

EVOLVED QMD-MELT PARENTAGE FOR LUNAR HIGHLANDS ALKALI SUITE CUMULATES: EVIDENCE FROM ION-PROBE RARE-EARTH ELEMENT ANALYSES OF INDIVIDUAL MINERALS Gregory A. Snyder, Lawrence A. Taylor, and Eric A. Jerde, Planetary Geosciences Institute, Dept. of Geological Sciences, University of Tennessee, Knoxville, TN 37996-1410; Lee R. Riciputi Oak Ridge National Lab, Chemistry and Analytical Sciences Division, Oak Ridge, TN 37831-6365.

Rare-Earth Element analyses have been performed on cores of single grains of pyroxene, olivine, and plagioclase from several Apollo 14 Alkali Suite rocks using the SIMS technique. The ion probe analyses indicate that plagioclase is not only enriched in the REE (La = 15-30x chondritic), but can exhibit either a small positive Eu anomaly or the total lack of an Eu anomaly (14304,212). Pyroxene and olivine both exhibit large negative Eu anomalies. The evolved REE compositions of most lunar Alkali Suite rocks cannot be due to metasomatism or the accumulation of REE-rich minerals, such as whitlockite, and could have been inherited from their parental liquids. Furthermore, these analyses indicate that the minerals were precipitated from extremely evolved parental liquids, similar in REE composition to quartz monzodiorites (QMDs).

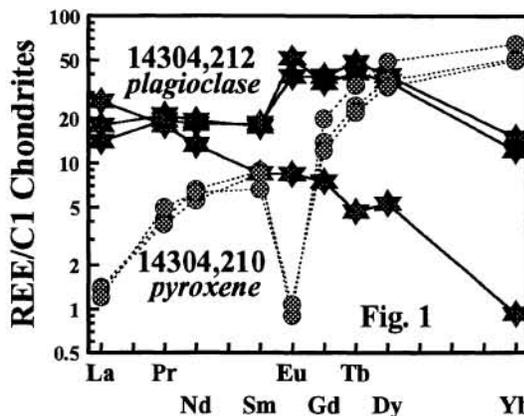
INTRODUCTION -- Alkali-rich rocks were first recognized from typical highlands suites such as ferroan anorthosites and norites (FAN) and Mg-suite rocks by Warren and Wasson [1]. Highlands Alkali Suite rocks exhibit evolved (elevated) large-ion lithophile element (LILE) whole-rock chemistry combined with evolved mineral chemistry (plagioclase, An < 90; pyroxene, En < 70), and are distinguished from metasomatized Mg suite rocks (also with evolved LILE chemistry) by their mineral chemistry (FAN-type plagioclase: An₉₁₋₉₇ or Mg-suite-type pyroxene: En > 70). Only those samples which are determined to have attained this character through primary igneous processes are included in the Highlands Alkali Suite.

Warren and Wasson [2] and Warren et al. [3] concluded that the Alkali Suite rocks either were evolved differentiates of the Mg-suite or represent a separate, unique group. Hunter and Taylor [4] suggested, based on plagioclase and mafic mineral compositions, that these rocks represent cumulate crystallization products of evolved magmas, possibly related to the Mg-suite. Based on whole-rock trace- and major-element chemistry, and Nd and Sr isotopic systematics, Snyder et al. [5,6,7] postulated that the Highlands Alkali Suite represents a group of cumulates from evolved QMD-like liquids. We present REE chemistry of individual minerals from three Alkali Suite rocks (14304,210; 14304,212; and 14318,149) which support this hypothesis.

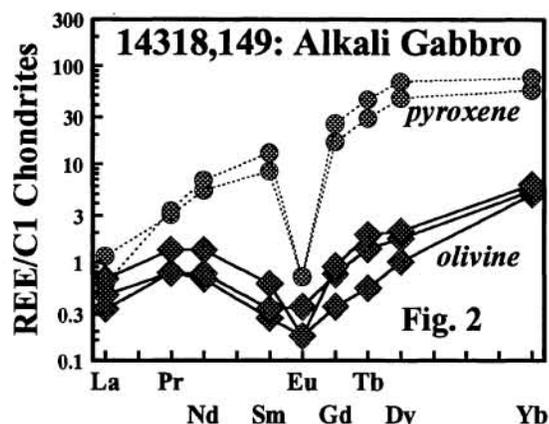
The petrography and mineral chemistry of probe mounts 14304,210 and 14304,212 are described in detail in Snyder et al. [7]. These probe mounts are considered to be portions of the the same large clast, designated clast "b" (14304,100) by Goodrich et al. [8]. This clast is anorthositic, but contains minor amounts of low-Ca pyroxene. Probe mount 14304,210 contains a larger proportion of low-Ca pyroxene and is classified strictly as a norite. Clast 14318,149 was studied in detail by Warren et al. [9]. He described this large clast (~1.5 g) as an "Mg-rich norite", but it has since been re-classified as part of the Alkali Suite [7]. The clast consists of 55% plagioclase, 35% low-Ca pyroxene and 12% olivine (thus, it is not truly a norite, but a gabbro) with traces of ilmenite, troilite and Fe-Ni metal [9].

