

ENDOGENOUS LUNAR VOLATILES: INSIGHTS INTO THE ABUNDANCES OF VOLATILES IN THE MOON FROM LUNAR APATITE. F. M. McCubbin, NASA Johnson Space Center, Mailcode XI2, 2101 NASA Parkway, Houston, Texas 77058, USA (email: francis.m.mccubbin@nasa.gov).

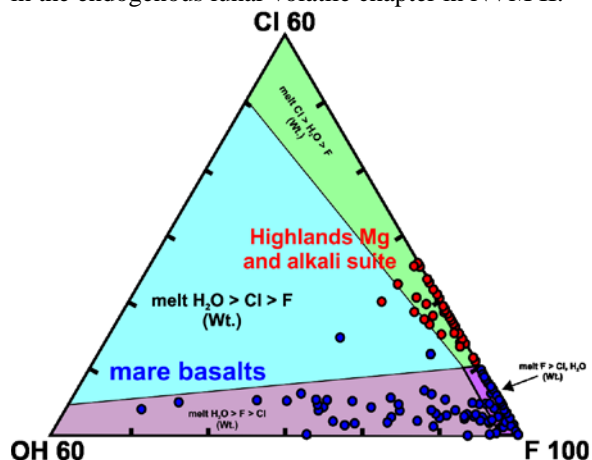
Introduction: At the time of publication of *New Views of the Moon* [1], it was thought that the Moon was bone dry with less than about 1 ppb H₂O. However in 2007, initial reports at the 38th Lunar and Planetary Science Conference speculated that H-species were present in both apatites [2] and pyroclastic volcanic lunar glasses [3]. These early reports were later confirmed through peer-review [4-8], which motivated many subsequent studies on magmatic volatiles in and on the Moon within the last decade. Some of these studies have cast into question the post-Apollo view of lunar formation, the distribution and sources of volatiles in the Earth-Moon system, and the thermal and magmatic evolution of the Moon. The mineral apatite has been one of the pillars of this new field of study, and it will be the primary focus of this abstract. Although apatite has been used both to understand the abundances of volatiles in lunar systems as well as the isotopic compositions of those volatiles, the focus here will be on the abundances of F, Cl, and H₂O.

Apatite in lunar rocks: Apatite, ideally Ca₅(PO₄)₃(F,Cl,OH), is the most common volatile-bearing mineral in lunar rocks and along with merrillite, makes up the primary reservoir for phosphorus and rare earth elements on the Moon [9]. Apatite occurs in nearly all lunar rock types (apatite has not been reported in ferroan anorthosites or volcanic glass beads), but the ubiquity of apatite in lunar samples should not be misconstrued as apatite being abundant because it is always a trace mineral and can be somewhat elusive in many samples. Nonetheless, a substantial amount of new data on lunar apatite have emerged in the last decade from both electron probe microanalysis (EPMA) and secondary ion mass spectrometry (SIMS) instruments, in part due to the recent development of high quality apatite standards [9]. One can now begin to assess the variability of apatite occurrences and compositions among the various lunar rocks types [9].

Apatites in lunar samples range in crystal habit from anhedral to euhedral and range in size from sub-micron to 2 mm [9]. Many of the anhedral apatites are clearly late-crystallizing phases that are filling the available space interstitial to the earlier formed phases. Although there has been one report of a chlorapatite in sample 14161, 7062b [9], and hydroxylapatite has been reported in the brecciated matrix of Northwest Africa (NWA) 773 [9], nearly all of the apatites that have been analyzed in lunar samples are fluorapatite [9]. However, within the fluorapatite field there is substan-

tial compositional variability in the volatile abundances of apatite that correlates with lunar rock type (Figure 1). Specifically, apatite grains in mare basalts typically contains little chlorine (Figure 1), and many of the grains have elevated hydroxyl abundances (Figure 1). Apatite grains in the magnesian suite, alkali suite, and KREEP-rich impact melts are enriched in chlorine compared to mare basalts, and they typically have much lower water contents (Figure 1). A compilation of apatite F-Cl-OH components from mare basalts and highlands alkali and Mg suite samples are presented in Figure 1, which was used to demonstrate a heterogeneous distribution of volatiles in the lunar interior [9].

Conclusion: This work demonstrates the utility of apatite in advancing our understanding of lunar volatiles, hence apatite should be among the topics covered in the endogenous lunar volatile chapter in NVM II.



Truncated ternary plot of apatite X-site occupancy (mol%) from highlands apatite and mare basalt apatite plotted on the relative volatile abundance diagram from [10]. The solid black lines delineate fields of relative abundances of F, Cl, and H₂O (on a weight basis) in the melt from which the apatite crystallized. The diagram was constructed using available apatite/melt partitioning data for fluorine, chlorine, and hydroxyl [11-12].

References: [1] Jolliff et al (2006) *RiMG* 60 721 pp [2] McCubbin et al (2007) *37th LPSC* #1354 [3] Saal et al (2007) *37th LPSC* #2148 [4] Saal et al (2008) *Nature* 454, 192-195 [5] McCubbin et al (2010) *PNAS* 107, 11223-11228 [6] Boyce et al (2010) *Nature* 466, 466-469 [7] Greenwood et al (2011) *Nat. Geosci.* 4, 79-82 [8] Tartèse et al (2013) *GCA* 122, 58-74 [9] McCubbin et al (2015) *Am. Min.* 100, 1668-1707 [10] McCubbin et al (2013) *MAPS* 48, 819-853 [11] McCubbin et al (2015) *Am. Min.* 100, 1790-1802 [12] Boyce et al (2014) *Science* 344, 400-402