

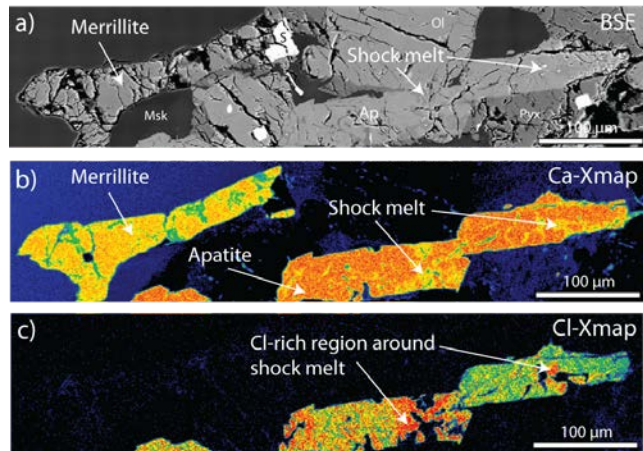
**APATITE AND MERRILLITE PETROGENESIS IN THE NEW ENRICHED LHERZOLITIC SHERGOTTITE NWA 7755.** G.H. Howarth<sup>1</sup>, J.F. Pernet-Fisher<sup>1</sup>, R.J. Bodnar<sup>2</sup>, and L.A. Taylor<sup>1</sup>. <sup>1</sup>Planetary Geosciences Institute, Earth and Planetary Sciences Dept., The University of Tennessee, Knoxville, TN, 37996 USA. <sup>2</sup>Department of Geosciences, Virginia Tech, Blacksburg, VA 24061, USA.

**Introduction:** North West Africa 7755 is a new example of an enriched lherzolitic shergottite, the fourth of its group described in detail. The meteorite is composed of coarse-grained pyroxene oikocrysts containing high Fo olivine and chromite chadacrysts set in a groundmass of abundant lower Fo, euhedral olivine, low- and high-Ca pyroxene, maskelynite, phosphates, spinel, ilmenite, and sulfide. The main difference in the mineralogy relative to the other enriched lherzolites is the presence of coarse-grained (up to 500  $\mu\text{m}$ ) apatite.

We report detailed mineral chemistry and REE abundances in merrillite and apatite in order to constrain the petrogenesis of phosphates in enriched shergottites. Apatite is the major volatile-bearing phase in shergottites and constraining the petrogenesis will further aid in interpreting the volatile evolution of martian magmas.

**Analytical Techniques:** Apatites in this study were analysed using a CAMECA SX-100 EMP at the University of Tennessee following the methodology outline by Goldoff et al. [1]; who showed that the most accurate results for apatite analyses are obtained using an acceleration voltage of 10 kV with a 4 nA beam current for F, Cl, and Na first, followed by analysis of P, Si, Fe, Mg, Mn, and Ca at 15 kV and a 20 nA beam current. All analyses were conducted with a defocused 10  $\mu\text{m}$  beam and peak and background counting times of 30 s and 15 s, respectively. All other analyses in silicate minerals were done using standard microprobe protocols. Trace-element concentrations were analysed using the Agilent 7500 ce inductively coupled plasma – mass spectrometer (ICP-MS), attached to an Excimer 193 nm ArF GeoLasPro laser ablation (LA) system, and housed at Virginia Tech. A similar protocol to that used in Howarth et al. [2] was followed.

**Petrography and Mineral Chemistry:** Apatite and merrillite are discriminated based on the presence of volatiles F and Cl, as well as lower CaO and P<sub>2</sub>O<sub>5</sub> and higher Na<sub>2</sub>O and MgO in merrillite. Phosphate abundance is ~2 vol.% with a merrillite:apatite ratio of 3:1. Composite merrillite-apatite grains are observed; in these cases, the merrillite is generally observed at the grain terminations and around the margins of the apatite. In addition, the apatite has undergone partial shock melting, which has resulted in irregular patches of devolatilized material with CaO content similar to that of merrillite (Fig. 1).



**Fig. 1.** BSE image and X-ray maps of a representative apatite grain illustrating the occurrence of shock related melts and associated Cl-enrichment surrounding them.

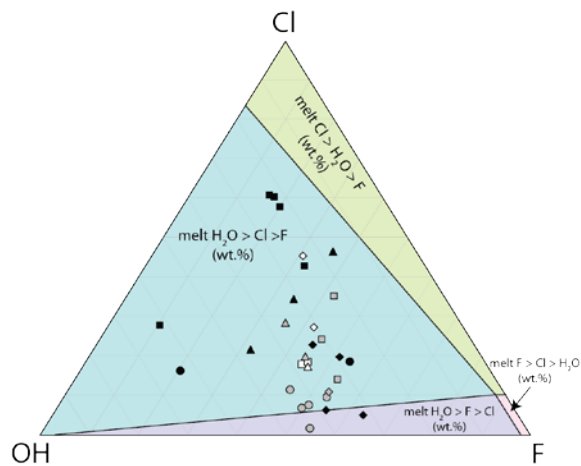
Apatites have variable F and Cl abundances. Fluorine ranges from 0.4 to 2.3 wt.% and chlorine from 0.4 to 4 wt.%, and variation is observed within single grains (Fig. 1 and 2). Chlorine-rich zones are observed in association with shock melted portions of the apatite, which results in the highly variable volatile contents analyzed (Fig. 1).

Merrillite has higher REE abundances than apatite with little variation between grains. The REE are ~1000 x CI-chondrite, with minor negative Eu anomalies ( $\text{Eu}/\text{Eu}^* \sim 0.7$ ) (Fig. 3). Apatite contains REE abundances of 70-600 x CI-chondrite and considerable variable Eu anomalies ranging from  $\text{Eu}/\text{Eu}^* 0.1$  to 1 (Fig. 3).

