VARIATIONS IN APATITE F, Cl, AND OH ABUNDANCES IN PRIMITIVE ACHONDRITES: EVIDENCE OF FRACTIONAL MELTING? F. M. McCubbin[1], J. W. Boyce[1], B. A. Anzures[2], T. J. Barrett[3], J. J. Barnes[4], N. G. Lunning[1], K. T. Tait[5], R. Tartèse[6], and J. M. D. Day[7], [1]NASA Johnson Space Center, Mailcode XI, 2101 NASA Parkway, Houston, Texas 77058, U.S.A., [2]Jacobs, NASA Johnson Space Center, 2101 NASA Parkway, Houston, Texas 77058, U.S.A. [3]Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston, Texas 77058, U.S.A., [4]Lunar and Planetary Laboratory, University of Arizona, 1629 E University Boulevard, Tucson, Arizona 85721, U.S.A., [5]Department of Natural History, Royal Ontario Museum, 100 Queen's Park, Toronto, Ontario M5S 2C6, Canada, [6]Department of Earth and Environmental Sciences, The University of Manchester, Manchester M13 9PL, UK. [7]Scripps Institution of Oceanography, University of California San Diego, La Jolla, California 92093, U.S.A. (francis.m.mccubbin@nasa.gov).

Introduction: The apatite group minerals [$Ca_5(PO_4)_3(F,Cl,OH)$] are some of the primary mineralogical reservoirs for phosphorus on Earth [1] and a common phosphate mineral within a broad range of extraterrestrial samples [e.g., 2]. Naturally occurring apatite hosts F, Cl, and OH as essential structural constituents, and all three make up the apatite endmembers fluorapatite, chlorapatite, and hydroxylapatite, respectively. Although apatite is one of the most common phosphate minerals in meteorites and rocks from Earth, it typically occurs at minor to trace abundances. Apatite has been widely used as a mineralogical tool to probe the interiors of both differentiated and undifferentiated parent bodies for information about volatiles [2]; however, little work has been done on apatite F, Cl, and OH abundances of apatite from primitive achondrite meteorites.

There are broad differences between apatite X-site chemistry in chondrite parent bodies (typically F-poor [3, Fig. 1]) compared to apatite from basaltic rocks from many achondrite parent bodies (Cl-poor, apart from Mars [2, 3]). These differences could indicate that
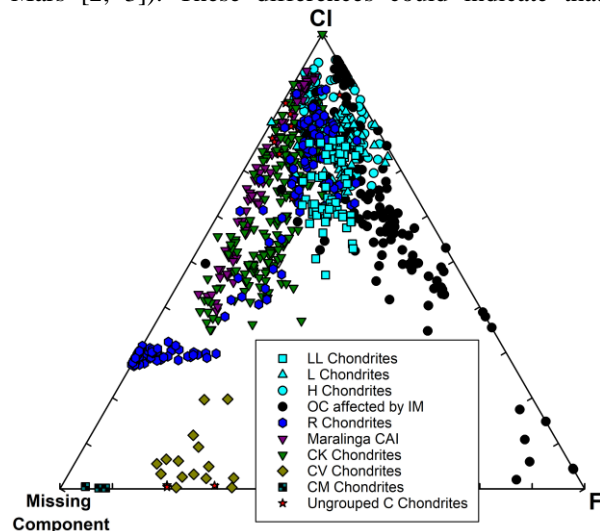

Figure 1. Ternary plot of apatite X-site components (mol%) from chondrite meteorites [3-14]. The missing component was calculated based on 1 – F – Cl = missing component.

planetary differentiation processes, namely melting, play an important role in the evolution of apatite X-site chemistry. In fact, some ordinary chondrite meteorites that exhibit evidence of minor impact melting have apatite with X-site compositions that are much more F-rich than typical chondrite apatite [3]. McCubbin et al., [3] hypothesized that the F-rich compositions of the apatite in ordinary chondrites affected by impact melting could be the result of apatite partially melting, driving the residual apatite to more F-rich compositions; however, they also indicated that degassing of the more volatile Cl and H may also contribute to the F-enrichment.

To further test the partial melting hypothesis, we investigate the F, Cl, and OH (by difference) abundances of apatite from primitive achondrite parent bodies given that they are thought to come from partially differentiated parent bodies that represent residues after partial melting. Consequently, their apatites could provide valuable insights into the effects of melting on apatite X-site chemistry. In this study, we report F and Cl abundances of apatite from a broad array of primitive achondrite meteorites, and we develop a model for apatite fractional melting using known apatite-melt partitioning relationships [15-16]. Together, we use these results to further elucidate the role of melting on apatite X-site compositions.

