

Cl-rich britholite substitution in apatite of high-titanium basalt 75055: A chlorine and REE-enriched phase of lunar phosphates. M. Lowe¹, S. Mahmood¹, B. McKeeby¹, and J. P. Greenwood¹. ¹Department of Earth & Environmental Sciences, Wesleyan University, 265 Church Street, Middletown, Connecticut 06459, USA. (me-low@wesleyan.edu).

Introduction: Understanding the volatile contents of lunar magmas is important in investigating the formation of both the Earth and Moon, as well as the origin of indigenous water on these planetary bodies. Recent research has shown phosphate minerals in lunar samples contain hydrogen, fluorine, and chlorine; indicating that the early moon was much wetter and more volatile-rich than previously understood [1]. The fact that these minerals form and contain these elements suggests that the magma was sufficiently enriched in volatiles and enough remained late in the crystallization process to form these volatile-bearing phosphates even with the lack of an atmosphere on the moon. We studied a rare earth element (REE) and silica-rich component of lunar phosphates with the intention of identifying its mineralogy and halogen site composition.

Methods: Analysis of lunar high-titanium Apollo 11 and 17 basalts was performed using the Yale FEG-electron microprobe, Wesleyan JEOL LV SEM with EDAX Genesis and a Wi-Tec alpha300R confocal Raman microscope system equipped with a 50 mW frequency doubled 532nm Nd:YAG excitation laser at the Stony Brook University Vibrational Spectroscopy Laboratory. The primary sample under analysis was Apollo 17 basalt 75055,50. We analyzed spectral data from SEM and Raman microscopy and elemental abundance measurements from electron microprobe analysis and WDS elemental mapping.

Results: We find a volatile-bearing REE-enriched phosphate unique from previously described apatite or merrillite. Figure 1 is a BSE image of the preliminary grain of interest showing approximate locations of study. The evolving composition of this phosphate grain is seen in Figure 2 with elemental abundance determined through electron microprobe analysis. With increased crystallization, further silica and REE-replacement of phosphate and calcium occurs. Additionally, as this silica-enrichment occurs, the mineral becomes increasingly chlorine-rich as seen in the Cl K α WDS map in Figure 3. Additional analysis using SEM spectra was employed to determine the other potential REE substituents and to evaluate other lunar samples for REE-enrichment and silica replacement in apatite. In a brief evaluation of three more lunar samples, thin sections 10044,12, 75035,79, and 10047,228, substantial REE-zoning was found and preliminary SEM spectral analysis showed a corresponding increase in silica content.

Preliminary Raman analysis indicated the presence of REE's in the broad luminescent peak at

1600-2400 cm⁻¹ (Fig. 4). Two distinct peaks appeared above background radiation with similar locations to those seen in the Ce-fluorbritholite data on RRUFF. Figure 4 shows three of these spectra obtained from the REE-rich grain. Further Raman analysis of other zoned apatite grains and terrestrial britholite samples will be obtained for further study. When overlaid with fluorapatite spectra (Figure 4B), the 950cm⁻¹ peak matched but the smaller but still distinct 840cm⁻¹ peak was missing. Ce-fluorbritholite from the RRUFF database matches both peaks but the relative intensities of the lunar sample peaks are nearly equal in contrast to the disparity between the 840cm⁻¹ and 950cm⁻¹ britholite peaks (Figure 4C). Location 75_q represents a more apatite-rich area of the grain while 75_m and 75_n are more fully in the REE-enriched section. There was no indication of an OH peak in the extended spectral analysis reaffirming the initial microprobe findings of primarily fluorine and chlorine in the halogen site.

Discussion: We found evidence of a F,Cl-bearing and REE-enriched phosphate in high-titanium basalts suggesting that substantial REE-replacement of Ca²⁺ was occurring in combination with silica and chlorine enrichment. Descriptions and analysis of REE-enrichment of lunar phosphates has been explored before in Apollo 14 granites with similar indications of chlorine enrichment [2]. However, there has been limited exploration of the necessary silica-enrichment to stabilize the Ca²⁺ replacement with REE³⁺.

Britholite is a terrestrial REE-bearing phosphate mineral with a similar structure to apatite but substitutes REE's for Ca and SiO₄ for PO₄. Apatite: Ca₅(PO₄)₃ (F,Cl,OH). Britholite: (REE, Ca)₅(SiO₄, PO₄)₃ (OH,F). Within the phosphate group, there is coupled substitution of REE³⁺ + Si⁴⁺ for Ca²⁺ + P⁵⁺ [3]. Our Raman spectra indicates that the zoning in these phosphates is more closely related to britholite than apatite. Terrestrial britholite is not described with chlorine in the halogen site as seen in the ideal formula above. Therefore, the Moon may represent a unique environment where REE-enrichment of phosphates is accompanied by chlorine halogen site occupation.

