PRISTINE ROCKS (8TH FORAY): GENETIC DISTINCTIONS USING Eu/Al AND Sr/Al RATIOS

Paul H. Warren, Gregory W. Kallemeyn and John T. Wasson, Inst. of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90024

On the impact-battered lunar highlands, the oldest, most volumetrically important lithologies suffered near-total disintegration, and were mixed as obscure components into impact breccias and melt rocks. Data for rare "pristine" fragments, intact from endogenous lunar magmatism and/or metamorphism, place rudimentary constraints on relationships among the older lithologies. Among samples analyzed at UCLA this year is a large, pristine norite clast from 76255 [1]. Considering that this clast is a gabbronorite [2], its Sc/Sm ratio is surprisingly low (3.2). Our sample was probably not 100% matrix-free, but assuming that the matrix of 76255 is compositionally similar to matrices of other Station 6 breccias [3], the clast's Sc/Sm ratio must be <5, even if the sample was 10% matrix. The average Sc/Sm ratio of four previously analyzed gabbronorites is 12 [2].

It was suggested in 1979 [4, 5] that among the ancient cumulates, only the ferroan anorthosites formed directly from the primordial magma ocean. The diversity of pristine rocks has even raised doubts about whether the Moon ever had a magma ocean [6]. On the other hand, McCallum [7] still argues that all the ancient cumulates formed out of the magma ocean, although metasomatism later supplied incompatible elements to the Mg-rich rocks.

The crux of the single-magma petrogenesis vs. multi-magma petrogenesis debate is compositional diversity of pristine rocks. For example, most ferroan anorthosites contain <0.1 μg/g Sm (five have <0.05 μg/g), whereas most alkali anorthosites contain >4 μg/g, and two whitlockite-rich anorthosites contain 46-86 μg/g [8]. Magnesian troctolites exhibit comparable diversity of REE contents. There is also a tendency for the most REE-rich anorthosites and troctolites to come from one landing site, Apollo 14 [8]. Conceivably, such compositional diversity could be due to sampling errors in the data base. The samples analyzed are small (typically 10-500 mg), and surely not always fully representative of their parent lithologies. Uneven sampling of minor minerals can lead to large trace element variations. However, the REE enrichments among Apollo 14 anorthosites and troctolites can only be due to sampling errors in the sense that cumulates produced by the magma ocean in the Apollo 14 region might be radically different from cumulates produced 20-30 degrees of longitude to the east (implying extreme heterogeneity of magma ocean composition). In a sense, there is no such thing as a representative sample of a cumulate, which is by definition a heterogeneous assemblage of cumulus crystals plus varying amounts of trapped liquid.

Compositional data do constrain cumulate petrogenesis, but it is best to focus on elements and element/element ratios that are relatively insensitive to sampling method. The dichotomy between ferroan anorthosites and Mg-rich rocks was discovered by plotting mg in mafic silicates vs. Ca/(Ca+Na+K) in plagioclase [5]. These are ratios that feature small but significant fractionations between melt and crystals. Variations in these ratios caused by faulty sampling (e.g., trapped liquid vs. cumulus crystals) must be small, yet the ranges in the data are large enough to resolve the two rock types.

The Eu/Al and Sr/Al ratios of pristine rocks are also hard to explain via single-magma models. In basaltic lunar magmas, Eu, Al and Sr all have crystal/melt distribution coefficients slightly greater than 1 for plagioclase (about 1.9-2.5 for Al, 1.1 for Eu, and 1.6 for Sr), and <<1 for all other important solids [9]. These distribution patterns imply that (a) all plagioclase in lunar cumulates must contain 1.0-2.5 times as much Al, 1.0-1.1 times as much Eu, and 1.0-1.6 times as much Sr, as the parent magma (uncertainties

