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Projectile material in Meteor crater

N. Artemieva (1,2) and E. Pierazzo (1)
(1) Planetary Science Institute, Tucson, USA (2) Institute for Dynamics of Geospheres, Moscow, Russia (artemeva@psi. edu)

Abstract

We have modeled the formation of Meteor crater to investigate the fate of the projectile material. After the impact, most of the projectile is molten, with some remaining solid. Ejected molten spherules are deposited mainly in the downrange direction close to the crater rim. Some unshocked fragments separate from the main body during the passage through the atmosphere and are dispersed on the plains by the impact plume.

1. Introduction

The discussion of the fate of the Canyon Diablo impactor has had a particularly rich history, starting from Barringer's belief that most of the solid meteorite may have been buried under the crater floor [1], to later suggestions that the meteorite had completely vaporized [2,3], to more realistic recent estimates indicating a mostly molten impactor [4]. We have modeled the formation of Meteor Crater with the 3D hydrocode SOVA [5] to investigate the post-impact projectile material distribution. As the projectile gets disrupted in the atmosphere (without significant deceleration) [6], we used various scenarios: a standard solid spherical projectile, a tight swarm of smaller projectiles, and a low-density high-velocity jet (mixture of melt and vapor).

2. Projectile compression and dispersion

Incipient and complete melting of iron occurs at shock compressions of 162 and 200 GPa, respectively, while vaporization starts around 320 GPa. At a 16 km/s impact velocity and steep impact angles (>45° from the surface) about 20% of the projectile remains solid, ~30-40% is partially vaporized, and ~20% is molten. At lower impact angles (<45°) the amount of solid fraction increases sharply from 30% (45°) to 95% (15°), and vaporized material decreases from 25% to <5%. The amount of ejected projectile material depends on the impact scenario, varying from 50% (dry silicate target, single solid projectile) to 98% (water-rich target, dispersed projectile). Distribution of projectile material around the crater for the former is shown in Fig.1.

3. Canyon Diablo Meteorites

Substantial part of the Canyon Diablo impactor may land separately from the impacting swarm [6]. A similar situation has been observed in many terrestrial small craters (strewn fields) where a trail of solid fragments shows clearly the direction of impact and allows for speculations about impact angle [7,8]. Such "trail" of small fragments has not been observed in the vicinity of Meteor crater, where most meteorites (with low if any shock compression and regmaglipts) are irregularly scattered on the plains [1]. The results of our model show that the largest (m-size) meteorites still land inside the crater, smaller (dm- and cm-size) fragments are engulfed in the expanding plume and thrown away from the crater in all directions. Distribution of these Canyon Diablo meteorites is shown in Fig. 2.

4. Comparison with observations

By far the largest projectile mass (10,000 tons) is identified in the form of small (0.5-2mm) iron spherules scattered throughout the soil within a few miles of the crater. These spherules have been found mainly NE of the crater [9]. In the model, the amount of spherules is 3-4 times higher, concentrated mainly downrange of the crater up to 2.5 km away. Some of these particles (and smaller ones) may be additionally dispersed by local winds.

There is a well-known difference between Canyon Diablo specimens found near the crater rim and on the surrounding plains [10,11]: the former have smaller size and are highly shocked (>75 GPa), the latter are larger on average and weakly shocked (<13 GPa). We argue that true ejecta (fragments originating from the main impact event) are highly shocked, i.e. only Canyon Diablo meteorites may be unshocked. Figs.1-2 show that Canyon Diablo meteorites (Fig.2) may be found further from the crater than ejecta (Fig. 1) except for the downrange direction. However, a quantitative comparison between model results and observations is difficult, as the total amount of "meteorites" is unknown and depends on the badly known strength properties of the impactor.

