Natural occurrence of Fe$_2$SiO$_4$-spinel in the shocked Umbarger L6 chondrite

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ABSTRACT

Here we report the first natural occurrence of Fe$_2$SiO$_4$-spinel in a shock-induced melt pocket of the Umbarger L6 chondrite. Optical microscopy, scanning electron microscopy, electron microprobe analysis, and analytical transmission electron microscopy were used to examine the sample. Fe$_2$SiO$_4$-spinel was identified by TEM using selected-area electron diffraction and energy-dispersive X-ray spectroscopy. The symmetry of the diffraction patterns, the ratios of d-spacings, and interplanar angles are consistent with the spinel structure. However, the cell parameter of Fe$_2$SiO$_4$-spinel (8.52 Å), calculated from d-spacing data, is 3.5% larger than that of synthetic Fe$_2$SiO$_4$-spinel (8.235 Å). Chemical analyses of the spinel show olivine stoichiometry with Fe/(Fe + Mg) ratios ranging from 0.62 to 0.99. Fe$_2$SiO$_4$-spinel and stishovite occur within FeO-SiO$_2$-rich zones in the melt pocket, surrounded by SiO$_2$-rich glass and Fe-rich phyllosilicates. Fe$_2$SiO$_4$-spinel plus stishovite also occur with other high-pressure minerals in the melt pocket: ringwoodite, akimotoite, augite, and hollandite-structured plagioclase. We infer that the Fe$_2$SiO$_4$-spinel crystallized from a zone of FeO-SiO$_2$-rich melt within the shock-induced melt pocket. Two models for FeO-SiO$_2$-rich melt are discussed: it was either a residual melt after crystallization of MgO-rich silicates in a chondritic melt pocket, or it was produced by shock melting of FeO-SiO$_2$-rich material.

INTRODUCTION

High-pressure minerals are common in highly shocked (S6) L6 chondrites, occurring within or adjacent to shock-induced melt veins and pockets (Mason et al. 1968; Binns et al. 1969; Putnis and Price 1979; Stöffler et al. 1991; Chen et al. 1996). The most common of these minerals are ringwoodite ((Mg,Fe)$_2$SiO$_4$-spinel) (Mason et al. 1968), majorite ((Mg,Fe)$_2$SiO$_3$-perovskite), magnesiowüstite ((Mg,Fe)O), (Mg,Fe)SiO$_3$-ilmenite, and (Na,K,Ca)(Si,Al)$_2$O$_3$- hollandite are less common (Sharp et al. 1997; Tomioka and Fujino 1997; Gillet et al. 2000). High-pressure minerals in shock-induced melt veins provide a record of high-pressure and -temperature conditions during impact events on chondrite parent bodies (Chen et al. 1996; Sharp et al. 2001). They also provide natural examples of high-pressure minerals that are expected to make up the Earth’s transition zone (410 to 660 km depth) and lower mantle. Chemical and textural heterogeneities in melt veins can provide insight into the nature of shock melting, melt mixing, and melt-vein crystallization. This study is part of an ongoing investigation of shock-induced melt veins as indicators of crystallization conditions and shock processes.

Fe$_2$SiO$_4$-spinel, the spinel-structured polymorph of fayalite, was synthesized by Ringwood at 600 °C at 3.8 GPa (Ringwood 1958). Although ringwoodite, Mg-rich (MgFe)$_2$SiO$_4$-spinel, is believed to be a major mineral of the Earth’s transition zone (Ringwood 1958; Irifune 1993), and is commonly found in shocked chondritic meteorites, natural Fe$_2$SiO$_4$-spinel has not been reported previously. Here we describe the natural occurrence of Fe$_2$SiO$_4$-spinel in a shock-induced melt vein in the Umbarger L6 chondrite.

SAMPLE AND METHOD

The Umbarger chondrite was found in 1954, 2.9 km WSW of Umbarger, Randall Co., Texas. The single stone of 13 kg is highly oxidized with a remnant fusion crust (Dod et al. 1981). Petrographic classification was given as L3 and L6 (Dod et al. 1981). The reason for this dual classification is that heterogeneity of the olivines suggests a Type 3, yet abundant plagioclase and partial recrystallization of the matrix suggest Type 6 (Dod et al. 1981). Our optical examination shows no evidence for the Type 3 classification. The heterogeneities in the olivines are likely a result of shock metamorphism and weathering, which are consistent with Umbarger being a shocked L6 chondrite. The shock metamorphism in Umbarger was previously classified as shock stage S4, based on deformation features of olivine (Stöffler et al. 1991). However, our discovery of ringwoodite in melt pockets and the presence of maskelynite and normal plagioclase glass indicate that the shock stage of Umbarger is S6 (Xie and Sharp 2000).

A polished thin section of Umbarger was investigated by a combination of optical petrography using transmitted and reflected light, scanning electron microscopy (SEM), electron microprobe analysis (EMPA), and analytical transmission elec-