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Microstructural and chemical responses of lunar pyroxene to shock shearing under low-to-moderate shock conditions

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Abstract

Pyroxene is a primary constituent mineral in basaltic lunar regolith. These minerals form through the cooling and crystallization of lunar basaltic magma and are subsequently altered by impact events. Thus, pyroxene can serve as a significant indicator for interpreting lunar magmatic processes and impact phenomena. For lunar samples that are mostly mafic and frequently shocked to various degrees, deciphering the effect of shock on pyroxene is necessary for a better understanding of the primary magmatic processes. However, previous studies have neglected to investigate the impact metamorphism of pyroxene in lunar regolith and the potential compositional changes that may result from such impacts. Lunar regolith samples returned by the Chang'E-5 (CE-5) mission are reworked from a monolithic mafic protolith with well-constrained compositions and record strong to mild shock effects that are widespread in the samples. The returned samples provide an excellent chance to distinguish the signatures of impact processes from magmatic activities. Here we report microstructural and compositional variations in a shocked pyroxene within a basaltic clast from CE-5 lunar regolith, which were analyzed by Raman spectroscopy, analytical scanning electron microscopy, electron probe microanalysis, and scanning transmission electron microscopy. The shock microstructures are characterized by the glide system of dislocation [001](100), pigeonite formation induced by shock-related deformations, and solid-melt partitioning and localized frictional melting at grain boundaries or within pyroxene. Combined with the occurrence of shock twins in ilmenite adjacent to the shock melt vein, these shock phenomena are approximately indicative of low-to-moderate shock pressure (9–17 GPa). Most parts of the pyroxene have abnormal Raman peaks at ~822 cm^{-1}, suggesting the substitution of Si^{4+} by Al^{3+} in the tetrahedral site of this shocked pyroxene structure, and this characteristic is recognized as a shock indicator. Evidence from the morphology and elemental distribution of pigeonite within host augite suggests that the Si-Al substitution is consistent with the pigeonite formation, which is triggered or modified by shock-induced deformations and local frictional melting under the fast shear stress. The multiple trends of composition evolution in this single shocked pyroxene reflect sequential processes of magma crystallization, shock-related exsolution, and frictional melting. Our findings indicate that shock effects in pyroxene under low-to-moderate shock conditions can induce changes in composition and structure, and may obscure the evidence of magmatic evolution in pyroxene.

Keywords: Shocked pyroxene, pigeonite formation, frictional melting, plastic deformations, CE-5 lunar sample