ION MICROPROBE STUDY OF LUNAR HIGHLAND CUMULATE ROCKS: NEW RESULTS

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Introduction: Deciphering the origin and evolution of the lunar highland crust is difficult in the western lunar highlands because of the small size of the highland rock clasts recovered from breccias [e.g., 1], and because it is impossible to calculate parent magma compositions from whole rock chemical data on cumulate rocks. The composition of cumulate plutonic rocks, such as those which comprise the lunar highlands, are a function of primocryst composition, the proportions of cumulate phases, the proportion and composition of trapped melt, and subsequent reactions between the trapped melt and cumulate phases.

We report here new data from our effort to characterize the parent magmas of lunar cumulates by using the ion microprobe and electron microprobe to analyze their cumulus phases [2]. Parent magma compositions are calculated from the phase chemistry using equilibrium crystal/liquid partition coefficients. This approach eliminates the need for "representative" bulk rock samples, and it allows us to monitor the evolution of the trapped intercumulus melt during closed system crystallization. This approach is also effective for texturally pristine samples which are known only in thin section.

Results: Nine samples have been analyzed so far: enstatite-bearing troctolite 14305,347 [3,4], diopside-bearing troctolite 14305,301 [5], enstatite-bearing troctolite 14321,1237 [6], whitlockite-bearing Mg anorthosite 14321,1273 [6], troctolite 14321,1241 [6], troctolite 14321,1235 [6], alkali anorthosite 14305,303 [5], and two A-14 gabbronorites found only in thin section: 14305,102c and 14318,Ac [3]. Additional samples are scheduled for analysis in January 1995. Six of these samples are Mg-suite cumulates and one is an alkali suite cumulate; the two gabbronorites were thought to be Mg suite cumulates, but the data presented here suggests that they are probably mare basalt cumulates.

Four of these samples were analyzed with the UNM-SNL Cameca 4f SIMS ion microprobe, located at the University of New Mexico; these data were reported last year [2]. The new samples were analyzed with the MIT-WHOI Cameca 3f SIMS ion microprobe, located at the Woods Hole Oceanographic Institute and under the supervision of Dr. Nobu Shimizu. Two to eight spots were analyzed on each sample for 8 rare earth elements. In most cases, the cores of large relict cumulus grains were analyzed by SIMS. Several samples, however, were probed in more detail to check for zoning in the relict cumulus grains and to compare the relict cumulus grains to polygonal recrystallized grains. Post-cumulus pyroxenes were analyzed in several samples to trace the evolution of the trapped liquid, and to check for post-cumulus re-equilibration.

Melts in equilibrium with phases analyzed were calculated using experimental and empirical partition coefficients for pyroxene and plagioclase [7-10]. Samples that were analyzed in detail display compositional zoning in primary cumulus grains that can be attributed to normal igneous zoning. Our most detailed example, whitlockite-bearing Mg anorthosite 14321,1273, shows a progressive enrichment in REE from core to rim (La = 18x to 25x chondrite) in a large cumulus plagioclase with relict twinning, while polygonal recrystallized plagioclase is similar to the cumulus core in composition (La = 20x chondrite). Post-cumulus, interstitial clinopyroxene shows large variations in composition, with La ranging from 25x chondrite to 98x chondrite; the highest values are found in a small grain adjacent to whitlockite. Overall, these results suggest that primary magma-crystal partitioning relations are preserved in these samples, and that equilibrium crystal/liquid partition coefficients can be used with carefully chosen cumulus core compositions to calculate the trace element composition of the parent magmas.

Parent magmas calculated for the samples studied thus far are shown below, normalized to the high-K KREEP component of Warren [11]. Five of the six Mg-suite samples analyzed had parent magmas with REE concentrations similar to KREEP; the other sample (14305,347) had a non-KREEP parent magma (fig. 1). Eu concentrations vary from slight negative to large positive anomalies, suggesting enrichment in plagioclase-forming elements. These results are consistent with the hypotheses of Warren that most Mg-suite parent magmas assimilated at least some KREEP prior to crystallization [12], and were enriched in plagiophile elements (like Eu) by plagioclase dissolution [13]. The single alkali suite sample (14305,303) is almost identical to 15386 KREEP in its trace element composition (fig. 2), suggesting that alkali suite
cumulates may have formed from a "pristine KREEP" parent magma [1]. The two gabbronorites are strongly depleted in LREE relative to KREEP (fig. 3) and have "hump" shaped chondrite-normalized REE patterns, similar to some Apollo 14 mare basalts [14].

Conclusions: The data presented here show that ion microprobe analyses of primary cumulus phases in lunar highland cumulates can be used to determine the composition and petrologic history of their parent magmas independently of bulk rock compositional data. These data also show that analyses of post-cumulus accessory phases which formed from evolved trapped liquid do not result in accurate determinations of parent magma composition.