Shock-induced $P$-$T$ conditions and formation mechanism of akimotoite-pyroxene glass assemblages in the Grove Mountains (GRV) 052082 (L6) meteorite

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ABSTRACT

Akimotoite [(Mg,Fe)SiO$_3$-ilmenite] was encountered in shock-induced melt veins of Grove Mountains (GRV) 052082, a highly equilibrated low iron ordinary chondritic meteorite (L6). Coexistence of ringwoodite, majorite, and majorite-pyrope solid solution indicates the shock pressure at 18–23 GPa and temperature of 2000–2300 °C during the natural dynamic event. Most low-Ca pyroxene clasts entrained in the melt veins have been partially or entirely transformed into akimotoite-pyroxene glass assemblages, which contain micrometer-sized areas with various brightness in the backscattered electron images, different from the chemically homogeneous grains in the host-rock (F$\text{S}_{30.5-21.3}$). All analyses of the akimotoite-pyroxene glass assemblages plot on a fractionation line in FeO-MgO diagram, with the host-rock pyroxene at the middle between the compositions of FeO-depleted akimotoite and the FeO-enriched pyroxene glass. These observations are different from previous reports of almost identical compositions of akimotoite, bridgetmanite [(Mg,Fe)SiO$_3$-perovskite], or pyroxene glass to the host rock pyroxene (Chen et al. 2004; Ferroir et al. 2008; Ohtani et al. 2004; Tomioka and Fujino 1997), which is consistent with solid-state transformation from pyroxene to akimotoite and preexisting bridgetmanite that could be vitrified. The observed fractionation trend and the granular shapes of akimotoite suggest crystallization from liquid produced by shock melting of the host-rock pyroxene, and the pyroxene glass matrix was probably quenched from the residual melt. However, this interpretation is inconsistent with the static experiments that expect crystallization of majorite [(Mg,Fe)SiO$_3$-garnet], instead of akimotoite, from pyroxene liquid (Sawamoto 1987). Our discovery raises the issue on formation mechanisms of the high-pressure polymorphs of pyroxene and places additional constraints on the post-shock high-pressure and high-temperature conditions of asteroids.

Keywords: Akimotoite, pyroxene glass, high-pressure polymorphs, meteorite, shock, impact

INTRODUCTION

Orthopyroxenes [(Mg,Fe)$_2$SiO$_4$] are among the most important components of stony meteorites and the upper mantle of the Earth. At high-pressure and high-temperature conditions, pyroxene transforms to high-pressure polymorphs including majorite [(Mg,Fe)$_2$SiO$_4$-garnet], akimotoite [(Mg,Fe)$_2$SiO$_3$-ilmenite], and bridgmanite [(Mg,Fe)$_2$SiO$_3$-perovskite] (Tschauner et al. 2014), which are considered to be among the major constituents of the Earth’s deep mantle (e.g., Liu 1976; Ohtani et al. 1991; Presnall 1995). Natural occurrences of these high-pressure phases have been mostly discovered in and around shock-induced melt veins of chondrites (Chen et al. 1996; Miyahara et al. 2011; Tschauner et al. 2014; Sharp et al. 1997; Tomioka and Fujino 1997). They provide insight into equilibrium pressure–temperature conditions and the time scale of the dynamic events, and may mimic the phase transformations occurring in the deep Earth mantle and subducted lithosphere (Kerschofer et al. 1998; Liu et al. 1998; Mosenfelder et al. 2001).

The formation of high-pressure polymorphs of pyroxene in the shock-induced melt veins occurs in various settings and probably involves different mechanisms. The fine-grained crystals in the matrix of the shock melt veins usually result from the crystallization from chondritic melts under high-pressure and high-temperature conditions (Chen et al. 1996; Sharp et al. 1997; Xie et al. 2006b). Large fragments, which were entrained from host rock into the melts, have been generally considered as being in solid-state transformed into polycrystalline assemblages.