Any of the impact scenarios investigated so far results in much more projectile material (especially solid fragments) around and within the crater than it has been identified so far. A possible explanation, already suggested back in the 1950s by Nininger [10] is that substantial amount of irons was removed from this area prior to any scientific mapping/exploration. Yet another possibility is that the projectile was a "molten-vaporized" jet with minimal amount of solid fragments. Upon the impact this jet was mostly vaporized and the resulting tiny particles were dispersed in atmosphere.

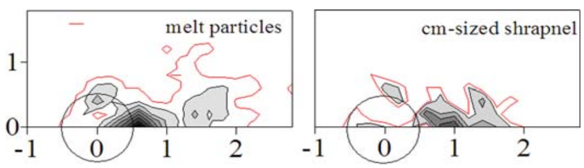

Figure 1: Surface density of projectile material around the crater (black circle). *Left*: Spherules (mm-size molten particles); the red line corresponds to a concentration of 10^6 particles/m^2, while the highest concentration (black region) is ~20 times higher. *Right*: shrapnel (cm-size highly compressed fragments); the red line shows 10^3 particles/m^2. For both types of ejecta the maximum concentration of particles is just beyond the crater rim in downrange direction.

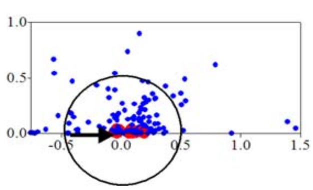

Figure 2: Distribution of Canyon Diablo meteorites (lightly shocked fragments of the main body arriving with a time delay) around the crater. Meter-size meteorites (red dots) are deposited inside the crater, smaller meteorites (blue dots) are partially dispersed on the plains in all directions. The farthest fragments (not shown in the figure) are 3-5 km downrange of the crater.

Acknowledgements

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References

[1] Barringer D.M. 1909. *Meteor Crater (formerly called Coon Mountain or Coon Butte), in Northern central Arizona.* Read before Nat. Acad. of Sci., Princeton Univ. Privately printed.

[2] Bryan J.B, Burton D.E., Cunningham M.E., Lettis, Jr., A. 1978. A two-dimensional computer simulation of hypervelocity impact cratering: Some preliminary results for Meteor Crater, Arizona. *Proceedings of the Lunar & Planetary Science Conference* 9: 3931-3964.

[3] Roddy D.J., Schuster S.H., Kreyenhagen K.N., Orphal D.L. 1980. Computer code simulations of the formation of Meteor Crater, Arizona: Calculations MC-1 and MC-2. *Proceedings of the Lunar & Planetary Science Conference* 11: 2275-2308.

[4] Schnabel C., Pierazzo E., Xue S., Herzog G.F., Masarik J., Creewell R.G., di Tada M.L., Liu K., Fifield L.K. 1999. Shock melting of the Canyon Diablo impactor: constraints from Nickel-59 contents and numerical modeling. *Science* 285: 85-88.

[5] Shuvalov V.V. 1999. Multi-dimensional hydrodynamic code SOVA for interfacial flows: Application to thermal layer effect. *Shock Waves* 9:381–390.

[6] Artemieva N. and Pierazzo E. 2009. The Canyon Diablo impact event: projectile motion through the atmosphere. *M&PS* 44: 25-42.

[7] Passey Q. R. and Melosh H. J. 1980. Effects of atmospheric breakup on crater field formation. *Icarus* 42: 211-233.

[8] Artemieva N. and Shuvalov V. 2001. Motion of a fragmented meteoroid through the planetary atmosphere. *JGR* 106: 3297-3309.

[9] Rinehart J.S. 1958. Distribution of meteoritic debris about the Arizona meteorite crater. *Smithsonian Contributions to Astrophysics* 2: 145-159.

[10] Nininger H.H. 1956. *Arizona's Meteorite Crater.* World Press, Inc., Denver, CO, USA. 232 pp.

[11] Heymann D., Lipschutz M.E., Nielsen B., and Anders E. 1966. Canyon Diablo meteorites: metallographic and mass spectrometric study of 56 fragments. *Journal of Geophysical Research* 71: 619-641.