#### **Discussion:**

**Timing of Phosphate Crystallization.** In previous studies, it has been shown that merrillite generally crystallizes before apatite [4, 5]. However, the presence of apatite with merrillite around the margins suggests that apatite formed first, which is also consistent with Eu anomalies in the phosphates. Merrillite is characterized by minor negative Eu anomalies suggesting crystallization at a relatively late stage post-dating the onset of plagioclase. The variable Eu anomaly observed for apatite suggests initial crystallization pre-dating that of plagioclase (grains without Eu anomalies; Fig. 3b) and continuing during plagioclase crystallization (grains with Eu anomalies; Fig. 3b). The correlation of LREE abundances and Eu anomalies in apatites is consistent with apatite crystallization over a large temperature

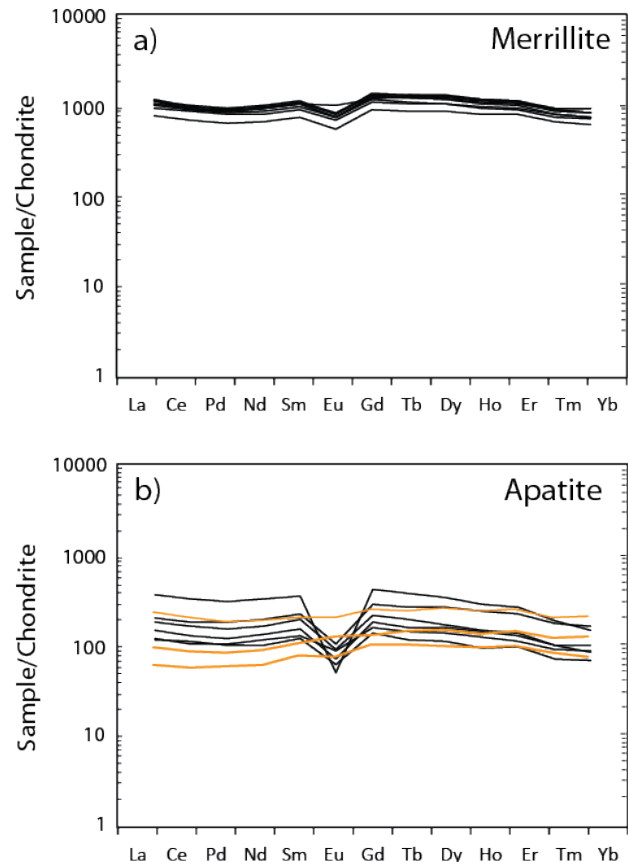
interval during Eu depletion and LREE enrichment of the residual liquid. Therefore, it appears that apatite crystallized prior to merrillite and continued to crystallize/equilibrate with the evolving residual liquid.



**Fig. 2.** Volatile ternary for apatites. Individual symbols represent multiple analyses for single apatite grains. OH was calculated based on stoichiometry. Fields of relative volatile abundances after McCubbin et al. [3].

*Volatile contents of REE Enriched Magmas.* Apatite is the major volatile-bearing phase in the groundmass of enriched shergottites, and is crucial in understanding the evolution of the volatiles in the evolving melt. In typical terrestrial basaltic magmas, early formed apatite is F-rich evolving to more Cl-rich composition at later stages. However, it has been suggested that martian magmas are Cl-rich relative to typical basaltic systems [6], which may result in Cl-rich apatite forming earlier. The volatile content of the apatite in NWA 7755 overlap with those of other martian meteorites, such as NWA 6234 [4]. Using the ternary diagram of McCubbin et al. [3] (Fig. 2), the apatite in NWA 7755 indicate crystallization from a liquid dominated by H<sub>2</sub>O (melt H<sub>2</sub>O > Cl > F; Fig. 2).

Several processes are able to modify the proportions of volatiles within a magma and can result in zoned volatile contents in apatite, for example: 1) degassing; Cl preferentially partitions into the fluid phase relative to F and is lost from the system [e.g., 4, 5] and 2) Introduction of Cl- and REE-rich fluids from deeper within the cumulate system, resulting in re-equilibration to more Cl-rich compositions [e.g., 7]. However, the clear spatial association of shock melted apatite and Cl enrichment indicates volatile alteration in apatite through shock melting. Several apatite grains show no petrographic features of shock melting



**Fig. 3.** REE profiles for Merrillite and Apatite.

and no heterogeneous Cl distribution. Therefore, these grains represent primary unaltered apatite and indicate the volatile content of the parental magma; they have volatile ratios of Cl:F:OH of 10:54:36 (Fig. 2). These primary apatites plot close to the F-OH dominated region of Fig. 2 with low Cl component (<10) relative to other shergottites. Therefore, we show that the primary apatite composition of NWA 7755 is significantly less Cl-rich than previously reported and that Cl contents can be significantly altered during shock metamorphism. The effects of shock metamorphism on apatite volatile contents in shergottite meteorites need to be carefully evaluated in the future prior to interpretation.

**References:** [1] Goldoff B. et al. (2012) *Amer.Min.*, 97, 1103–1115. [2] Howarth G.H. et al. (2014) *Meteoritics & Planet. Sci.*, 49, 1812–1830. [3] McCubbin et al. (2013) *Meteoritics & Planet. Sci.*, 48, 819–843. [4] Gross J. et al. (2013) *EPSL*, 369–370, 120–128. [5] Shearer C.K. et al. (2014) *Meteoritics & Planet. Sci.*, DOI: 10.1111/maps.12355. [6] Filiberto J. and Treiman A.H. (2009) *Geology*, 37, 1087–1090. [7] McCubbin F.M and Nekvasil H. (2008). *Amer.Min.*, 93, 676–684.