Gradational Evolution of Young, Simple Impact Craters on the Earth; J.A. Grant and P.H. Schultz, Brown University, Providence, RI 02912.

Introduction: Impact craters on the Earth occur in a variety of geologic and climatologic settings. As random, non-volcanic, instantaneously created landforms, consideration of their preserved gradational morphologies provides an unique opportunity to assess the number and intensity of erosional processes acting since the time of their formation. The present study examines the age and preserved morphology associated with three simple impact craters in varying stages of preservation in order to develop a gradational evolutionary sequence. All three are unglaciated and formed into nearly flat-lying target rocks: A) the 1.2 km diameter, 50,000 year-old Meteor Crater in Arizona (35.3°N, 111.2°W); B) the 1.8 km diameter, 62,000 year-old Lonar Crater in India 20.0°N, 76.5°E); and C) the 1.75 km diameter, 0.5-3.0 million year-old Talemzane Crater in Algeria (33.3°N, 4.0°E). It is concluded that backwasting and downwasting of the raised-rim by fluvial and mass-wasting processes dominates erosion of these craters.

Discussion: The present morphology around all three craters demonstrates that fluvial processes dominate erosion over-all; however, it is recognized that other processes predominate in some geologic settings (e.g. eolian at Wabar Craters, Saudi Arabia). Lithology is considered to impart mainly second order controls on gradational morphology at these impact sites despite differences in target rock types. General similarity between erosional styles developed on limestone/dolostone and sandstone ejecta types at Meteor Crater (1,2) supports this contention. Conclusions are based on the results of field work (Meteor Crater), analyis of air photos (all three), and Landsat TM images (Meteor Crater). The following first-order gradational evolutionary sequence is proposed (Fig. 1).

Subsequent to impact, the steep interior walls and rim-crest undergo rapid erosion by mass-wasting, fluvial, and lesser eolian activity. These processes combine to create a smoothed, undulating, but largely unincised rim-crest supported by an interior wall backwasted to expose more coherent bedrock along upper sections. Lower portions of the interior wall are buried by talus (debris chutes and aprons) and alluvium (Meteor Crater). As the upper walls become stabilized, fluvial activity incises the now largely inactive debris chutes and erodes bounding talus deposits (Meteor Crater). During this stage, the slope of the interior wall is reduced, but remains fairly high (Fig. 1). Fluvial and eolian processes dominate early modification of the crater exterior at rates in near-rim areas (<0.25R) that are 10-20X higher than those on more distal ejecta. Fluvial activity outside the crater creates small incised gullies on the upper and mid flank that transport material to lower flank alluvial fans and more distal diffuse-drainage (Meteor Crater). Drainage densities on interior and exterior walls are high at this early stage (Fig. 1); however, the small scale of exterior drainage precludes accurate mapping both in air photos and Landsat images, whereas apparently high densities on interior walls primarily reflect drainage control by relict debris chutes.

At intermediate stages (Fig. 1), crater walls continue to backwaste and rim-crest elevations decrease, thereby leading to increased amounts of crater fill (3, Lonar). Reduced average slopes on the interior wall indicate mass-wasting processes are still active, but are becoming less important relative to fluvial processes. A paucity of exposed talus and ejecta along interior walls (Lonar) supports this statement. Erosion of rim-crest ejecta down to uplifted bedrock leads to fairly uniform elevation and lower erosion rates. Drainage densities (determined from air photos) decrease in the crater interior as largely relict debris chutes and talus are destroyed; however, remaining systems are larger and extend up to the rim, thereby resulting in a "notched" appearance (Fig. 1). Erosion of the ejecta surrounding the crater continues by fluvial and lesser eolian activity causing enlargement of radial gullies and (presumably) continued deposition in larger alluvial fans. The scale of most drainages implies detectability at TM resolution (30 m/pixel).

At more advanced stages (Fig. 1), the crater rim becomes wholly breached by some interior drainages resulting in capture of some exterior near-rim systems. The resultant increase in drainage area causes additional flow into, and deposition on the crater floor leading to burial of relict mass-

wasting deposits (4). The rim-crest continues to be lowered and narrowed through downwasting, backwasting of the interior wall, and lesser erosion of the lower gradient exterior flank. A decrease in raised-rim width from early (Meteor Crater) to late (Talemzane) of ~0.1-0.15R accounts for ~10% crater enlargement. The continued paucity of exposed talus on the lower interior wall coupled with decreasing average wall slope (5) highlight the lessening importance over-all of mass-wasting activity. Interior/near-rim drainage density during late stage erosion (from air photo) is high as new systems evolve/are captured on the exterior mid and upper flank (Fig. 1). Exterior drainage capture by interior systems results in reduced exterior stream power and density on the crater flanks. The large scale of interior drainages implies easy detection in Landsat TM imagery; however, the reduced scale of exterior systems suggests they may go undetected. As fluvial processes decrease on the crater exterior due to loss of high gradient tributaries, the relative importance of eolian processes may increase.

