

SUMMARY OF SESSION ON CREATION OF THE STRUCTURE OF COMPLEX CRATERS, SUNDAY, FEBRUARY 9, 8:30 A.M.

Summary by William B. McKinnon

Complex craters, with their central peaks, flattened floors, and terraced outer rims, are the arguably the most fascinating of all crater types. The largest of these, the peak and multiringed basins, are the most magnificent. Planetary images of relatively pristine complex craters on the moon, Mars, Venus, and the satellites of the outer planets never fail to entrance. But the only complex craters we can study in situ and in three dimensions are here on Earth. These are also the crater forms that are the most challenging to understand, for the mass motions that materials have undergone are complex (if not convoluted) and the material properties that seem to be implied are in many regards counterintuitive. A workshop session was devoted solely to complex craters. Nearly all the talks focused on terrestrial structures, and on both their geological exploration and modeling. Two talk cancellations by foreign guests allowed ample time for discussion, plus an additional talk at the end.

The lead invited talk by V. L. Sharpton and B. O. Dressler was given by Virgil Sharpton. In abstract, the talk was centered on field work at the Haughton crater on Devon Island in the Canadian arctic, and whether its structure could be adequately explained by traditional excavation flow models such as the Maxwell Z. As given, the talk took a broader look (or swipe) at field exploration of impact sites and how field geologists have been (unduly?) influenced by modelers. As armchair scientific philosophy, it was entertaining, informative, and presented with a great deal of humor. As a critique of the scientific method, however, it falls into the long and basically unresolvable debate as to whether it is better to simply gather up all the facts and figure out the conclusion later or gather facts or experimental evidence in order to test a preexisting model or paradigm. My personal view can be summed up as "whatever works." As we all stumble towards a more complete truth, either approach may be the most useful or fruitful.

It should hardly be taken as a scientific failing that most modelers have taken to interpretation of planetary complex craters, and that existing modeling results should influence field interpretations of terrestrial craters. After all, terrestrial craters are often deeply eroded (or if not, they survive by being buried and thus explorable only by drill core, gravity, or

seismics), so the field geologist is left with an a conundrum: to interpret afresh, or try to see the structure as a deep section of complex structure whose preexisting surface expression they can visualize. It is all a bit like the blind men and the elephant, but here we have terrestrial field studies and planetary morphological interpretations playing clearly complementary roles. Neither will come to resolution of complex impact structure without the other. If there is any failing in modeling, it is that the emphasis has been on explaining resulting external morphologies, and not what changes take place subsurface and at scales accessible to the field geologist. The clear purpose and result) of this workshop was to build a bridge between these approaches.

The second invited talk by G. S. Collins and E. P. Turtle was given by Gareth Collins. He described state-of-the-art numerical calculations of complex crater collapse and central peak and peak ring formation. This talk was related in spirit and content to earlier modeling talks but emphasized a key point. In order to collapse, the region around the crater must be weakened by some mechanism: (1) fracturing and bulking; (2) acoustic fluidization or block oscillation; (3) melt production; (4) thermal softening; (5) shear melting; and (6) combinations of some or all of the above. All these mechanisms can be incorporated in models at gross physical scales and parameters adjusted to allow collapse and peak formation. But adjusting parameters to get the right morphology may not give the right answer if the physics is not right. How can we tell? Field studies! These hold the key what actually happened to the rock during the cratering event. But modelers, who spend much of their time thinking about rock mechanics, need also to think about the field scale. John Spray's frequent cries that the cratered rocks he has examined don't look like they were acoustically fluidized begs the question of what should acoustic fluidization look like (see Friday morning discussion above).

A contributed talk by G. R. Osinski and J. G. Spray was given by "Oz" Osinski before the break. It also concerned detailed field observations at Haughton crater and the kinematics of the failure of the rim and development of the central peak, as revealed by families radial and concentric faults and the nature of the fault contacts (part of GRO's Ph.D thesis). Their

studies do not indicate much of a role (if any) for melting in weakening during crater modification, but do indicate much evidence for localized, brittle deformation (fault planes). Many of the radial faults display substantial volumes of fault breccia but relatively little offset. The interesting question to this writer is whether the displacements were in fact much larger (say, at the time of the maximum transient crater) but were effectively restored during crater collapse (as seen in model calculations and lab experiments). This rich data set, based on four field seasons, should prove enormously valuable as for modelers. I predict that high fidelity simulations of the formation of Haughton crater, with its sedimentary over metamorphic gneiss target and final mapped fault and displacement pattern, will lead to a breakthrough in understanding complex crater formation.

The session continued with contributed papers. W. B. McKinnon, P. M. Schenk and J. M. Moore discussed empirical laws relating final to transient crater size for complex craters (largely lunar). Bill McKinnon pointed out that the laws published by Croft (best known), McKinnon and Schenk, and Holsapple, are sufficiently different that they cannot be all be correct. The time has come for reexamination of this issue, if only because complex crater scaling is important in using crater counts to date retention ages of terrains throughout the solar system.

Gareth Collins returned to the stage to present preliminary modeling results (with E. P. Turtle and H. J. Melosh) of simulation of the formation of the graben rings surrounding the Silverpit pit structure in the North Sea. They used an initial transient structure derived from the Z-model and incorporated weakening by acoustic fluidization near the crater and assumed a weak lower chalk layer to allow sliding toward the crater center. Model results presented indi-

cate a concentric zone of extensional stresses that can be interpreted as potentially graben-forming, but field geologists should understand that the numerical models used are incapable of predicting the form or spacing of such "localized" phenomena as graben. Much remains to be learned from both exploring and modeling Silverpit.

The official session ended with J. B. Plescia describing the utility of gravity studies for understanding subsurface deformation, shock effects (brecciation), and even the basic morphometry of terrestrial impact structures, especially if the surface expression is less than informative (think Chicxulub!). Several examples were discussed in detail.

The discussion period began with an impromptu talk by H. J. Melosh, describing some results sent to him by Boris Ivanov, who could not be present due to pointless visa delays. The results were modeling calculations of the growth and collapse of a complex crater, one in which the strain history was tracked cell by computational cell. The point of the calculations was to show, in case anyone needed reminding by this time, that strain \neq displacement, that some computational cells at least can go through large displacements, can be highly strained, and yet the strain can be reversed so that the total resultant strain at the end of the modification stage can be modest. This may help geologists reconcile their field observations with impressions they take away from modeling efforts. The areas of the final crater that appear to achieve the highest final strains are within the central peak region and near the surface of the rest of final crater. The implication was that in an eroded section, the zone of maximum deformation (strain) should appear confined to the crater center. Much discussion of complex crater formation along these lines ensued.