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KREEP cumulates in the western lunar highlands: Ion and electron microprobe study of alkali-suite anorthosites and norites from Apollo 12 and 14

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ABSTRACT

Alkali suite anorthosites and norites are the second most common plutonic rock association in the western lunar highlands (after the magnesian suite), but their origin poses an enigma for most petrologic models of lunar crustal evolution. Some models suggest that the alkali and magnesian suites formed from distinct, unrelated parental magmas, whereas other models propose that both suites formed from the same parental magma. The contrast in major element chemistry of the cumulus phases in each suite is difficult to reconcile with their similar incompatible element chemistry.

We present herein a detailed ion microprobe (SIMS) and electron microprobe study of seven alkali suite rocks. Our data show that most alkali suite anorthosites preserve major and trace element characteristics acquired during their formation as igneous cumulate rocks, and that these characteristics can be used to reconstruct the parental-magma composition. The data indicate that cumulates of the alkali suite crystallized from magmas with rare-earth element (REE) contents ~0.6–2.0× high-K KREEP, and small but consistently positive Eu anomalies (Eu/Eu* ~2) relative to KREEP. Snyder and others (1995a) have proposed that the alkali suite parental magma is similar to Apollo 15 pristine KREEP basalt. Our model suggests that the major element composition of cumulus plagioclase in most alkali suite rocks is too sodic for the calculated crystal line-of-descent of pristine KREEP basalt, and that assimilation of pre-existing calcic anorthosite is required. This conclusion is supported by the REE patterns of th alkali-suite parental magma determined here.

We propose that alkali suite anorthosites formed as flotation cumulates in KREEPy plutons that may have formed norites as complementary bottom cumulates. The alkali flotation cumulates reflect fractional crystallization of their parental pluton, local equilibrium crystallization, assimilation of plagioclase-rich roof rock, and episodic magma-mixing during convective overturn of the crystallizing magma bodies. Texturally pristine alkali anorthosites exhibit petrographic characteristics that are consistent with their origin as cumulates in a KREEPy pluton, including abundant modal plagioclase, post-cumulus pyroxenes (both augite and pigeonite) that generally lack exsolution lamellae and that have equilibration temperatures of 950–1100 °C, relict igneous textures and, in some cases, igneous lamination. The lack of cumulus mafic phases in rocks that should be pyroxene-saturated suggests separation of the plagioclase by flotation, not sinking. Assimilation of plagioclase from older, anorthositic highlands crust is indicated by the high Eu contents of the cumulates and by the positive Eu anomalies in their calculated parental melts relative to high-K KREEP. Mixing of the evolved alkali-suite parental magma with primitive melt occured episodically, as shown by reverse zoning profiles in some cumulus plagioclase. Injection of this primitive, hot magma into the crystallizing pluton may have induced convective overturn of the magma chamber.