ION PROBE REE DATA -- Rare-Earth Element contents have been determined in different minerals from three Alkali Suite samples, norite 14304,210, anorthosite 14304,212 and gabbro 14318,149. Plagioclase from anorthosite 14304,212 shows a considerable amount of variability in REE abundances, especially in the HREE (Fig. 1). These three analyses were taken from within a large maskelynitized plagioclase "clump" (2-3 mm) and could constitute separate grains (and/or generations) of plagioclase. The cause of the extreme variability in these analyses is not known, but either could have been inherited from a heterogeneous source (impact melt?) or could have been caused by the meteorite impact which maskelynitized the plagioclase.

Pyroxene was analyzed in two different samples, 14304,210 and 14318,149 and was found to be remarkably uniform in both REE abundances and pattern (Fig. 1 & 2). The major striking difference between the two samples



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is the deeper negative Eu anomaly in norite 14304,210. Olivine in gabbro 14318,149 contains relatively low REE abundances (0.5-10 x chondrites) and exhibits a negative Eu anomaly (Fig. 2).

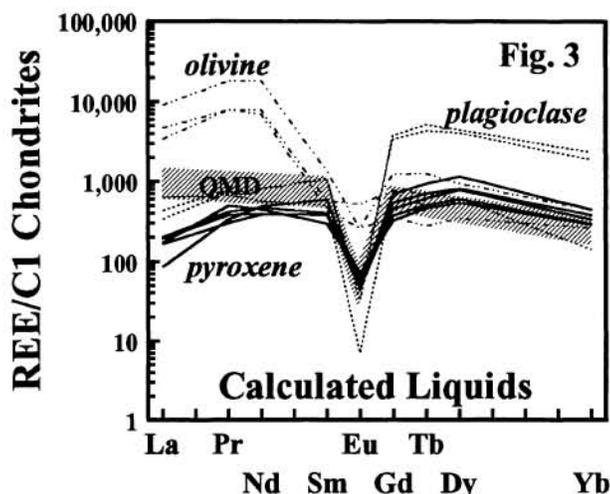
CALCULATED EQUILIBRIUM LIQUIDS -- Using the simple partition coefficient relation, $k_D = C_{\text{mineral}}/C_{\text{melt}}$ and the measured abundances of the REE in individual minerals, we can calculate melts which could have been in equilibrium with each mineral. These calculated liquids are shown in Fig. 3 relative to a field for actual whitlockite-free quartz monzodiorites (QMD). QMDs which contain even small amounts of whitlockite exhibit similar $(La/Yb)_n$ ratios to whitlockite-free QMDs, albeit with higher REE abundances (La = 2000-5000x chondrites) and larger negative Eu anomalies. As can be seen in Fig. 3, all of the

melts calculated from pyroxene analyses, along with one calculated from plagioclase analyses, plot within or near the field of QMDs and have similar $(La/Yb)_n$ ratios. The HREE and Eu abundances of all but two calculated liquids plot within or near the QMD field.

The LREE of calculated melts show considerable variability (i.e., two orders of magnitude, La = 100-10,000x chondrites). This may be due to the extremely low abundances of the LREE in both the olivine and the pyroxene analyses. Differences in only a few tens of ppb would make a large difference in the REE abundances of these minerals, and thus, a large difference in the LREE of the calculated liquids. The HREE in both pyroxene and olivine are 10-50x more abundant than the LREE and would, therefore, not be as subject to error in the analysis

(which are, comparatively, quite large for the LREE at such low abundances). The HREE are a more robust indicator of actual REE composition in each mineral. We find it compelling that the HREE abundances calculated for all minerals generally plot within or near the field of QMDs.

QMD-MELT PARENTAGE FOR ALKALI SUITE ROCKS -- Snyder et al. [6,7] have shown major- and trace-element modelling which points to QMD-melt heritage for highlands Alkali Suite rocks. Furthermore, isotopic analyses have also confirmed this link [6]. Analyses of the REE in minerals of Alkali Suite rocks indicates that these minerals precipitated from evolved liquids which have undergone extensive plagioclase fractionation and thus, contain high REE concentrations (La = 100-2000x chondrites) and large negative Eu anomalies. The REE character of these calculated liquids are similar to that of QMDs. This evidence, combined with previous isotopic, trace-, and major-element modelling [6] is consistent with the scenario whereby Alkali Suite rocks are precipitation cumulates of an evolved melt similar in composition to lunar QMDs.



- REFERENCES:** [1] Warren, P.H. and Wasson, J.T. (1977), *PLSC 8th*, 2215-2235; [2] Warren, P.H. and Wasson, J.T. (1980), *PLPSC 11th*, 431-470; [3] Warren, P.H. et al. (1981), *PLPSC 12th*, 21-40; [4] Hunter, R.H. and Taylor, L.A. (1983), *PLPSC 13th*, A591-A602; [5] Snyder, G.A. et al. (1993), *LPSC XXIV*, 1325-1326; [6] Snyder, G.A. et al. (1994), *LPSC XXV*, this volume; [7] Snyder, G.A. et al. (1994), *GCA*, submitted; [8] Goodrich, C.A. et al. (1986), *PLPSC 16th*, D305-D318; [9] Warren, P.H. et al. (1983), *PLPSC 13th*, A615-A630.