Methods: Major and minor element compositions of apatite were acquired by electron probe microanalysis using a JEOL 8530 field emission electron microprobe from NASA Johnson Space Center using methods like those described in [3, 17].

Results: We combined previously published data on apatite X-site chemistry from primitive achondrites with new data collected as part of this study to understand the distribution in X-site chemistry exhibited by apatite from primitive achondrite parent bodies. These data indicate a broad range of compositions that include ternary apatite that are Cl-rich (brachinites and brachinite-like meteorites) to OH-poor apatite with a wide range of F/Cl ratios that span the chlorapatite-fluorapatite join (all primitive achondrite samples) (Fig.

2). Hydrogen was not measured directly in this study, so the missing component could be OH, or it could indicate the presence of other *X*-site anions and/or structural vacancies.
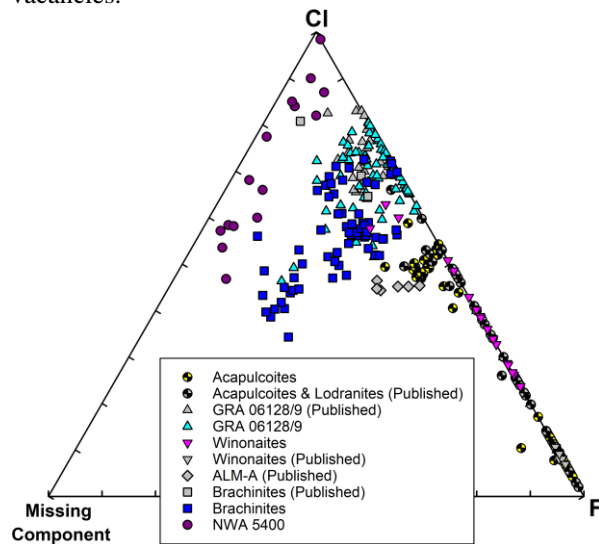

Figure 2. Ternary plot of apatite *X*-site components (mol%) from primitive achondrite meteorites collected during this study (in color) and from the literature (in grey [7, 18-30]). The missing component was calculated based on 1 – F – Cl = missing component.

Fractional Melting Model: To assess the effects of residual apatite compositions after partial melting of apatite, we used apatite-melt partitioning relationships [15-16] to construct a fractional melting model (Fig. 3).
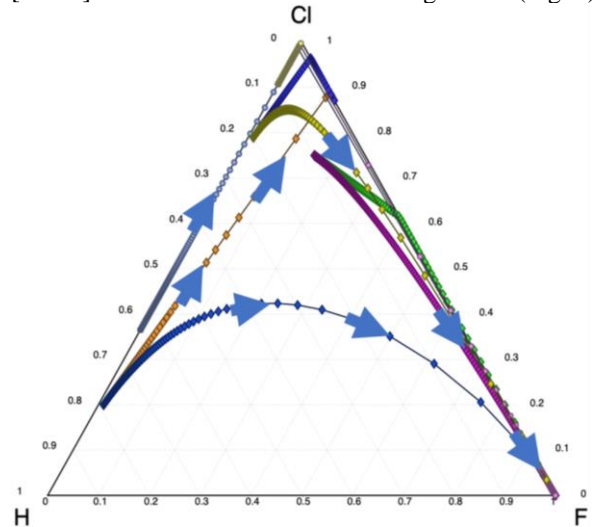

Figure 3. Ternary plot of apatite *X*-site components (mol%) indicating the path of residual apatite *X*-site evolution during fractional melting (model modified from [31]). The blue arrows indicate the direction of evolution along each array (all data points from an individual array are plotted in the same color and connected with a line).

This model indicates that residual apatite compositions evolve toward F-rich compositions as they melt, although they will dehydrate toward the F/Cl join at a faster rate than the F/Cl ratio increases.

Discussion: The variation in apatite *X*-site composition exhibited by primitive achondrites and chondrites that have experienced minor impact melting is consistent with the variation that would be induced by fractional melting of apatite that had starting compositions within the broad field of chondrite apatite compositions. This consistency indicates that more detailed textural and chemical studies are warranted to understand the effects of melting on residual apatite compositions in primitive achondrites and chondrites affected by minor impact melting. For example, we would expect the F/Cl ratio of apatite in these samples to positively correlate with other compatible/ incompatible element ratios in apatite. Furthermore, we expect that larger apatite grains may exhibit reverse zoning with rims that have higher F/Cl than their corresponding grain cores. These additional textural and chemical investigations are underway.

Importantly, fractional melting of initially chondrite-like apatite cannot explain the differences in apatite compositional variations exhibited by chondrites and basaltic achondrites (poor in Cl and large range in F-OH [2-3] apart from Mars), indicating that other processes are required to explain their differences.

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