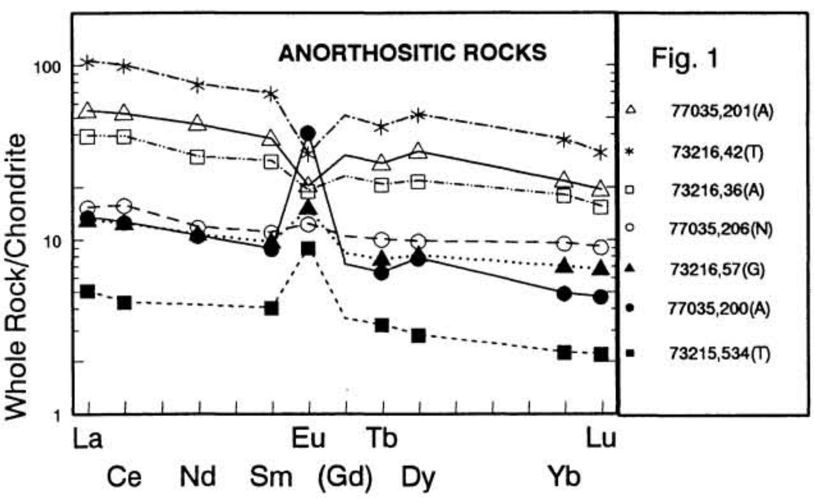
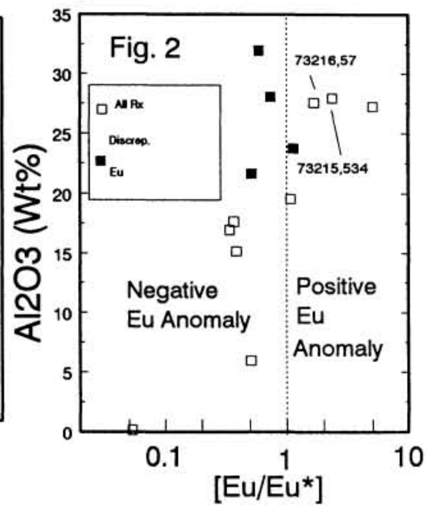
ANORTHOSITES WITH NEGATIVE Eu ANOMALIES IN APOLLO 17 BRECCIAS: FURTHER EVIDENCE FOR "REEP" METASOMATISM; James O. ECKERT, Jr., Lawrence A. TAYLOR, Clive R. NEAL*, and Allan D. PATCHEN, Department of Geological Sciences, Univ. of Tennessee, Knoxville, TN 37996; *Present address: Department of Earth Sciences, Univ. of Notre Dame, Notre Dame, IN 46556

Many Mg-suite rocks of the lunar highlands exhibit evolved whole-rock REE patterns (i.e. high REE abundances, LREE enrichment, and deep negative Eu anomalies) which are dichotomous with the relatively primitive nature of the mineral chemistry [1,2,3,4,5]. This discrepancy, which includes anorthosites and plagioclase-rich troctolites and norites with negative Eu anomalies, is reconciled by the presence of whitlockite, which is extremely enriched in all REE except Eu [1,2,3,4,5]. Such REE-rich phosphate was recognized in early documentation of pristine magnesian anorthosites with evolved trace-element signatures [2].

APOLLO 17 ANORTHOSITIC CLASTS. We have presented elsewhere in this volume [6] the mineralogy, petrography, and geochemistry for 13 cumulate lithologies from clasts in Apollo-17 breccias 73215, 73216, and 77035. Three anorthosites and four other anorthositic rocks are highlighted here. Criteria for a cumulate origin of these anorthositic rocks are similar to those applied by Haskin et al. [7], including mineralogy, relict medium to coarse grain size in most samples, relict cumulate textures in gabbro 73216,57 and noritic anorthosite 73216,36, and, in some cases, calcic (An_{96-98}) plagioclase and magnesian olivine. In 73216,57, distinct tabular to subequant, zoned chadocrysts of plagioclase, to ~1 x 1.5 mm, are surrounded by oikocrystic clinopyroxene and orthopyroxene, indicating an origin by plagioclase accumulation [6]. In 73216,36, a less distinct but still evident relict cumulate texture (plagioclase chadocrysts and orthopyroxene oikocrysts) also indicates formation by plagioclase accumulation.

