DECIPHERING PROJECTILE COMPOSITIONS OF IMPACT CRATERS VIA SHOCK RECOVERY EXPERIMENTS ON SIMPLE METAL-SILICATE SYSTEMS
L. R. Rowan and F. Hörz, NASA-Johnson Space Center, SN4, Houston, TX, 77058

We are conducting shock recovery experiments in which a silicate cylinder (dunite, diopside, orthoclase, or basalt) is accelerated to velocities between 3 - 6 km/s and impacts a metal target (1100 Al, Cu, SS304, or Mo) in order to understand the chemical processes (i.e., shock melting, fractionation, oxidation) during impact and in the short post-shock cooling stage that produce the heterogeneous and intimately mixed impact melts within the metal craters. We intend to relate these simpler systems to the larger scale, more complex systems of natural craters to determine their evolution and ultimately to identify the bolide from the subtle and possibly modified compositional signature left in the shocked products. Examination of the shocked material lining the metal craters shows heterogeneous mixing and melting of the phases. The complex stratigraphic relations observed on a small scale suggest that care should be taken when interpreting small samples of impact melts in natural craters. Preliminary chemical analysis of some of the dunite shots indicates no reaction with the Al, Cu, or SS304. Although the composition of the olivine remained constant, the rounded, vesicular texture of some of the shocked olivine grains suggests melting of the dunite.

Introduction: An important aspect of terrestrial impact crater studies is to identify the composition of the bolide. Such information is key to estimating the projectile size and velocity, understanding the mechanical and chemical evolution of the crater, interpreting the consequences of the impact on the environment, estimating the size and population of meteorites that have bombarded the earth, and other related questions. Furthermore, the origin of tektites and lunar materials, which are related to meteoritic bombardments, would be easier to interpret if we can understand meteoritic contamination in impact melts from terrestrial craters where clues are generally more abundant and accessible. In a few cases, such as Meteor Crater, Arizona and Wabar Crater, Saudi Arabia, pieces of the projectile have been found allowing unambiguous impactor identification. Detailed studies of the impact melts from these craters have been carried out by various workers [1,2,3,4,5] to gain a greater understanding of the projectile-dissemination processes and associated potential modification of the impactor's initial composition. What are the roles of melt-miscibility, selective oxidation, and vapor-fractionation, if any? The main problem with the above approach is that the significant heterogeneity of the impact products makes a complete understanding of their origin difficult even with known target and projectile compositions. To address this dilemma we are conducting shock recovery experiments with simple target and projectile compositions to determine the extent to which processes like preferential shock melting, fractionation and/or selective oxidation effect the laboratory impact melts and how such effects may be scaled to much larger impact craters.

Method: The experiments are being carried out on a 5 mm light gas gun. For each experiment, a silicate cylinder is accelerated to velocities between 3.5 and 6.0 km/s toward a metal target. These cylinders were cored from single crystal diopside and orthoclase, and from polycrystalline dunite and basalt, representing a range of compositions of interest to terrestrial and planetary impacts. We chose four metals, 1100 Al, Cu, SS304 and Mo for our targets, to give us a range of different chemistries and increasing densities (i.e., increasing shock-stresses at limited laboratory velocities). A low and high velocity shot was done for each metal-silicate pair and the peak shock pressure in the silicate was estimated via impedance match methods assuming a planar impact. Craters filled with a mixture of silicate and metal residue were formed in the targets. We described, measured and photographed the craters and then they were epoxied, cross-sectioned, and prepared for chemical analysis. Chemical analysis of the impact products within the craters was conducted on the JSC Cameca electron microprobe.
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Results: Our general, macroscopic observations are that larger craters with well-defined rims and more silicate residue were formed in the softer metals, 1100 Al and Cu; whereas the SS304 and Mo had shallower craters, with almost no rims, less silicate residue, but more melting of the silicates. Some silicate in the craters was fractured and brecciated producing an approximately uniform crater coating of fine (500-100 μm) to very fine (<100 μm) grains mixed with the metal residue. Rounded blebs and spheres of clear to whitish glass are also present in some craters. This glass was more abundant in the SS304 and Mo craters versus the 1100 Al and Cu craters. The increase in melt production is consistent with the increasing density of the targets and in fact for the dunite high velocity (>5 km/s) shots into Cu, SS304, and Mo we obtained shock stresses >100 GPa (Maximum stress for the dunite-Mo shot was ~121 GPa). Laboratory impact melts have not been recovered at such high pressures in any previous work that we are aware of and these melts provide a unique opportunity to extend our observations to more extreme P-T conditions. Also we observed more melting of the Al and Cu targets, which is expected given their lower densities and melting points, while the SS304 and Mo showed less melting and more brittle brecciation and spallation of the metal. A prominent spall zone surrounded the Mo craters and almost separated the crater from the metal surface and the crater interior has a black discoloration suggesting oxidation of the Mo surface.

Microscopic observations on the SEM of the dunite shots revealed two important textural features. First there is an interesting stratigraphic relation between the melted metal and shocked dunite. Metal beads are visible along the crater wall below and above a piece of shocked dunite. Also for the SS304 shots, it appears that shocked metal and dunite residue has been injected along some of the cracks into the crater walls. The other interesting feature is the rounded and vesicular texture of some of the shocked dunite that suggests the olivine has been melted to a glass.

There is no significant solution between the metal and dunite in these melts for the 1100 Al, Cu, or SS304 shots. Although there is intimate physical mixing between the two melts, they remain chemically segregated. Minor depletions of SiO₂, FeO, and MgO were detected in the shocked dunite, yet they are within the standard deviations of the dunite standard and can be attributed to a slightly poorer probe signal from the shocked silicate caused by fractures, vesicles and uneven sample depth. The minor additions of CuO for the Cu shots and NiO and Cr₂O₃ for the SS304 shots are likely to be caused by the appropriate metal, typically found as spherules within the shocked dunite being close to the analysis spot. We must note however that we have not completed the analyses of the Mo-dunite shots and given our observations of glass and discoloration of the crater surface we feel that there may have been some reaction between the Fe and Mo in this system.

Conclusions: We did not observe any significant reaction between the dunite and diverse metal targets analyzed so far. We hope to see more chemical exchange in the Mo shots and in the other silicate-metal shots which contain more volatile species like Na and K. Although the composition of the olivine remained constant, the morphological and possible structural changes in the shocked silicate are significant. The rounded, vesicular texture of some of the shocked olivine grains suggests melting of the dunite. TEM investigations are planned to explore whether this material is holohyaline or cryptocrystalline. Furthermore, the heterogeneous spatial distribution of target melt in the form of metallic spherules within the crater suggest that care should be taken when interpreting the distribution of metallic spherules in natural impact melts.


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