On the origin of fluorine-poor apatite in chondrite parent bodies

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ABSTRACT

We conducted a petrologic study of apatite within one LL chondrite, six R chondrites, and six CK chondrites. These data were combined with previously published apatite data from a broader range of chondrite meteorites to determine that chondrites host either chlorapatite or hydroxylapatite with $\leq 33$ mol\% F in the apatite X-site (unless affected by partial melting by impacts, which can cause F-enrichment of residual apatite). These data indicate that either fluorapatite was not a primary condensate from the solar nebula or that it did not survive lower temperature nebular processes and/or parent body processes. Bulk-rock Cl and F data from chondrites were used to determine that the solar system has a Cl/F ratio of $10.5 ± 1.0 \times 10^{-3}$. The Cl/F ratios of apatite from chondrites are broadly reflective of the solar system Cl/F value, indicating that apatite in chondrites is fluorine poor because the solar system has about an order of magnitude more CI than F. The CI/F ratio of the solar system was combined with known apatite-melt partitioning relationships for F and CI to predict the range of apatite compositions that would form from a melt with a chondritic CI/F ratio. This range of apatite compositions allowed for the development of a crude model to use apatite X-site compositions from achondrites (and chondrite melt rocks) to determine whether they derive from a volatile-depleted and/or differentiated source, albeit with important caveats that are detailed in the manuscript. This study further highlights the utility of apatite as a mineralogical tool to understand the origin of volatiles (including H$_2$O) and the diversity of their associated geological processes throughout the history of our solar system, including at its nascent stage.

Keywords: CK chondrite, R chondrite, phosphate, volatiles, chlorine, fluorine, water; Experimental Halogens in Honor of Jim Webster

INTRODUCTION

The mineral apatite [Ca$_5$(PO$_4$)$_3$(F,Cl,OH)] is one of the primary mineralogical reservoirs for phosphorus on Earth (Piccoli and Candela 2002), and it is a common phosphate mineral within a broad range of extraterrestrial samples (e.g., McCubbin and Jones 2015). Naturally occurring apatite hosts F, Cl, and OH as essential structural constituents (ESC), and all three make up the apatite end-members fluorapatite, chlorapatite, and hydroxylapatite, respectively (Hughes et al. 1989, 1990). In addition to the full ternary solution in the F-Cl-OH apatite system, natural apatite can host a wide range of anions and/or molecules in this anion site (henceforth referred to as the X-site), including Br$^-$, I$^-$, S$_2^-$, O$_2^-$, CO$_3^{2-}$, and H$_2$O among others (Brounce et al. 2019; Fleet et al. 2004; Hughes and Rakovan 2015; Mason et al. 2009; Pan and Fleet 2002; Schettler et al. 2011), potentially making it a broadly applicable mineralogical tool to understand volatile abundances and processes in Earth and planetary systems. In fact, apatite has gained prestige over the last two decades as one of the only volatile-bearing minerals that occurs within a broad array of astromaterials (e.g., McCubbin and Jones 2015). However, as its name implies (i.e., the name apatite is derived from the Greek verb “to deceive” (Patrick and Martine 2015)), apatite has also gained notoriety as being a particularly difficult phase to analyze and interpret (e.g., Boyce et al. 2014; Černok et al. 2019; Goldoff et al. 2012; McCubbin et al. 2010; Stock et al. 2015; Stormer et al. 1993; Webster and Piccoli 2015). Nonetheless, substantial progress has been achieved in developing apatite as a quantitative tool to understand the origin, abundances, and isotopic compositions of volatiles in Earth and planetary systems.