target materials. In addition, in the presence of such preimpact weakness zones, the target would behave somewhat differently in response to the impact. For example, motions would preferentially occur along these weakness zones when shock waves pass through the target medium; this condition may inhibit the formation of new fractures, rather they would preferentially reactivate the existing ones. For example, *Gault et al.* [1968] show that crater flow during excavation can be greatly influenced by preexisting weakness zones. Nuclear explosion craters also provide ample evidence in support of the reactivation process. For example, the explosion craters formed in the alluvial flat of Yucca region of Nevada clearly suggest that the development of explosion-related fracture systems around the craters have been greatly influenced by the preexisting weakness zones in the bed rocks (Figure 14d).

[21] Impact fractures form as a result of the passage of shock waves in the target medium [see *Sagy et al.*, 2004, and references therein]. For example, cratering experiments on water ice has indicated the relationship between the passage of shock waves and the initiation of tensile radial fractures, which apparently form immediately after the passage of seismic precursor waves [*Arakawa et al.*, 2000]. Also in rocks, the radial fractures are formed immediately behind the outgoing stress wave, whereas the concentric fractures are initiated at later times and appear to be related to the tensile phase of the stress pulse associated with sudden release of the impulsive force applied at the surface [see *Ahrens and Rubin*, 1993, and references therein]. The radial cracks are formed perpendicular to the direction of peak tension, and thus normal to the quasi spherical compressive wavefront. These mechanical processes can probably be extended to natural craters. The impact structures documented from Meteor Crater can thus be related to the response of target rocks to the shock wave propagation at the time of crater excavation and crater wall slumping related to the crater modification after excavation. However, the presence of preexisting weakness zones and their geometry significantly affect the interaction between the target bedrock and the expanding shock wave, and, thus, the formation of the transient crater and any subsequent crater wall collapse. For example the excavation flow and the crater collapse should occur preferentially along any preexisting weakness zones.

8. Conclusions

[22] Over 2500 structural measurements reveal that the upper crater walls of Meteor Crater are crosscut by three distinct groups of fractures: radial, concentric, and conical fractures. These are similar to the types of fractures that occur at Lonar Crater [*Kumar*, 2005]. We also confirm that the target was crosscut by three prominent sets of preimpact tectonic fracture systems. The majority of the preimpact fractures are parallel to the crater long walls, suggesting that either the excavating flow preferentially hinged and overturned material along the fractures or that crater wall slumping preferentially occurred along those fractures (or both).

[23] When the crater rim is restored to preimpact condition, the geometry of the radial and concentric fractures resembles preimpact fracture populations, indicating that crater wall deformation and rim uplift was partly accommodated by activation of preexisting fractures. In contrast, the conical fractures have orientations that are dissimilar to the preimpact fractures and apparently formed as a direct result of impact deformation. Some of the fractures were transformed into tear faults during the impact event. Furthermore, we confirm that a combination of fractured-controlled motion along the crater walls and along the tear faults created the unusual square shape of Meteor Crater in plan view. This feature was subsequently enhanced by preferential erosion along those fractures/faults and the authigenic breccia in them. A symmetric distribution of conical fractures appears to have been produced prior to crater rim uplift and complex motion along tear faults. Thus, most conical fractures were produced prior to motion that was activated along radial and concentric fractures during crater rim uplift and subsequent slumping of inner crater walls.

[24] The preimpact fracture system in the Meteor Crater region weakened the target lithologies affected by the impact event. Not only did this entrench and facilitate motion along radial and concentric fractures, it led to greater rim uplift (at least 30 to 60 m) than that seen at Lonar Crater (only 20 m) in a stronger set of basaltic lava flows. These data imply that structural deformation, crater rim uplift, and the morphology of simple craters are influenced by the preimpact structural state of target lithologies. Similar affects may occur on the Moon where some impacts occur in relatively strong crystalline lithologies and others occur in weakened cataclastites or thick regolith. Likewise, similar affects may occur on Mars, where some impacts may occur in relatively strong crystalline lithologies while others occur in relatively weak sedimentary and pyroclastic deposits.

Figure 14. (a and b) Secondary electron micrographs of impact craters formed on the solar panels of spacecrafts by micrometeoroid impacts [*Graham et al.*, 2004] (with permission from the Geological Society of London); box b1 in Figure 14b shows the traces of radial (labeled R) and concentric (labeled C) fractures and the relationship between them. (c) A cross section of an experimentally produced crater on San Marcos gabbro by *Polanskey and Ahrens* [1990] (with permission from Elsevier); note the occurrence of three types of fractures: radial (RF), concentric (CF), and near-surface fractures (NSF), which all occur below a theoretical near-surface zone (TNSZ). (d) Fractures around a nuclear test site in the Yucca flat region of Nevada [*Barosh*, 1968] (with permission from the Geological Society of America). This is a classic example for a fracture pattern formed in response to the reactivation of preimpact fractures by a nuclear explosion. The NW-SE (labeled 1) and NE-SW fractures (labeled 3) are subparallel to the preexisting faults/fractures in the basement rocks exposed around Yucca flat. However, a few of them are similar to the radial fractures seen in the meteorite impact craters. The concentric fractures (labeled 2) may be related to the crater collapse.