Discovery of asimowite, the Fe-analog of wadsleyite, in shock-melted silicate droplets of the Suizhou L6 and the Quebrada Chimborazo 001 CB3.0 chondrites

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ABSTRACT

We report the first natural occurrence and single-crystal X-ray diffraction study of the Fe-analog of wadsleyite \([a = 5.7485(4), b = 11.5761(9), c = 8.3630(7) \text{ Å}, V = 556.52(7) \text{ Å}^3]\); space group \text{Imma}\). spineloid-structured \(\text{Fe}_2\text{SiO}_4\), a missing phase among the predicted high-pressure polymorphs of ferroan olivine, with the composition \((\text{Fe}_{10}^{2+} \text{Mg}_{0.80}^{2+} \text{Cr}^{3+}_{0.04} \text{Mn}^{2+}_{0.02} \text{Ca}_{0.02} \text{Al}_{0.02} \text{Na}_{0.02} \text{Si}_{2.01} \text{O}_{10} (\text{Si}_{0.97} \text{Al}_{0.03})_2 \text{O}_8)\). The new mineral was approved by the International Mineralogical Association (No. 2018-102) and named asimowite in honor of Paul D. Asimow, the Eleanor and John R. McMillan Professor of Geology and Geochemistry at the California Institute of Technology. It was discovered in rare shock-melted silicate droplets embedded in Fe,Ni-metal in both the Suizhou L6 chondrite and the Quebrada Chamorazo (QC) 001 CB3.0 chondrite. Asimowite is rare, but the shock-melted silicate droplets are very frequent in both meteorites, and most of them contain Fe-rich wadsleyite \((\text{Fe}_{90-40})\). Although the existence of such Fe-rich wadsleyite in shock veins may be due to the kinetic reasons, new theoretical and experimental studies of the stability of \((\text{Fe,Mg})_2\text{SiO}_4\) at high temperature (>1800 K) and pressure are clearly needed. This may also have a significant impact on the temperature and chemical estimates of the mantle’s transition zone in Earth.

Keywords: Wadsleyite, iron, spineloid, chondrite, meteorite, crystal structure, microprobe analysis, Earth’s transition zone

INTRODUCTION

Most of the major rocky planet-forming materials \([i.e., M-Si-O (M = Mg, Fe)]\) such as majorite (Tomiska et al. 2016), akimotoite-hemleyite (Tomiska and Fujino 1999; Bindi et al. 2017), wadsleyite (Price et al. 1983), ringwoodite-ahrensite (Binnis et al. 1969; Ma et al. 2016; Bindi et al. 2018), and bridgmanite (Tschauer et al. 2014) have been discovered in extraterrestrial rocks that have experienced high-pressure and high-temperature collisions in outer space. Such rocks, known as shocked meteorites, represent a fascinating challenge for geoscientists because their mineralogical assemblages, and the processes they underwent, could give important indications on the mechanisms affecting planets and asteroids through the evolution of the solar system. Furthermore, the studies of shocked meteorites could give important hints for the mineralogy of Earth’s deep interior, which are currently inferred from the investigation of mantle xenoliths (Collerson et al. 2000) and inclusions in diamonds (Moore and Gurney 1985; Walter et al. 2011), as well as from experimental studies of phase equilibria of silicates and oxides (e.g., Gasparik 2003; Irifune and Tsuchiya 2007).

Among the high-pressure \(M-Si-O\) phases, wadsleyite \([\beta\text{-polymorph of (Mg,Fe)}_2\text{SiO}_4]\) is considered the dominant phase in the upper portions of the transition zone (e.g., Irifune and Ringwood 1987). In addition, the transition of olivine into wadsleyite structure has been considered as the cause for the observed discontinuity in seismic wave velocities near 410 km depth (e.g., Bina and Wood 1987; Katsura and Ito 1989). Experimental works at conditions relevant for the Earth’s transition zone (<1873 K) yield that the Fe content of wadsleyite seems limited to \(\text{Fa}_{30}\). Above this Fe-content, as long as no Fe\(^{2+}\) is involved, olivine directly transforms to ringwoodite. However, Finger et al. (1993) synthesized a single wadsleyite crystal with \(\text{Fa}_{80}\) at 15.2 GPa and 1973 K, which should lie within the ringwoodite stability field of \(\text{Mg}_2\text{Si}_2\text{O}_5 – \text{Fe}_2\text{Si}O_4\) phase diagram (Fei and Bertka 1999). The \(\text{Fe}_2\text{SiO}_4\) end-member requires much lower pressures to transform directly from fayalite to its high-pressure polymorph alherite (Ono et al. 2013). The FeO content of natural wadsleyite depends on the transformation mechanism (Sharp and de Carli 2006). Wadsleyite in ordinary chondrites, mostly coexisting with ringwoodite, shows values of \(\text{Fa}_{80}\) (e.g., Miyahara et al. 2008; Ono et al. 2013), whereas wadsleyite grains studied in barred olivine fragments in shock melted areas in the CB\(_1\) chondrite Gujba range...