FROM SIMPLE TO COMPLEX CRATERS: THE MECHANICS OF LATE-TIME CRATER ADJUSTMENTS.

K. A. Holsapple, University of Washington, 352400, Seattle, WA, 98195, holsapple@aa.washington.edu.

Introduction: The primary remaining puzzle about impact cratering is how and why all large craters have a broad and shallow complex morphology, and all small ones have simple bowl shapes. Code and theoretical modelers believe that all craters go through a simple transient crater shape during their formation, but then readjust (collapse) during the latter stages of formation into the very broad and shallow complex shapes observed. It is commonly now accepted that the transformation is gravitationally driven. However, geologists study the very structured lithology of a terrestrial crater with, say, 100 km diameter, and have a tough time believing that it was ever in a transient excavation stage with a depth of many 10's of kilometers, only to reconstruct itself with nearly its original structure.

Modeling of Collapse: Code models of cratering formation cannot generally produce these late-stage collapse mechanisms without adding features not commonly a part of the behavior of geological materials. It is commonly believed that the collapse mechanism requires a mechanism for temporary strength degradation in the rocks surrounding the impact site. The most common explanation for this degradation is the acoustic fluidization mechanism proposed by Melosh [1] in 1979 and used by many of his collaborators and students since that time (See [2] for a review). In that model, pressure fluctuations in the cratered regions are presumed to be sufficient to temporarily remove the overburden pressure and shear strength, so that the material behaves as a fluid with a certain viscosity, according to the Bingham model. The model itself does not directly predict the rheology of the material, but it is presumed to give validity to the Bingham model. More recent work is being done to better quantify that connection [2].

That model is turned on in the latter stages of the cratering process, and can lead to the late-stage collapse mechanisms. The results can be tuned to give final craters much as they are observed, so to that extent the model is successful. However, direct physical evidence and confirmation of the acoustic fluidization mechanism has been scarce. To my knowledge, the only tie to physical measurements was a study of the near-crater ground motions for some 10-ton explosive cratering events [3], in which fluctuations in the measured signals were judged sufficient to relieve the local overburden and cause acoustic fluidization. However, those familiar with such experimental field measurements are aware of the ubiquitous noise always present in the measurements, so doubt about the conclusion remains. No acoustic fluidization was actually observed during the experiments. While in principle centrifuge tests using a shaker table (which are used for slope stability measurements) might address this problem; no one has undertaken such an experimental study. Consequently, I remain very skeptical about acoustic fluidization as a slump mechanism.

An alternate possibility is a reduction in strength caused by the processing of the material by the outgoing shock. O'Keefe and Ahrens [4, 5] studied shock heating as a mechanism, and, more recently O'Keefe et al. [6] study non-thermal geological damage models which have been successfully developed and calibrated in the weapons community to calculate impacts into brittle materials including ceramics. While they have some success in producing late-stage collapse, they could only do so by reducing the rock angle of friction to less than 22°, a very small value. In principle, these models could also be investigated by measuring the properties of previously shocked rocks.

The Actual Mechanism: In my talk I will propose a new and radical idea: that no such ad-hoc mechanisms are necessary for late-stage collapse mechanisms. Instead, I will point out significant shortcomings in our previous modeling. I will argue that there is no need for substantial loss of strength, but that the commonly measured properties of soils and rocks are sufficient, if the impact processes are modeled correctly. And, the computer gods being willing, I will present computer calculations to quantify my claims.

References:

[1] Melosh, H. J. J. (1979) *J. Geophys. Res*. 84, 7513-7520.
[2] Melosh H. J. and Ivanov B. A. (1999) *Ann. Rev. Earth Planet. Sci* 27:386-415.
[3] Gaffney E. S. and Melosh H. J. (1982), *J. Geophys Res*. 87:1871:79.
[4] O'Keefe J. D. and Ahrens T. J. (1993) *J. Geophys Res.* 98:17011:28.
[5] O'Keefe J. D. and Ahrens T. J. (1999) *J. Geophys Res.* 10 27091:27104.
[6] O'Keefe J. D. et al. (2001) *Intl. J. Impact Engr.* 26 543:553.