Reproducing the high-pressure metallic, oxide and silicate minerals found in meteorites using novel shock-recovery experiments

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Shock metamorphism features in meteorites provide important records of the pressure-temperature-time (*P-T-t*) conditions of shock events, which in turn constrain the impact history of their parent bodies. A general scale for shock pressures can be defined on the basis of deformational shock features and was calibrated directly using shock-recovery experiments by many authors. On the other hand, shock-induced high-pressure (HP) minerals should be particularly useful because their (meta)stability fields can accurately indicate shock conditions, but there have been many difficulties in calibrating the application of HP minerals in meteorites because they are rarely recovered using shock experiments. This is because (1) a laboratory impact produces a shock pulse 5-6 orders of magnitude shorter than planetary impact, which limits the time available to drive HP reactions and (2) the post-shock temperature of millimeter-scale recovery charges can be uniformly high and last long enough for low-pressure annealing to back-transform any HP phases that may have formed. To overcome these difficulties, we designed novel shock experiments with well-defined *P-T-t* conditions that have led to successful recovery of multiple high-pressure metallic, oxide and silicate phases.

The common metallic phases in chondrites, i.e. Fe-Ni alloys, are resistant to shock deformation all the way to their melting points. In contrast, the rare Al-Cu-Fe-Ni alloys observed exclusively in two chondrites can form a number of intermetallic phases, including the first and only natural quasicrystalline phases (QC) with 5-fold (i.e. icosahedrite) and 10-fold (i.e. decagonite) forbidden rotation axes. Previous synthetic QCs all formed during superfast quenching, which is an unlikely pathway in most geological settings except a shock event. Inspired by this idea, we tried a number of shock experiments with a wide range of compositions in Al-Cu-Fe-Ni space around the narrow stability fields of QCs. Indeed, we successfully reproduced icosahedral and decagonal quasicrystals, which is definitive proof of admissible impact origin for their natural occurrences. In one such experiment, we used a starting material containing a smooth compositional gradient from Al to Cu, encompassing all intermediate Al/Cu ratios. This experiment precisely reproduced a natural phase-assemblage of stolperite + khatyrkite + hollisterite + icosahedral quasicrystal, which greatly strengthens the case for a natural impact origin of the quasicrystals in the Khatyrka CV3 meteorite.

Silicate high-pressure minerals are more difficult than metallic phases to produce by shock because of the generally sluggish diffusion of their constituents. The few successful examples of HP silicate mineral recovery reflect either displacive transformation (e.g. zircon to reidite), formation of short-range order (e.g. stishovite), or growth from fast-quenched shock melt (e.g. wadsleyite). In light of these examples, we design our experiments to achieve either higher shock temperature (to enhance the reaction kinetics) or lower post-shock temperature (to limit annealing). To increase shock temperature, we use the known Hugoiots of basalt, dunite, silica and feldspar to design non-reverberating experiments that reach the peak shock pressure in a single step. This setup creates much higher shock temperature at any given shock pressure than the multiple reflected shock path used in most previous studies. To decrease recovered temperature and annealing, we used graded density impactors to create quasi-isentropic loading paths with lower shock temperature and nearly ambient release temperature. With these setups, we recovered, for example, a zagamiite-like hexagonal phase from shocked labradorite and produced olivine disproportionation to spinel phases by dunite-steel reaction.

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