DIVERSITY OF PARENT MAGMAS OF PRISTINE LUNAR ROCKS

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Most lunar petrologists think that ferroan anorthosites formed by floatation in an ocean of magma surrounding the primitive Moon and that Mg-suite rocks formed from magmas that intruded the anorthositic crust; see Warren's review (1). This story is not universally believed (2,3), however. Even if it is basically correct, many questions remain: Was the magma ocean a total or partial melt of bulk lunar material? What processes operated in it? Could any of the Mg-suite magmas have formed in it? How many magmas gave rise to the observed collection of Mg-suite rocks? What were the source rocks that melted to form these magmas? How were the magmas affected by assimilation and fractional crystallization? To address these questions we are measuring the concentrations of minor elements in olivines and pyroxenes in pristine highland rocks. We report our initial results here. The value of such measurements was shown by Smith et al. (4). Unlike whole-rock chemical analyses, measurements of individual mineral grains do not suffer from sampling problems, so they might provide less ambiguous information about the compositions of the magmas in which they crystallized. However, they can be affected by subsolidus redistribution of elements and by the effects of closed-system crystallization, especially if they crystallized from liquids trapped in a pile of cumulate crystals.

Results: We made the measurements with our JEOL 733 electron microprobe, using a beam current of 200 na and counting times of up to 1200 seconds. These conditions resulted in low detection limits (less than 30 ppm) and high precision (+ 1-3% relative) for the elements we report on here, Al, Ti, and P. We tried to obtain at least 6 acceptable analyses in each sample, though some anorthosites are so poor in mafic silicates that we had to settle for one or two grains. Data for olivine appear in Figs. 1-3.

Mg-suite: In the samples studied to date (mostly troctolites), TiO_2 varies by over a factor of six with little change in mg, the mole ratio Mg/(Mg + Fe) x 100. Similarly, Al_2O_3 varies by a factor of five. (Low-Ca pyroxenes show the same features as do olivines.) Although slight negative trends are apparent in the diagrams, consistent with fractional crystallization, the ranges are too large compared to the small range in mg to be accounted for by fractional crystallization of a single magma type. This confirms previous suggestions that numerous separate parent magmas are represented by our collection of Mg-suite rocks. These magmas might have differed in Ti content by a factor of six, thus explaining the six-fold variation of Ti concentrations in olivine, but it is unlikely that Al could have varied by that much in magmas that consistently produced rocks composed of roughly equal amounts of olivine and plagioclase. Perhaps variations in intensive variables such as oxygen fugacity caused changes in the partitioning of Ti and Al between melt and olivine.

The east-west dichotomy among pristine rocks (5) is shown clearly in Fig. 3. P_2O_5 is significantly greater in olivines in Apollo 14 troctolites than in the others. This is consistent with the overall greater contents of incompatible elements in pristine samples from Apollo 12 and 14, which is probably the result of assimilation of greater amounts of KREEP (5,6). Aluminous mare basalts from Apollo 14 also show the effects of assimilation (7).

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Ferroan anorthosites: Olivines in this suite have lower concentrations of Ti, Al and P than do most of the Mg-suite samples (Figs 1-3). This is consistent with their bulk concentrations of these elements and of incompatible elements in general (1,8). The data do not form clear trends, however. This suggests that the processes operating in the magma ocean (assuming there was one) were more complicated than simple fractional crystallization. Complex magma mixing processes may have operated in an initially totally-molten system (8,9) or in a partially melted one (10-12).

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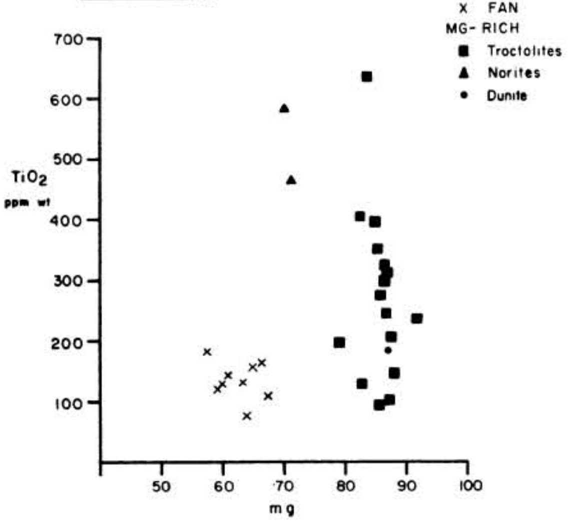

Fig. 1

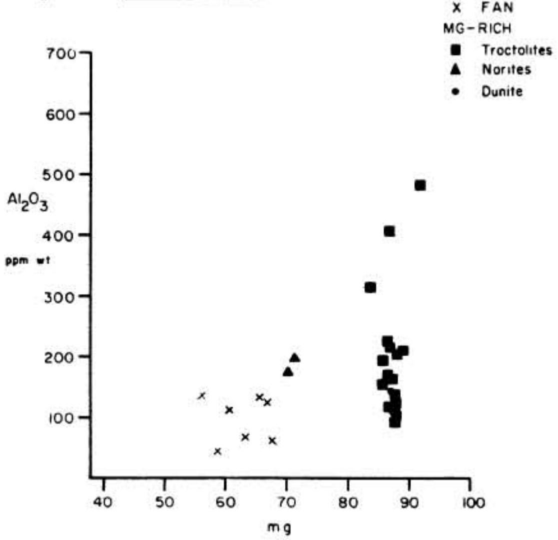

Fig.2

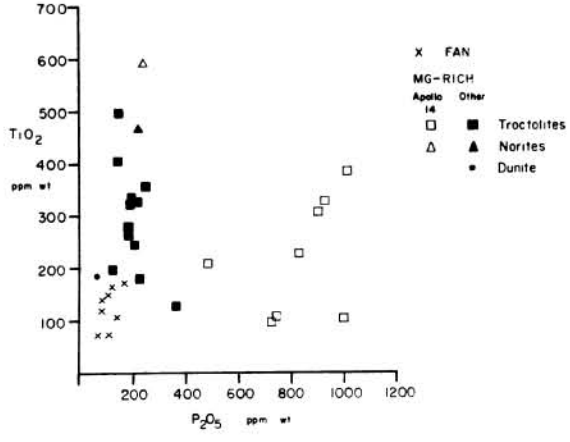

Fig. 3