Summary: From these three craters a first-order gradational evolutionary sequence can be proposed. As crater rims are reduced by backwasting and downwasting through fluvial and mass-wasting processes, craters are enlarged by ~10%. Enlargement of drainages inside the crater eventually forms rim breaches, thereby capturing headward portions of exterior drainages. At the same time, the relative importance of gradational processes may reverse on the ejecta: eolian activity may supersede fluvial incisement and fan formation at late stages of modification. Despite actual high drainage densities on the crater exterior during early stages of gradation, the subtle scale of these systems results in low density estimates from air photos and satellite images. Because signatures developed on surfaces around all three craters appear to be mostly gradient dependent they may not be unique to simple crater morphologies. Similar signatures may develop on portions of complex craters as well; however, important differences may also occur. As progressively larger craters are formed, the probability of interrupting pre-crater drainages increases. Hence, crater modification by regional fluvial activity may become more important. Deposition by pre-crater drainages on the distal ejecta at Meteor Crater supports this statement.

References: (1) Grant, J.A. and Schultz, P.H., 1990: p. 433-434, in Lunar and Planet. Sci. XXI (abstracts), Lunar and Planetary Institute, Houston, Texas. (2) Grant, J. A., 1990: Ph.D. Dissertation: Geology, Brown University, Providence, Rhode Island, 401p. (3) Fredriksson, K., Dube, A., Milton, D.J. and Balasundaram, M.S., 1973: *Science*, v. **180**, p. 862-864. (4) Lambert, P., McHone, J.F., Jr., Dietz, R.S. and Houfani, M., 1980: *Meteoritics*, v. **15**, p. 157-179. (5) Karpoff, R., 1963: *Meteoritics*, v. **1**, p. 31-38.

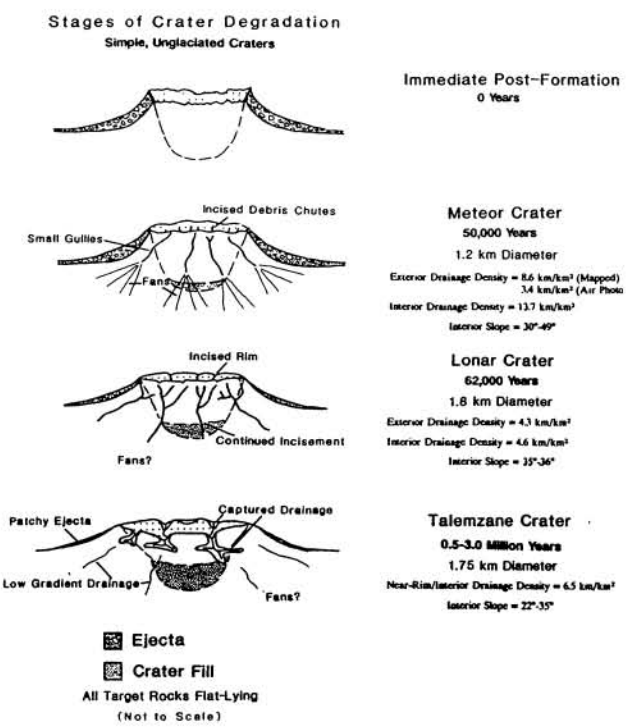

Figure 1. Hypothesized stages of crater degradation. Profiles are exaggerated for illustration. With increasing erosion: A) the rim-crest outline changes from rough and irregular to more undulating (Meteor Crater) to notched (Lonar) to incised (Talemzane); B) rim-crest elevations are reduced as the crater is rapidly widened (Meteor Crater) until underlying bedrock is exposed (Lonar) whereupon slower rates prevail as the rim-crest diameter and elevation continue to slowly increase and decrease, respectively (Talemzane). A well-defined raised-rim is present at all stages; however, breaches form in the rim during advanced fluvial dissection of the interior, resulting in drainage capture of outer flank systems and increased flow into the crater (Talemzane). Initially steep wall slopes (Meteor Crater) decrease (Lonar and Talemzane) as the importance of mass-wasting decreases relative to fluvial activity. The evolution of drainage reflects this change in styles as initially high drainage densities first decrease as debris chutes and aprons on the interior wall are destroyed (Meteor Crater to Loner) then increase again as the systems begin to breach the raised-rim (Lonar to Talemzane). All drainage densities are derived from air-photos except as noted.