FERROAN ANORTHOSITES FROM AN EVOLVING MAGMA OCEAN.

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The crystallization history of the magma ocean is not yet understood. We are attempting to understand its crystallization history by studying minor element distributions in olivines and pyroxenes in pristine highland rocks. We began with the premise that if the lunar anorthosite crust is the product of fractional crystallization of a magma ocean, then minor elements in mafic minerals in FANs should have distributions consistent with fractional crystallization models. What we have discovered is that some element distributions appear to support the fractional crystallization model, but others appear to argue against it.

Bersch et al.(1) noted that there is a good positive MnO-FeO correlation and a good negative Cr_2O_3-FeO correlation in low Ca pyroxenes in pristine highlands rocks. Both distributions appear to conform to a Rayleigh fractionation model. The model predicts a decrease in Cr_2O_3 with increasing MnO concentration (Figure 1, Mn concentration used as the index of differentiation); however, we have a used a $D^{Cr}{}_{opx} = 5$, which may be high for lunar magmas, to obtain the necessary bulk distribution coefficient to fit the data. The fractionation model also predicts a decrease in Al_2O_3 concentration with differentiation. The negative Al_2O_3-MnO correlation is observed but Al decreases more rapidly than predicted by fractional crystallization alone (Figure 2).

Other element trends appear inconsistent with fractional crystallization. TiO_2 and P_2O_5 show no increase in pyroxenes and olivines (Figures 3 and 4) even though fractional crystallization would predict that both would increase substantially in the melt. There are important ionic substitution couples in pyroxenes (2) and interpretation of crystallization histories from pyroxene compositions is extremely complex (e.g. 3). For example, TiO_2 concentrations in low Ca pyroxenes do not follow the predicted Rayleigh fractionation curve (Figure 3) but there is a fair fit of the predicted TiO_2/Al_2O_3 ratio with the actual data (Figure 5). There may be a complex crystal chemical control of P concentration in pyroxene, for example, P^{+5} substitution might be in the form of $R^{+2}R^{+2}PAlO_6$. In order to maintain charge balance, the amount of P in the pyroxene may then be a complex function of the concentrations of Ti, Cr, and Al. Olivines show a very good positive CaO-MnO correlation which is opposite of that predicted by fractional crystallization (Figure 6).

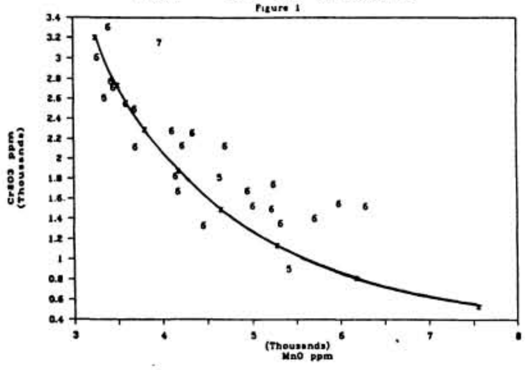
We are exploring two hypotheses to explain some of the puzzles presented by ferroan anorthosites. Hypothesis # 1: FANs originated as fractional crystallization products of an evolving magma ocean that became progressively more iron-rich. Using this hypothesis, we would explain the apparently inconsistent element correlations, e.g. Ti and P, as due to crystal chemical control. The positive MnO-CaO correlation in olivines would be the result of the formation of a layered anorthosite crust. This crust would be the product of the fractionally crystallizing magma ocean and each successive layer would have higher Fe/Mg. The positive Ca correlation would result from the increase in temperature with depth. The olivines in each layer retained their different Ca concentrations because of rapid cooling when all layers were ecavated by meteorite impact. Hypothesis # 2: FANs originated as fractional crystallization products of an evolving magma ocean that became progressively more magnesian. In this model, the magma ocean is fed by a magmifer (4). However, the magma ocean begins as a low-degree partial melt and recharge magmas from the magmifer were progressively higher degree partial melts. As a consequence, the magma ocean became richer in Mg with time. Using this hypothesis, we would explain the apparently inconsistent element correlations, e.g. constant P in pyroxenes, as the result of buffering by crystallization of major phases and recharge of mafic magmas low(er) in incompatible elements from the evolving mantle. The positive MnO-CaO correlation in olivines would be the result of a layered anorthosite crust but with the relatively more Fe-rich zones near the lunar surface.

