
Impact cratering studies have traditionally drawn upon field observations, experimental testing, and theoretical calculations to help examine the complex physical processes involved in the formation of craters and their ejecta deposits. More recently, numerical code calculations have received increased use by a number of workers to provide improved understanding of large-scale cratering mechanics in terms of dynamic physical processes, cratering formation sequences and quantitative material responses (1,2,3,4,5). A much larger body of research data on explosion cratering mechanics has also provided additional information useful in analyzing large-scale impact cratering events. For example, comparisons of calculations for bowl-shaped impact craters with more detailed calculations of bowl-shaped explosion craters have emphasized a number of aspects known to be critical in large-scale impact events, such as interpretations of particle velocity flow fields and scaled times of formation, choices of initial energy scaling, internal versus kinetic energy partitioning, material property responses and effects of layering as a function of depth, calculational grid sizes, and other conditions (6).

In order to further explore these problems, comparisons between Meteor Crater, AZ and a comparable, well-studied, bowl-shaped explosion crater, Middle Gust III are currently in progress. Meteor Crater, which originally averaged ~1022 m across and 150 m deep measured at pre-impact ground surface, was formed by an iron meteorite impacting into flat-lying sandstone and dolomitic limestone about 25,000 years ago in north-central Arizona (Fig. 1a) (7). Middle Gust III, about 32 m across and 6.5 m measured at original ground level, was formed by detonation of a 100-ton TNT sphere lying surface tangent on soil over flat-lying, water-saturated Pierre shale in southern Colorado (Fig. 1b) (8). Comparisons of the observational, experimental, and numerical code results indicate that both craters followed a similar dynamic sequence to form bowl-shaped craters (Fig. 2a, 2b). The following table shows a summary of their initial cratering conditions.

<table>
<thead>
<tr>
<th>Event</th>
<th>Source</th>
<th>Total Energy</th>
<th>Initial Pressures</th>
<th>Geology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meteor Crater</td>
<td>Iron meteorite(s)</td>
<td>5-20 Megatons, 5 x 10^18 ergs</td>
<td>1 to 1000 GPa</td>
<td>sandstone, limestone, dolomite, nearly flat-lying</td>
</tr>
<tr>
<td>Middle Gust III</td>
<td>TNT sphere tangent above ground</td>
<td>100 tons TNT, 4.2 x 10^15 ergs</td>
<td>&lt;200 to 400 kgs, 20 to 40 GPa</td>
<td>soil, weathered shale and shale, water-saturated, flat-lying</td>
</tr>
</tbody>
</table>

A review of the extensive parametric calculations completed previously for Middle Gust III, for example, show that the particle velocity vector flow fields for both Meteor Crater and Middle Gust III became very similar at real computational times by ~180 milliseconds for Meteor Crater and ~25 milliseconds for Middle Gust III, despite their different origins (Fig. 3). After these times, the particle velocity fields for both cratering events show comparable flows of target material to cratering termination. This permits the large number of different parametric code runs calculated for Middle Gust III to be used to infer, at least preliminarily, similar target material trends for a Meteor Crater-type event. Selection of certain of the more critical trends indicated by the explosion data, such as large rim uplift as a function of energy ducting in upper layers, has helped define which cratering aspects of Meteor Crater would benefit from additional numerical treatment, thereby greatly reducing calculation search costs.
Comparisons of Meteor Crater and Middle Gust III

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The Middle Gust calculation raises another point regarding generalized scaling of explosion energies to predict meteorite impact energies. The Middle Gust results confirm that only a few percent of the total energy of the exploding TNT is coupled to the target media. Our Meteor Crater calculations, however, indicate ~30 to 40% of the meteorite kinetic energy (at 25 km/sec impact velocity) is converted to kinetic energy in the target rocks (4). Consequently, it appears that simple linear scaling \((E \propto D^n)\) of explosion energies, impact energies and diameters require consideration of conversion factors to properly express the kinetic energy coupling efficiencies. Simply stated, it appears that if total energies of explosions are used for predictive scaling of impact energies, then a coupling efficiency should be included to more accurately predict impact energies. A number of other cratering aspects, as mentioned previously, have been identified in the comparisons between the Meteor Crater and Middle Gust data and are currently under study.

References


Figure 1a.
Oblique aerial view of Meteor Crater, Arizona looking northwest. Present rim crest diameter averages \(438.6\) m and rim crest depth to present floor is \(467\) m. U.S. Geological Survey photograph by D. J. Roddy and K. Zeller.

Figure 1b.
Oblique aerial view of Middle Gust III explosion crater. Rim crest diameter averages \(43\) m and rim crest depth \(4.5\) m. Surrounding ejecta blanket consists of fine soil debris overlain by fragments of shale. White crosses are aerial markers. U.S. Geological Survey photograph by D. J. Roddy and K. Zeller.
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Figure 2. Crater profiles of Meteor Crater, Arizona (left side) and Middle Gust III (right side) drawn by scaling the average apparent diameters measured at original ground surface. From (7,8).

Figure 3a. Particle velocity field for Meteor Crater calculation MC-1 at about 181 milliseconds with only every other velocity vector plotted (4).

Figure 3b. Particle velocity field for Middle Gust III calculation at about 25 milliseconds (written communication from S. Schuster, 1981). Note velocity reversal zone occurs at depth in both the Meteor Crater and Middle Gust calculations. Vectors inside growing cavity of Meteor Crater (3a) represent expanding meteorite and rock material due to release of very high pressure. Equivalent region in Middle Gust III does not show vectors of expanding TNT products because initial conditions used the final pressure boundary created by actual calculation of TNT detonation.