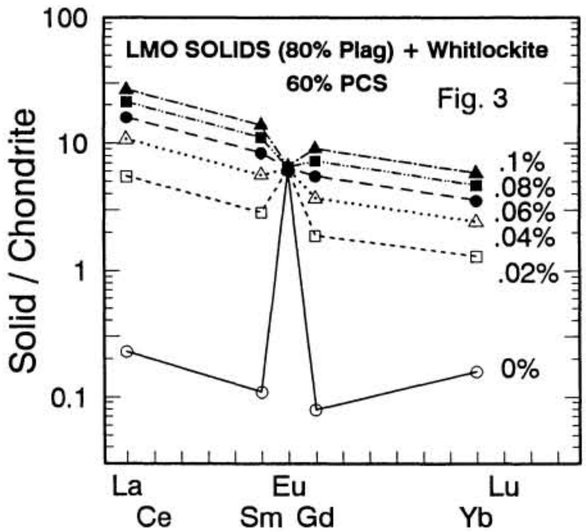
REE Abundances. Three of these anorthositic rocks (Fig. 1) also exhibit positive Eu anomalies which are generally similar to patterns expected for plagioclase accumulation under lunar oxygen fugacities (73215,534; 73216,57; and 77035,200, all of which are considered largely monomict [6]). However, 73216,36, 77035,201, and 73216,42 exhibit *negative* Eu anomalies; of these three, only 73216,36 is considered largely monomict [6]. In addition, the magnitudes of the positive Eu anomalies in norite 77035,206, gabbro 73216,57 and troctolite 73215,534 are small (Eu/Eu* = 1.15, 1.69, and 2.39, resp. [6] (Fig. 1); of these three, only 77035,206 is considered polymict [6]. A plot of whole-rock Al_2O_3 vs. Eu/Eu* (Fig. 2) illustrates further this discrepancy for these six samples.

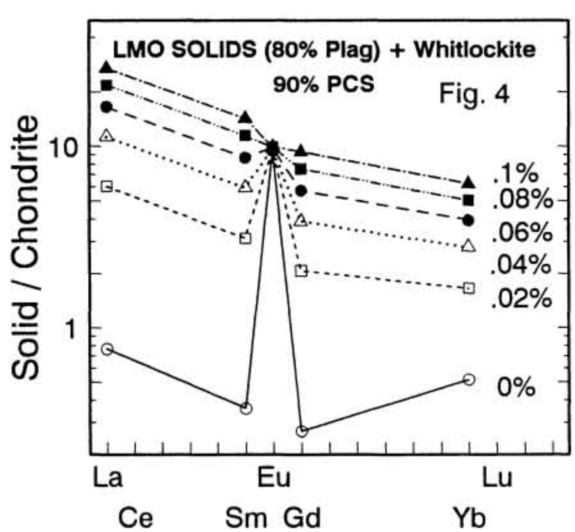




The dichotomous relationship of plagioclase-rich rocks, which crystallized under lunar oxygen fugacities but which exhibit negative or small positive Eu anomalies, indicates either that these anorthositic rocks crystallized from an extremely Eu-depleted magma or that some syn- or post-emplacement process overprinted the original REE abundances. Similar relationships in other lunar anorthosites have been linked to the presence of whitlockite, analyses of which were reported previously from 73216,36 and 73216,42 [3,5]. Minute grains of whitlockite have been confirmed using the EMP by EDS spectra in 73216,57, and 77035,201. In addition, Cl-apatite appears more abundant than whitlockite in 73216,57 and occurs alone in 73215,534 and 77035,206. The presence of whitlockite and/or apatite argues for the operation of post-crystallization overprinting effects to reconcile the relatively primitive major-element compositions with the highly evolved REE patterns. For polymict samples the introduction of elevated REE may involve only mechanical mixing. For samples which appear texturally monomict, "REEP" metasomatism may be indicated [3,5].

