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Mushroom-shaped growth of crystals on the Moon

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Abstract

Over the past three decades, advances in crystal nucleation and growth have led to the understanding that crystallization proceeds through various pathways, ranging from the conventional atom-by-atom model to the particle aggregation- or amorphous transformation-based non-classical modes. Here, we present a novel mineralization mechanism exemplified by a lunar chromite formed via solid-liquid interface reactions through investigations of a lunar breccia returned by the Chang'e 5 mission. The chromite occurs in the middle of a whisker-shaped intergrowth structure made by olivine at the bottom and nanospheres of troilite and metallic iron at the top. Morphological observation and size statistics of the nanospheres, including those within the whisker structure and the others dispersed in glass, suggest the nanophases attached to olivine with coherent crystallographic orientations, possibly through an oriented aggregation process. The chromium deficiency in the olivine near the interface between olivine and chromite suggests that Cr in chromite originated from olivine, but the significantly reduced ferrous concentration in the glass surrounding chromite indicates the iron was derived from surrounding impact-induced glass. Based on laboratory observations and simulated calculations of energy and lattice mismatch, we propose that chromite crystallized at the interface between troilite and olivine in the impact melts, during which the nanospheres were lifted and transported away from olivine surface and formed a mushroom-shaped structure. This finding suggests that oriented attachment growth, chiefly confined to homogeneous systems thus far, can also occur in heterogeneous systems far from equilibrium, such as that produced by the impacts. It is conceivable that the studied crystallization pathway occurring on the heterogeneous interfaces may have been a common mineralization mode at highly nonequilibrium conditions.

Keywords: Chang'e 5 lunar regolith, whisker growth, nanoparticles, nonequilibrium crystallization, impact melt, chromite