TRACE ELEMENTS IN THE PLAGIOCLASE OF LUNAR FERROAN ANORTHOSITES. Odette B. James, U.S. Geological Survey, Reston, VA, 22092

Ferroan anorthosites are thought to be relics of a primordial lunar crust that formed by flotation of plagioclase in a magma ocean. Despite the importance of these rocks, the processes by which they crystallized are not well understood. The variation trend shown by their plagioclase and mafic minerals has proved especially difficult to explain. The plagioclase has a very narrow compositional range and is very calcic, with anorthite (An) content varying from An_{94} to An_{98}. The mafic minerals, in contrast, have a wide compositional range and are relatively ferroan, with mg' (100 x molar Mg/Mg+Fe) varying from 40 to 75. In the ferroan anorthosites as a group, An content of the plagioclase is not correlated with mg' of the mafic minerals (although positive correlations are observed in minerals within a few samples [1]). Numerous explanations have been offered for the mineralogic variation trend [1-8], but none have explained all aspects of the compositional variations. This abstract presents a preliminary report on trace-element studies relevant to the origin of the mineralogic variation.

As one aspect of a comprehensive evaluation of ferroan-anorthosite chemistry, I am using bulk compositional data to estimate the contents of trace elements in ferroan-anorthosite plagioclase, to try to determine whether or not these elements vary in any systematic manner that can be attributed to crystallization from an evolving parent magma. Studies addressing this question were carried out earlier by others [9-11], but the data bases were smaller and different approaches were used. The approach used in this study is as follows. (1) All analyses of ferroan anorthosites for which a large number of elements (including Fe and/or Na) have been determined on the same split were compiled from the literature. (2) Trace elements were plotted against Fe in order to select a set of high-purity plagioclase analyses (Fe is the best indicator of the purity of plagioclase samples, as mafic minerals are the most abundant minor phases in the rocks). A set of 32 analyses (of splits from 18 different rocks) having <3300 ppm Fe was arbitrarily selected; for these analyses, the contents of the trace elements that concentrate in plagioclase closely approximate those in pure plagioclase, and the data set is large enough that any trends that are present should be evident. A few analyses having <3300 ppm Fe were excluded from the data set on the basis of plots of K versus Na and Lu versus Sc, because the trace-element contents of these splits appear to be affected by the presence of minute amounts of trace-element-rich phases. (3) For the set of high-purity plagioclase analyses, trace elements were plotted against Na, a measure of the albite (Ab) content of the plagioclase, and also against mg' of low-Ca pyroxene in the samples, if known from electron-microprobe data.

The Na variation diagrams for Eu, Sr, Ga, La, Sm, and Ba (Fig. 1) show that the contents of these elements in ferroan-anorthosite plagioclase are correlated with the Na (Ab) content of the plagioclase. (A previous ion-microprobe study [10] showed similar positive correlations of Na, Sr and Ba in ferroan-anorthosite plagioclase.) The data for Sr and Ga show relatively wide ranges, probably because analytical precision is lower for these elements than for the others. Also, a few samples are enriched in Sm and depart from the trend defined by most of the samples on the plot of Na versus Sm. The sporadic Sm enrichments probably reflect the presence of small amounts of augite or rare-earth-rich phases in the splits; because Sm is the least plagiophile of the elements plotted, small amounts of other phases will affect the bulk data for this element more than the data for the other elements.

The results suggest that the plagioclases in all the rocks may have crystallized from an evolving liquid, in which Na, Eu, Sr, Ga, light rare earths, and Ba were all becoming progressively enriched. (Palme et al. [9] reached similar conclusions, based on a smaller sample suite.) The interpretation that there was a single parent magma is not firmly established by the data, however. The data points are not aligned along a smooth curve, and their distribution suggests that there may be more than one trend represented.

The Na variation diagrams for elements that concentrate in pyroxene (Sc, Yb and Lu) show no correlation of these elements with the Na content of the plagioclase. Plots of Yb and Lu against Sc show good positive correlations, suggesting that even at the low abundances of pyroxene in these splits, most of the Sc and the heavy rare earths in the splits are in the pyroxene.

No correlations are apparent in the plots of all the elements listed above against mg' of low-Ca pyroxene. The preliminary results of this study thus support previous observations that, in ferroan anorthosites as a group, mg' in mafic minerals and An in plagioclase are not correlated. Uncertainties in mg' are high, however. Because individual subsamples of some anorthosites contain pyroxenes with very different mg', it is not certain that an mg' reported in the literature for a given rock pertains to all splits from that rock.

The results of this study further suggest that, in the An versus mg' trend, it is the mg' variation that is anomalous, because the An variation is well correlated with variation in trace-element contents. Some variant of the Raedeke-McCallum hypothesis [8] may be necessary to explain the mg' variations. According to this hypothesis, the mafic minerals in ferroan anorthosites consist of two components: one crystallized early and was incorporated as a minor constituent into the floating plagioclase cumulates, and the other crystallized late from interstitial liquid. During the late stages of crystallization and subsequent subsolidus cooling, these components equilibrated, and the final composition of the mafic minerals in a given rock depends on the relative proportions of the two components. The composition of the plagioclase is effectively buffered by the abundance of the cumulus grains, so that equilibration with interstitial liquid does not greatly affect the bulk composition of this mineral. Although the compositional data indicate that no significant amount of highly evolved liquid was incorporated in the anorthosites [7,11], equilibration between early-formed mafic minerals and somewhat more evolved interstitial liquid, followed by loss of that liquid (perhaps by adcumulus growth or filter pressing), might explain some of the mg' variations. It may also be that the cumulus plagioclase and the mafic minerals incorporated in the flotation cumulate were juxtaposed by strictly mechanical means, and they crystallized at different times and places in the parent magma.

