A new mineral with an olivine structure and pyroxene composition in the shock-induced melt veins of Tenham L6 chondrite

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ABSTRACT

We report a new mineral that occurs in shock-induced melt veins of the Tenham L6 chondrite. The new mineral, identified by transmission electron microscopy (TEM), occurs as acicular nanocrystals in a glassy matrix at the edge of shock-induced melt veins that crystallized during rapid quench at high pressure. The elongate crystals have aspect ratios up to 25. Widths range from ∼5 to ∼40 nm and lengths are up to 500 nm. Energy-dispersive X-ray spectroscopy (EDS) analyses provide the relative cation abundances that are consistent with a pyroxene-like stoichiometry: Na1.06Ca0.02Mg0.71Fe0.20Al0.11Si0.93O1.8. Selected area electron diffraction (SAED) patterns from single-crystal and polycrystalline aggregates indicate an olivine structure with refined cell parameters: \(a = 4.778\), \(b = 10.11\), and \(c = 5.94\) Å and a calculated density of 3.32 g/cm³. Synchrotron X-ray microdiffraction data are consistent with an olivine structure and provide similar cell parameters: \(a = 4.778\), \(b = 10.267\), \(c = 5.937\) Å. The pyroxene composition represents a large deviation from olivine stoichiometry, \((Na_0.06Ca_0.02Mg_0.71Fe_0.20Al_0.11Si_0.93O_1.8)_{0.28}\)\(_{0.72}\) for 0.28 formula units of vacancies (\(\square\)), 0.11 of Na⁺ plus Ca²⁺, and 0.25 of Si⁴⁺, in octahedral sites. Our observations indicate that a metastable and nonstoichiometric olivine structure can crystallize from a silicate melt during rapid quench. Trace amounts of such defects may be present in stable olivines in the deep upper mantle.

Keywords: Shock-induced, Tenham, olivine, melt vein

INTRODUCTION

Impact metamorphism resulting from hypervelocity collisions between planetary bodies is a fundamental process in the solar system (Chao 1967; Stöffler 1972; Stöffler et al. 1991; Leroux 2001; Sharp and DeCarli 2007). The high-pressure minerals in the shock-induced melt veins of chondrites not only provide high-pressure indicators for these shock events; they also provide natural samples similar to those expected in the Earth’s transition zone (410 to 660 km depth) and lower mantle (>660 km depth) (Mason et al. 1968; Binns et al. 1969; Price et al. 1979, 1982; Putnis and Price 1979; Sharp et al. 1997, 1999; Tomioka and Fujino 1997; El Goresy et al. 1998, 2000; Gillet et al. 2001; Madon and Poirier 1983; Mori and Takeda 1985; Langenhorst et al. 1995; Tomioka and Fujino 1997; Beck et al. 2005; Z. Xie et al. 2006a). The crystal sizes in the Tenham melt veins range from several micrometers down to tens of nanometers, and are beyond the resolution of many analytical instruments, such as scanning electron microscopy and Raman spectroscopy. Therefore, transmission electron microscopy (TEM) is the primary tool to investigate these sub-micrometer crystals. We have published prior studies of the mineralogy and crystallization history of the melt veins in Tenham (Z. Xie et al. 2006a, 2006b; Xie and Sharp 2007). Here we report on the structure, crystal chemistry, and composition of a new mineral in the same sample, and discuss its origin as a high-pressure crystallization product in shock-induced melt veins.

SAMPLES AND METHODS

The Tenham L6 chondrite fell as a shower of individual fragments in 1879 near Tenham Station (25°44’S, 142°57’E) in South Gregory, Queensland, Australia (Spencer 1937). A 31.6 g piece of the chondrite was obtained from the Center for Meteorite Studies at Arizona State University (ASU sample no. 647.6) and a 30 μm thin section was prepared. The sample was investigated with a combination of optical petrography using transmitted and reflected light, scanning electron microscopy (SEM) with a field-emission electron source, and analytical transmission electron microscopy (ATEM), using both thermal and field-emission electron sources.

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