CALCULATED EFFECT OF WHITLOCKITE ABUNDANCE. We have calculated estimates of the amount of whitlockite necessary to overprint positive Eu anomalies in a representative plagioclase-rich composition (Figs. 3,4). REE abundances for the bulk solid were calculated from lunar-magma-ocean compositions of Snyder et al. [8] for 60, 70, 80%, and 90% total crystallized solid. This is after plagioclase has begun crystallization (@~55%) [8]. Corresponding magnesium numbers (100*Mg/Mg+Fe) of mafic minerals at these stages are 81, 77, 67, and 55, which bracket those of pyroxene in all but one of the anorthositic rocks discussed here. REE abundances for this model anorthosite calculation were made for a composition of 80% plagioclase, 10% olivine, and 10% orthopyroxene, roughly similar to the modal estimates calculated for most of these breccia clasts. Distribution coefficients for calculating REE abundances in the solid are the same as used by Snyder et al. [8], including a K_d for Eu [9] which maximizes the Eu anomaly. Using the whitlockite analysis for REE of Lindstrom et al. [10], sample 14305, various proportions of whitlockite were tested for their ability to suppress a positive Eu anomaly and create a negative anomaly in the calculated lunar-magma-ocean-derived solids. At 60% and 90% crystallized solid, unmodified values of Eu/Eu* calculated are 65 and 30, respectively. For both 60% and 90% crystallized solid, any *whitlockite abundances above 0.1% overpowered these strong positive Eu anomalies and produced negative Eu anomalies* (Figs. 3,4). The modification shown in Figs. 4 and 5 uses whitlockite abundances of 0 to 0.1%, in 0.02% increments. For 60% crystallized solid, the positive Eu anomaly is diminished to almost flat (Eu/Eu* = 1.1) by only 0.05% whitlockite. As little as 0.01% produces a drastic reduction in the anomaly; "crossover" from positive to negative anomalies occurs at 0.055% whitlockite (Fig. 3). The somewhat higher abundance of Eu at 90% crystallized solid resists this reduction in the Eu anomaly more effectively, but only 0.01% whitlockite produces a marked decrease and 0.05% reduces the Eu anomaly greatly (Eu/Eu* = 1.65); crossover to negative anomalies occurs at 0.085% whitlockite (Fig. 4). Modification by the lower abundances in apatite would require more of that phosphate to achieve similar effects.





<u>**DISCUSSION**</u>. The small positive Eu anomalies exhibited by 73215,534, 73216,57, and 77035,206 (Fig. 1) conform only generally to the plagioclase accumulation witnessed by the high whole-rock Al_2O_3 (Fig. 2) and the high modal percentage of plagioclase (68-78%). Although these anomalies are smaller than expected for rocks which contain abundant plagioclase, only ~0.01-0.02% whitlockite might impart an effect of this magnitude; particularly note the similarity of the REE pattern for 73215,534 (Fig. 1) to the 0.02% whitlockite, 60% crystallized solid curve (Fig. 3). Cl-apatite is present in these three rocks, and whitlockite also is present in 73216,57. Negative anomalies in rocks with 80% plagioclase (77035,201, 73216,36 and ,42, Fig. 1) may be generated by incorporation of as little as 0.055% whitlockite (Figs. 3,4).

Whitlockite partition coefficients were applied previously to calculating REE contents of possible "equilibrium liquids" for analyzed whitlockite [5]. These calculated liquids are enriched by 4-10 times relative to various estimates of KREEP [5]. This result was applied to argue for metasomatism by the "REEP" fraction following silicate liquid immiscibility of a KREEPy magma and to argue against an origin of these evolved phosphates by assimilation of urKREEP [3]. Calculations summarized above indicate that as little as 0.01% whitlockite can modify substantially an earlier positive Eu anomaly. This occurs without affecting major elements or other trace elements than the REE. *Less than 0.1% whitlockite can overpower positive Eu anomalies and create negative anomalies in anorthositic rocks.* This would require introduction into many anorthosites of only a small amount of the "REEP"-fraction proposed to produce metasomatism and whitlockite crystallization [3,11].

References: [1] Shervais et al. (1983), PLPSC XIV, p. B177-B192. [2] Lindstrom et al. (1984), PLPSC XV, p. C41-C49.[3] Neal and Taylor, (1990), LPS XXI, p. 851-852. [4] Neal et al. (1990a), LPSC XXI, p. 859-860. [5] Neal et al. (1990b), LPSC XXI, p. 863-864. [6] Eckert et al. (1991), this volume. - Min.Pet. [7] Haskin et al. (1974), PLPSC, v. 2, p. 1213-1225. [8] Snyder et al. (1991), LPS XXII, this volume. [9] McKay and Weill (1977), PLSC VIII, p. 2339-2355. [10] Lindstrom et al. (1985), LPX XVI, p. 493-494. [11] Neal et al., (1991), submitted to GCA, in review.