References: 1) Bersch, M.G. et al. (1988) LPS XIX, 67-68. 2) Basaltic Volcanism Study Project (1981) Pergamon Press Inc. New York. 3)Bence, A.J. and Papike, J.J. (1972) PLSC 3rd, 431-469. 4) Shirley, D. (1983) PSPSC 13th, A519-A527. Research supported by NASA grant NAG 9-30 (to K. Keil).

EXPLANATIONS FOR ALL FIGURES: Numbers refer to missions-- 1 = Apollo 11; 5 = Apollo 15; 6 = Apollo 16; 7 = Apollo 17; 0 = Lunar meteorite ALH81005.

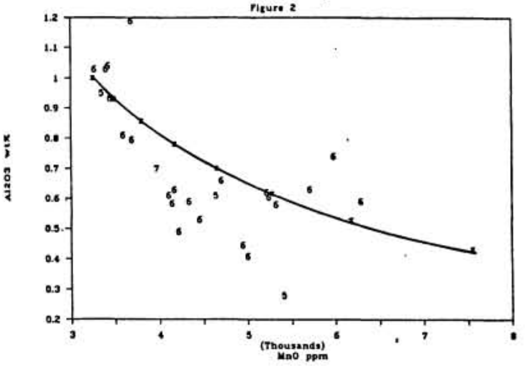
FANs - Low Ca Pyroxenes

Figure 1



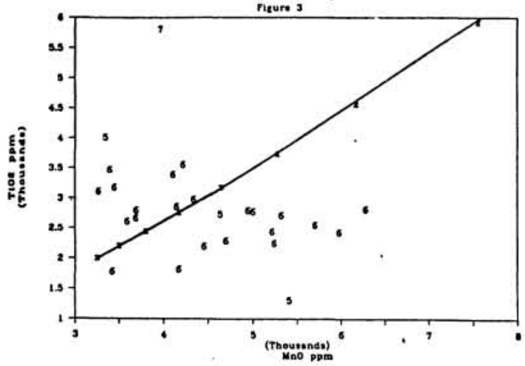
FANs - Low Ca Pyroxenes

Figure 2



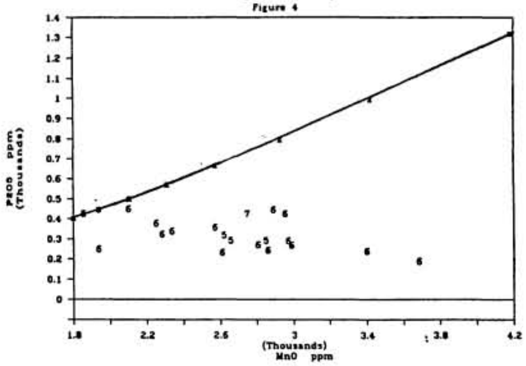
FANs - Low Ca Pyroxenes

Figure 3



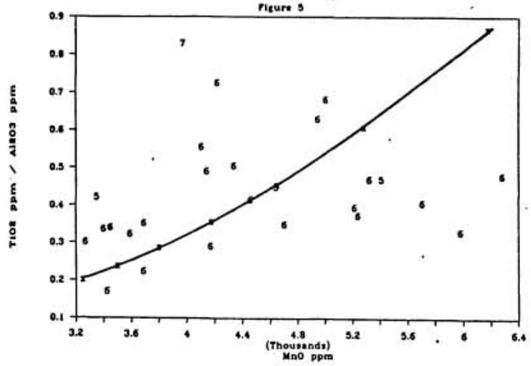
FANs - High Ca Pyroxenes

Figure 4



FANs - Low Ca Pyroxenes

Figure 5



FANs - Olivines

Figure 6