Apatite in brachinites: Insights into thermal history and halogen evolution

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Abstract

Apatite is an important petrogenetic indicator in extraterrestrial materials. Here, we report the mineralogical features of apatite and associated phases in three brachinites Northwest Africa (NWA) 4969, NWA 10637, and NWA 11756. Two types of apatite are observed: intergranular apatite and apatite inclusion within chrome and silicate minerals. The intergranular chlorapatite is enclosed by or penetrated by irregular porous merrillite, indicating chlorapatite replacement by merrillite. The intergranular chlorapatite is closely associated with a fine-grained pyroxene-troilite intergrowth along olivine grain boundaries, which is a sulfidization product of olivine. High-Ca pyroxene is observed as a constituent phase in the intergrowth for the first time. The apatite inclusions are either monomineralic or closely associated with subhedral-euhedral pore-free merrillite. In NWA 4969, the apatite inclusions show a large compositional variation from chlorapatite to fluorapatite and are systematically more F-rich than intergranular apatite; while the apatite inclusions in NWA 10637 and NWA 11756 are chlorapatite. Most of the two apatite types in brachinites contain oriented tiny or acicular chromite grains, suggesting the exsolution of chromite from apatite. We propose that the apatite replacement by merrillite, formation of pyroxene-troilite intergrowth, and exsolution of chromite in apatite were caused by a shock-induced, transient heating event (~930–1000 °C) on the brachinite parent body. This heating event resulted in halogen devolatilization during replacement of the intergranular apatite by merrillite, which probably disturbed the Mn-Cr isotopic system in brachinites as well. We also propose that the apatite inclusions could be a residual precursor material of the brachinites.

Keywords: Apatite, merrillite, halogen, replacement, sulfidization, exsolution, brachinite; Experimental Halogens in Honor of Jim Webster

Introduction

Apatite [Ca6(PO4)2(F,Cl,OH)] is a ubiquitous mineral in most terrestrial and extraterrestrial materials. It is an important carrier of both volatile elements (F, Cl, and OH) and rare earth elements (REE) (Harlov 2015; Hughes and Rakovan 2015). In the past decades, apatite in extraterrestrial materials has been extensively studied to: (1) constrain the petrogenesis and chemical evolution of host rocks (e.g., Shearer et al. 2011; Ward et al. 2017, and references therein); (2) reconstruct the abundance, origin, and evolution of halogen elements and hydrogen on Mars, Moon, and asteroids (e.g., McCubbin and Jones 2015; McCubbin et al. 2015; Ward et al. 2017; Brearley and Jones 2018; McCubbin et al. 2021, and references therein); (3) determine the age of geological events that its host rocks experienced (e.g., Norman and Nemchin 2014; Yin et al. 2014; Zhang et al. 2016; Zhou et al. 2018; Hu et al. 2019; Li et al. 2021, and references therein).

Brachinites are a group of primitive achondrites that are characterized by the dominance of equigranular FeO-rich olivine (>70 vol%; Krot et al. 2014; Keil 2014; Mittlefehldt 2014). Previous investigations have proposed that the brachinites are partial melts residues (e.g., Nehru et al. 1983; Day et al. 2012, 2019; Gardner-Vandy et al. 2013; Keil 2014; Collinet and Grove 2020, and references therein), although some brachinites have been described as cumulates (Warren and Kallenbach 1989; Swindle et al. 1998; Mittlefehldt et al. 2003). Apatite has occasionally been reported in brachinites or some brachinite-like achondrites; however, its mineralogical features and origins have not yet been studied in detail (e.g., Rumble et al. 2008; Hyde et al. 2014; Keil 2014; Goodrich et al. 2017; Crossley et al. 2020; Ito et al. 2022). All apatite grains reported from brachinites up to date have been chlorapatite (Hyde et al. 2014; Keil 2014; Goodrich et al. 2017; Crossley et al. 2020, and references therein). Hyde et al. (2014) reported that many chlorapatite grains in brachinite Northwest Africa (NWA) 4872 are surrounded by merrillite [Ca2Na2Mg3(PO4)3], another common Ca-phosphate mineral in extraterrestrial materials (Jolliff et al. 2006; Shearer et al. 2015). However, the chlorapatite in NWA 4872 was interpreted as an interaction product between merrillite and a CI-rich melt residuum or low-temperature fluid on the parent body (Hyde et al. 2014).

Previous investigations of brachinites focused mainly on their petrogenesis (e.g., Day et al. 2012, 2019; Keil 2014; Krot et al. 2014; Mittlefehldt 2014, and references therein). In contrast, their post-formation thermal history, which is an important part of the complete evolutionary history in the parent body of brachinites, was less constrained. Two aspects of petrologic records, that could be related to post-formation heating events, have been reported. First, a few brachinites contain pyroxene-troilite intergrowths (e.g., Rumble et al. 2008; Goodrich et al. 2010, 2017;