PRISTINE ROCKS: Eu/Al AND Sr/Al RATIOS

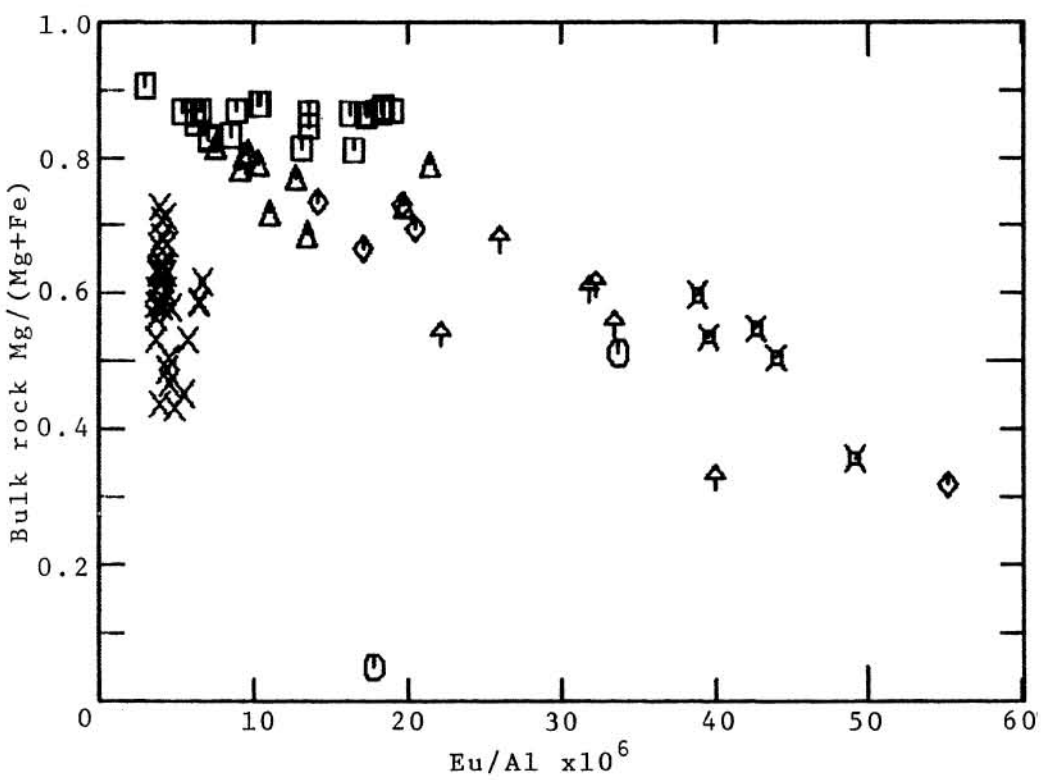
Warren, P. H., et al.

arise because the plagioclase may be in part derived from trapped liquid); (b) all non-plagioclase phases in plagioclase-rich lunar rocks contain negligible amounts of Al, Eu and Sr; and (c) samples from any plagioclase-rich lunar rock are always representative (to within a few percent) for Eu/Al and Sr/Al.

A lunar basaltic magma crystallizing plagioclase also crystallizes an approximately equal amount of mafic silicates. Bulk crystal/melt distribution coefficients are ∿1.1 for Al, 0.55 for Eu, and 0.8 for Sr. Even during ideal Rayleigh fractional crystallization, melt Eu and Sr concentrations are not doubled until the fraction of melt remaining (f) drops by factors of 4.7 and 32, respectively. Meanwhile, the overall composition of the melt changes radically. For example, if mg is initially 0.8, by the time f drops by a factor of 5, mg falls to 0.3. Even allowing for differing types (e.g., olivine vs. pyroxene, trapped liquid vs. cumulus) of mafic silicates, bulk chemical data should show inverse correlations for mg vs. Eu/Al and mg vs. Sr/Al, if only one magma was involved.

The figure below shows the Eu/Al and mg data. All Mg-rich rocks, alkali anorthosites, KREEPy rocks, and one granite [10] plot near a single, inversely correlated, trend. Ferroan anorthosites cluster in a vertical, low-Eu/Al field, and are clearly fundamentally unrelated to the others. Similar, albeit less clear-cut, trends are exhibited by sparser (and generally less precise) Sr/Al data. The single-magma model must be further convoluted, or scrapped.

REFERENCES: [1] J. L. Warner et al. (1976) Lunar Science VII, 915-917. [2] James and Flohr (1983) PLPSC 13, A603-A614. [3] Phinney (1981) Guidebook for Boulders at Station 6, Apollo 17: NASA JSC - 17243. [3] Warren (1979) Papers Presented, Conf. Lunar Highlands Crust, 192-194. [5] James (1980) PLPSC 11, 365-393. [6] Walker (1983) PLPSC 14, B17-B26. [7] McCallum (1983) LPS XIV, 473-474. [8] Warren et al. (1983) PLPSC 14, B151-164. [9] Warren (1983) GCA 47, 1559-1571. [10] Warren et al. (1983) EPSL 64, 175-185.




Symbols: Mg-rich rocks = squares (troctolitic types), triangles (noritic types), and diamonds (gabbronorites); ferroan an'sites = X's; alkali an'sites = small squares with X-like spines; granites = octagons; KREEPy rocks = pine trees.