Terrestrial britholite forms through extreme fractionation or metasomatism and is primarily found in highly differentiated alkaline pegmatites or metasomites [4,5]. Our research indicates that there is a previously unrecognized britholite-like phosphate phase on the moon. This zonation and replacement of silica for phosphate and the increasing quantities of rare earth elements show that there was extreme fractional crys-

tallization in the high titanium mare basalts and that even in late stages of crystallization, volatiles were incompletely degassed.

Future Work: We plan to carry out additional analyses using Raman spectroscopy and microprobe analysis to explore if the F,Cl-britholite phase is common in high titanium mare basalt phosphates.

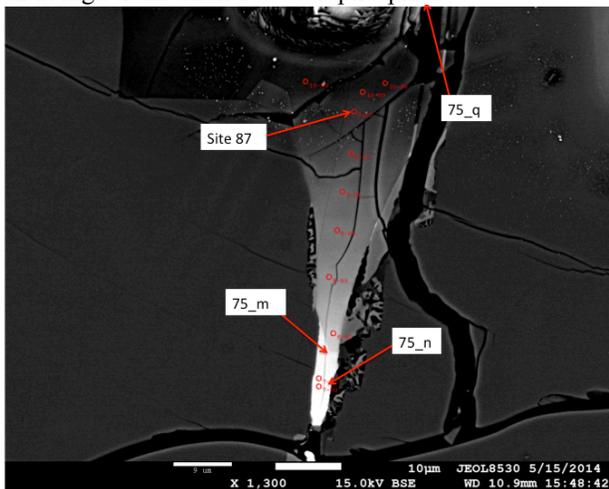


Figure 1: BSE image of apatite in 75055,50 with studied locations

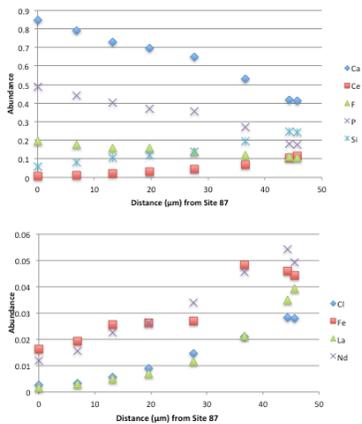


Figure 2: Elemental weight percent abundances from electron microprobe analysis.

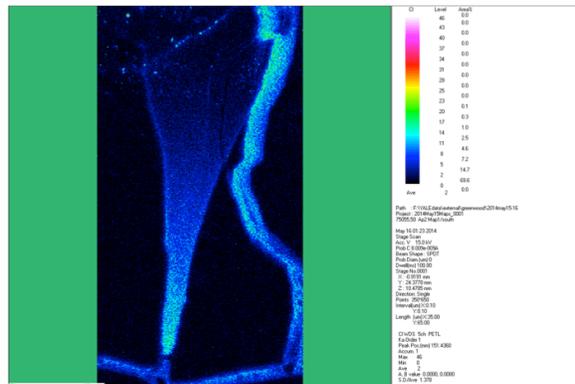


Figure 3: Chlorine Kα WDS elemental map. Chlorine is seen to increase as britholite component increases (Fig. 1 and 2).

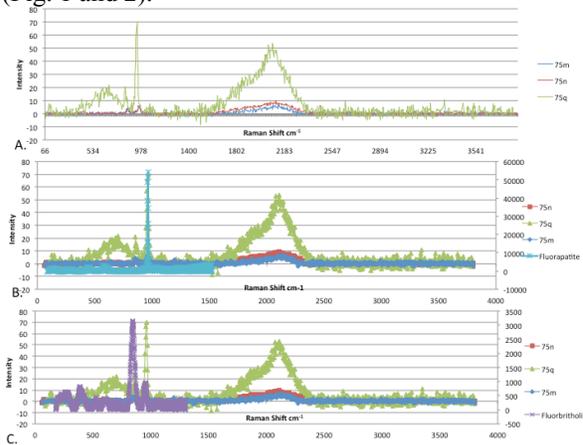


Figure 4: Raman spectra from 75055,50 with RRUFF data on apatite and Ce-britholite

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