This study raises an interesting possibility for the nature of the relations among the ferroan anorthosites -- that An content of plagioclase, rather than mg' of mafic minerals, is the best measure of extent of differentiation of the parent magma. This conclusion is not proven, however, as it depends heavily on data from just three rocks, those having relatively high Na and trace elements in their plagioclases (60025, 61015, and 67635). More analyses are needed, especially for anorthosites with relatively sodic plagioclases, to fill in the gaps in the data and establish whether or not there is a single continuous trend.

References: [1] Ryder G. (1982) GCA 46, 1591. [2] Steele I.M. and Smith J.V. (1973) PLSC 4, 519. [3] Roedder E. and Weiblen P.W. (1974) PLSC 5, 303. [4] Drake M.J. (1975) PLSC 6, 293. [5] Wood J.A. (1975) PLSC 6, 1087. [6] Longhi J. (1977) PLSC 8, 529. [7] Warren P.H. and Wasson J.T. (1980) Proc. Conf. Lunar Highlands Crust, 81. [8] Raedeke L.D. and McCallum I.S. (1980) Proc. Conf. Lunar Highlands Crust, 133. [9] Palme H. et al. (1984) PLPSC 15, C3. [10] Steele I.M. et al. (1980) PLPSC 11, 571. [11] Haskin L.A. et al. (1981) PLPSC 12, 41.

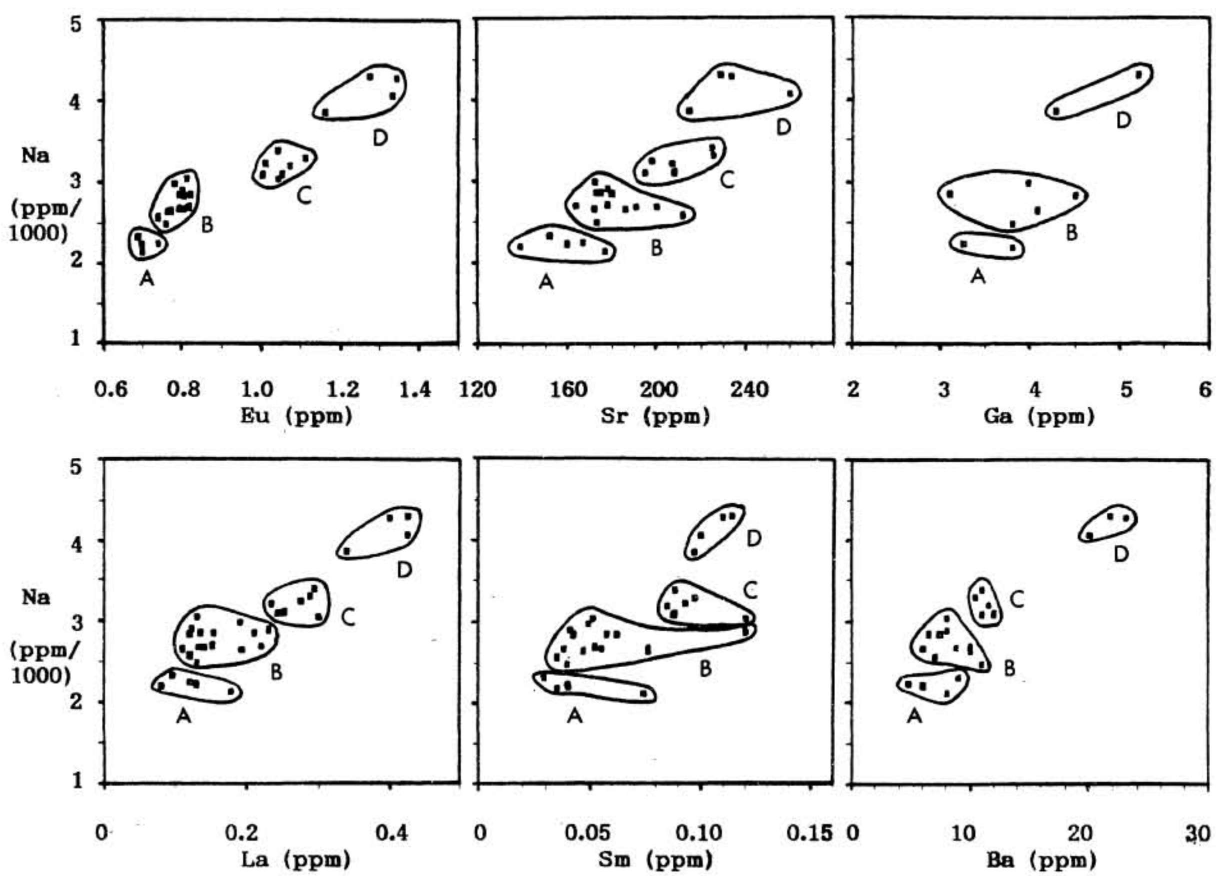

Figure 1. Contents of Eu, Sr, Ga, La, Sm and Ba plotted against Na for samples of ferroan anorthosites having <3300 ppm Fe. The diagrams show four coherent groups of rocks, as follows: A) 67455c, 64435c, 65327, 67525, 65315; B) 15415 (4 splits), 15295c, 67015c, 67535 (2 splits), 15362, 61016 (3 splits), 65325, 60639c, 60055, 60015; C) 61015, 60025 (6 splits); and D) 67635 (4 splits).