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Progressive change in dislocation microstructures in shocked calcite with pressure: Characterization of micrometeoroid bombardment on asteroid Ryugu

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Abstract

Shock recovery experiments were performed using a two-stage light gas gun to clarify the progressive deformation microstructures of calcite at the submicrometer scale concerning pressure. Decaying compression pulses were produced using a projectile that was smaller than the natural marble target. In two experiments, natural marble samples were shocked to 13 and 18 GPa at the epicenters of the targets. Calcite grains shocked in the pressure range of 1.1–18 GPa were examined using polarized light microscopy and (scanning) transmission electron microscopy. The density of free dislocations in the grains shocked at 1.1–2.2 GPa [10^{8-9} (cm^{-2})] is comparable to that of unshocked Carrara calcite grains. Subparallel bands of entangled dislocations <1 μm are formed at 4.2 GPa, and strongly entangled dislocations spread throughout the focused ion beam (FIB) sections at 7.3–18 GPa. Dislocations selectively nucleate and entangle near the slip planes at pressures above ~3 GPa, corresponding to the transition from sharp extinction to undulatory extinction, according to the microstructural evolution with shock pressure. Above ~6 GPa, the dislocations nucleated homogeneously throughout the calcite crystals. The dislocation microstructure in a calcite grain collected from the asteroid Ryugu particle is similar to that of the experimentally shocked calcite at 4.2 GPa. The estimated pressure of 2–3 GPa, determined through fault mechanics analyses and the presence of dense sulfide minerals in the Ryugu particles, is in line with this pressure.

Keywords: Calcite, shock recovery experiments, dislocation, transmission electron microscopy