Occurrence of tuite and ahrensite in Zagami and their significance for shock-histories recorded in martian meteorites

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Abstract

We report on the discovery of two high-pressure minerals, tuite and ahrensite, located in two small shock-induced melt pockets (SIMP 1 and 2) in the Zagami martian meteorite, coexisting with granular and acicular stishovite and seifertite. Tuite identified in this study has two formation pathways: decomposition of apatite and transformation of merrillite under high-P-T conditions. Chlorine-bearing products, presumably derived from the decomposition of apatite, are concentrated along the grain boundaries of tuite grains. Nanocrystalline ahrensite in the pyroxene clast in SIMP 2 is likely to be a decomposition product of pigeonite under high-P-T conditions by a solid-state transformation mechanism. The pressure and temperature conditions estimated from the high-pressure minerals in the shock-induced melt pockets are ~12–22 GPa and ~1100–1500°C, respectively, although previous estimates of peak shock pressure are higher. This discrepancy probably represents the shift of kinetic relative to thermodynamic phase boundaries, in particular the comparatively small region that we examine here, rather than a principal disagreement between the peak shock conditions.

Keywords: Tuite, ahrensite, Zagami, martian meteorite, high-pressure minerals

Introduction

Many meteorites from Mars (Baziotis et al. 2013; Hu et al. 2020; Miyahara et al. 2016; Sharp et al. 2019), the Moon (Kayama et al. 2018; Miyahara et al. 2013; Ohtani et al. 2011; Zhang et al. 2010), Howardite-eucrite-diogenite (HED) meteorites (Miyahara et al. 2014; Pang et al. 2016, 2018), and ordinary chondrites (e.g., Binns et al. 1969; Chen et al. 1996; Sharp and DeCarli 2006; Stöffler et al. 1991; Tschauer et al. 2014) are highly shocked, as evidenced by the observation of deformation in constituent minerals and formation of various high-pressure phases. The high-pressure minerals discovered in these extraterrestrial samples can reveal the impact history on their parent bodies and provide insights into the phase transformation mechanisms in the interior of the Earth (Petrova and Grokhovsky 2019). To date, high-pressure polymorphs of olivine (Binns et al. 1969; Chen et al. 2004; Ma et al. 2016; Miyahara et al. 2008; Putnis and Price 1979), pyroxene (Chen et al. 1996; Sharp et al. 1997; Tomioka and Fujiyogo 1999; Tschauer et al. 2014), feldspar (Fritz et al. 2020; Gillet et al. 2000; Liu 1978; Ma et al. 2018; Tschauer et al. 2021), zircon (Glass et al. 2000; Xing et al. 2020), silica (El Goresy et al. 2000b, 2004; Hu et al. 2020; Miyahara et al. 2014; Ohtani et al. 2011; Sharp et al. 1999), chromite (Chen et al. 2003; Ma et al. 2019), and Ca phosphate (Wang et al. 2017; Xie et al. 2002a, 2013) have been reported from various meteorites displaying shock effects.

Tuite, a high-pressure polymorph of Ca-phosphate with the structure of γ-Ca3(PO4)2, is of great significance as a host for larger lithophile elements in the deep Earth (Skelton and Walker 2017; Xie et al. 2002a). It has been reported in shocked chondrites (Hu and Sharp 2016; Xie et al. 2002a, 2016), martian meteorites (Baziotis et al. 2013; Boonsue and Spray 2012; Fritz and Greshake 2009; Wang et al. 2017), and iron meteorites (Litasov and Podgornykh 2017). Tuite was proposed to form from the decomposition of apatite or solid-state phase transformation of merrillite (Murayama et al. 1986; Xie et al. 2002a, 2013, 2016). Some tuite grains in Suizhou (Xie et al. 2016) and NWA 7755 (Wang et al. 2017) meteorites were found coexisting with Cl-rich apatite, with a Cl content of up to ~3.9 wt%, consistent with the possibility that they formed through decomposition of adjacent chlorapatite. However, the ideal formula of tuite, Ca3(PO4)2, similar to extraterrestrial merrillite, does not contain Cl or other halogens (Jolliff et al. 2006; McCubbin et al. 2014). A reasonable explanation is that the Cl measured in tuite is derived from partial decomposition of precursor apatite (Wang et al. 2017; Xie et al. 2016). Another explanation is that there are some other Cl-bearing products, e.g., CaCl2, accompanying the formation of tuite by decomposition of apatite (Murayama et al. 1986; Xie et al. 2013). However, the details about how these Cl-bearing products exist are still unclear, which are crucial for better understanding the transformation mechanism of apatite during shock metamorphism (Xie et al. 2013).