

**AUTO-METASOMATISM OF THE WESTERN LUNAR HIGHLANDS: RESULT OF CLOSED SYSTEM FRACTIONATION AND MOBILIZATION OF A KREEPY TRAPPED LIQUID.** SHERVAIS, John W., Department of Geological Sciences, University of South Carolina, Columbia SC 29208 and VETTER, Scott K., Department of Geology and Geography, Centennial College, Shreveport, LA 71134.

The discovery of REE-rich phosphates (dominantly whitlockite) in pristine, non-mare rocks of the western lunar nearside (Apollo 14, Apollo 12, and most recently, Apollo 17) has created a paradox for lunar petrologists. These phases are found in feldspar-rich cumulates of both the Mg-suite and the Alkali suite, which differ significantly in their mineral chemistries and major element compositions [1-7]. Despite the differences in host rock compositions, whitlockites in both suites have similar compositions, with LREE concentrations around 21,000 to 37,000 x chondrite [1-5]. Simple modeling of possible parent magma compositions using the experimental whitlockite/liquid partition coefficients of Dickinson and Hess [8] show that these REE concentrations are too high to form from normal lunar magmas, even those characterized as "urKREEP" [1-5].

These phosphates pose two separate problems: how to account for KREEPy trace element characteristics in primitive rocks of the Mg-suite (plagioclase An<sub>94</sub>) [3,4], and how to account for the occurrence of whitlockites with similar compositions in more evolved rocks of the alkali suite (plagioclase An<sub>82</sub>) [1-7]. Proposals which focus on the effects of KREEP assimilation by the parent magmas can explain the presence of KREEPy trace element patterns in both primitive Mg-suite rocks and evolved Alkali suite rocks, but they cannot resolve the "concentration problem" [1-4,7]. Similarly, previous proposals for the influx of an REE-rich metasomatic fluid have failed to address the question of how this fluid is derived, and where it comes from [2-4,7]. In contrast, Neal and others [5,6] have recently proposed that metasomatism of western highland cumulates occurs by the process of "REEP-frac metasomatism", where their hypothetical REEP-frac component forms by silicate liquid immiscibility fractionation of an urKREEP parent magma. This urKREEP represents extreme magma ocean fractionation, and the REEP-frac component is considered to enter the highland cumulates after crystallization is complete [5,6].

We present here an alternative hypothesis, which we proposed orally at the LPSC XXI, whereby REE-rich whitlockites in both suites form through a process of auto-metasomatism. By this we refer to metasomatic fluids derived from closed system fractionation of KREEPy trapped liquids which are mobilized along grain boundaries and fractures shortly before complete crystallization and thermal equilibration of the cumulates. The occurrence of KREEPy trapped liquids in both suites is attributed to assimilation of KREEPy wall rocks or mixing with a KREEP-rich residual magma [1-4,7]. Alternatively, the Alkali suite cumulates may have formed from a KREEP parent magma [7].

*Petrographic evidence for metasomatic origin:* Whitlockites of the Mg-suite occur most commonly as subequant interstitial grains in anorthosites, troctolites, or norites [3-5]. In the magnesian anorthosite 14321,1211/1273 [3,4], whitlockite occurs in a zone of recrystallized plagioclase with a polygonal-mosaic texture which cuts across large, finely twinned plagioclase primocrysts. In the Alkali suite, whitlockites occur both interstitially

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[1,9] and, rarely, as inclusions in plagioclase primocrysts [2]. The whitlockite inclusion in 14305,400 was originally interpreted to require a parent magma saturated in phosphate early in its crystallization history [2]. A closer examination, however, shows that this inclusion occurs along a healed fracture in the plagioclase primocryst, as shown by the offset in twin lamellae. Thus, the evidence seems to suggest that whitlockite formed late in the crystallization history of the rocks (unsurprisingly), and possibly after initial crystallization was more-or-less complete. While the petrographic data do not confirm a metasomatic origin for the whitlockite, they are compatible with such an interpretation.

*Whitlockite saturation and REE enrichment factors:* Dickinson and Hess [8] show that whitlockite saturation varies with  $P_2O_5$  concentration,  $SiO_2$ , and temperature. They show that, in basaltic rocks, whitlockite saturation requires around 4.5 wt%  $P_2O_5$ ; at slightly higher silica contents and lower temperatures which may be appropriate for KREEP, Warren et al [1] estimate whitlockite saturation at about 3.2 wt%  $P_2O_5$ . These saturation levels are 4x to 6x higher than estimated for high-K KREEP [9]. This would require 75% to 85% closed system fractionation of a KREEPy trapped liquid component. By comparison, Neal and others [5] calculate that the liquid from which these whitlockites crystallized was 4x to 10x more enriched in REE than typical KREEP compositions. Since bulk partition coefficients for the REE are probably  $< 0.1$  before whitlockite saturation, this would require 75% to 90% closed system fractionation – about the same enrichment required for whitlockite saturation. Thus, it appears that the similarity of whitlockite compositions in Mg-suite and alkali suite cumulates is a function of the similar enrichment factors for  $P_2O_5$  and REE, assuming a trapped liquid component with KREEPy trace element ratios. Differences in  $P_2O_5$  and REE concentrations in the respective trapped liquids (i.e., dilute KREEP vs concentrated KREEP) control only the amount of closed system fractionation required. This may explain the more common occurrence of whitlockite in alkali suite cumulates relative to Mg-suite rocks.

*Auto-metasomatism and heterogeneous phase distribution:* An important aspect of this model is that mobilization of the metasomatic fluids leads to a heterogeneous distribution of accessory phases which control incompatible trace element concentrations. Analysis of small, non-representative samples leads to trace element concentrations and ratios which are not representative of the initial magma or of simple closed system crystallization. Depending on the length scale of metasomatism, the average sample size required to recapture the trace element systematics of the magma system could be quite large. The fact that many whole rock samples of pristine highland cumulates *do* retain relatively consistent trace element systematics suggests that this process, while important locally, does not control the trace element geochemistry of the highlands.

*References:* [1] Warren et al, 1983, *PLPSC 14* in *JGR* 88, B151-B164. [2] Shervais et al, 1984, *PLPSC 15* in *JGR* 89, C25-40. [3] Lindstrom et al, 1984, *PLPSC 15* in *JGR* 89, C41-49. [4] Lindstrom et al., 1985, *LPS XVI*, 493-494. [5] Neal et al, 1990, *LPS XXI*, 863-864. [6] Neal & Taylor, 1990, *LPS XXI*, 851-852. [7] Shervais, 1989, *LPI Tech. Report 89-03*, Lunar and Planetary Institute, Houston, 118-127. [8] Dickinson & Hess, 1982, *LPS XIII*, 172-173. [9] Warren, 1988, *LPI Tech. Report 89-03*, Lunar and Planetary Institute, Houston.