) flow features; and D) late Pleistocene soils on most fans (6–8). Together with soil studies, present fan morphology indicates that formation occurred mainly during the wetter pluvial between 24,000–12,000 years ago. The change from active fan formation to present headward incisement indicates a change from frequent, relatively sediment rich run-off in the past to less frequent, higher intensity, clear water run-off (4). Similarly, fans formed in the southwest during the pluvial exhibit little variation in down-fan grainsize owing to reduced run-off and stream power caused by the more extensive vegetation and thicker soils that existed (5). Because precipitation 50,000–25,000 years ago was probably similar to today (Forester 1983, written comm.), significant fan formation then is unlikely.

Eolian activity over the past 10,000–12,000 years has produced the currently observed patchy windstreak northeast of the crater. Several lines of evidence indicate that the windstreak is now largely inactive: there is little active transport during high wind events; a paucity of active bedforms on the surface; and abundant vegetation. From the preserved record, windstreak formation is apparently not continuous through time, but undergoes periods of formation and preservation followed by epochs of enhanced erosion. Formation continues until the supply of fine-grained sediments, supplemented by the prior increased intensity of gradational processes (i.e. fluvial), is depleted.

Ejecta aquifer properties are equivalent to a fairly homogeneous, pure sand or sandstone aquifer (9), indicating that surface infiltration rates are high. Together with the absence of characteristic sapping morphology, these properties demonstrate the insignificance of erosion by groundwater processes. Only 5–10 cm chemical dissolution has occurred as indicated by: A) chert nodule relief on Kaibab blocks; B) survival of small (10–15 cm) Kaibab blocks on pre-impact surfaces; and C) and fragments spalled off large Kaibab ejecta blocks that can be easily traced to their original position. Little evidence was found around the crater exterior for modification by mass-wasting processes.

Erosion under present climate conditions has been minimal as demonstrated by the largely inactive fans and windstreak. Because precipitation between 50,000–25,000 is thought to have been generally similar to present amounts, denudation rates were probably similarly low. Maximum erosion occurred during the pluvial when rates were 2–3X present values and during a brief period following crater formation prior to surface stabilization.

CONCLUSIONS: Ejecta surrounding Meteor Crater has remained remarkably unmodified. The widespread coarse-grained surface lags on the Kaibab ejecta resulting from small amounts of erosion forms an armor that protects underlying ejecta and whose resistance may approach that of *in situ* Kaibab formation. Erosion was greatest during the pluvial and has been dominated by fluvial run-off and eolian processes. This study provides a framework for comparing the gradational history of other terrestrial and martian impact craters in order to understand their erosional/climate histories.

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