MAJOR AND TRACE ELEMENTS IN CRYSTALLINE ROCKS FROM APOLLO 15,

Philip A. Helmke, Douglas P. Blanchard, Larry A. Haskin, Karen M. Telander, Charles K. Weiss and Jeffrey W. Jacobs, Department of Chemistry, University of Wisconsin-Madison, Madison, Wisconsin 53706.

Thirty-one crystalline rocks from the Apollo 15 mission were analyzed for REE, and, in some cases, for major and other trace elements. We were seeking genetic relationships among these rocks similar to those found for terrestrial igneous rocks (e.g., Steens Mountain basalts, Helmke and Haskin, [1], submarine basalts, Kay et al., [2]). All materials analyzed have typical depletions of Eu (except for plagioclase separated from sample 15085). The basalts do not appear to be simply related to each other by ordinary processes of igneous fractionation.

Four samples have concentrations of trace elements that are characteristic of KREEP. Their average trace element concentrations are given in Table 1. The range of concentrations extends to about 20% above and below the mean for REE (except Eu) and most of the other trace elements. Unless otherwise specified, these four basalts are excluded from the discussions below.

The samples of mare basalt from Apollo 15 have higher concentrations of FeO, MgO, Mn, and Cr and lower concentrations of CaO, Na_2O, K_2O, and rare-earth elements (REE) than samples of mare basalt from Apollos 11, 12, and 14. The Apollo 15 mare basalts can be divided into two groups on the basis of their normative compositions. One group is quartz normative and has a low concentration of FeO. The other is olivine normative and has a high concentration of FeO. The average major and trace element concentrations for the two groups are given in Table 1. The overall range in REE concentrations for all 27 basalts is just over a factor of 2. The range for the individual groups is about the same. There is a systematic difference in concentrations of FeO between the quartz normative ($\leq$21%) and olivine normative ($\geq$22%) groups.

The trace element data allow that the samples of olivine normative basalt could be from different portions of a single lava flow. At least two, and possibly three, parent magmas are required to account for the samples of the quartz normative group, on the basis of their concentration ratios of Sm to Eu. Within each group, the compositions of the samples appear to be related by crystallization of olivine or pyroxene.

Considering ordinary processes of igneous fractionation only, the variation of the concentration ratio of Sm to Eu for the samples of mare basalt can be produced only by plagioclase-liquid equilibrium. However, the liquids that produced these basalts are not saturated with plagioclase (Humphries et al., [3]).

Some variation of the concentration ratio of Sm to Eu may be the result of sampling. Four of the samples were pyroxene vitrophyres in which crystallization of plagioclase never started (Albee et al., [4], Wiegand, [5]); therefore, selective sampling would be expected to have little or no effect upon the concentration ratio of Sm to Eu in those samples. The range of values of the concentration ratio of Sm to Eu for the samples of pyroxene vitrophyres is similar to that for the other samples of mare basalt. Thus, the four vitrophyres alone require more than one parent magma. The variation of the concentration ratio of Sm to Eu is greater than can reasonably be expected if only olivine and pyroxene-liquid equilibria are considered.

A mechanism that would produce variations in the concentration ratios of Sm to Eu like those observed would be the assimilation of relatively small amounts of a material with high concentrations of REE except for Eu into the liquid that produced the basalts. KREEP is an example of such a material. In order for KREEP to be the assimilated constituent, its relative enrichment in the light REE would have to be compensated by a light REE depletion in the other constituents of the magma. Such a depletion is characteristic of Apollo 11 B basalts, and would be an expected product of melting of a mafic cumulate.

Table 1. Mean compositions of Apollo 15 crystalline rocks.

Olivine normative basalts				Quartz normative basalts			
SiO_2	45.8	Quartz	-	SiO_2	49.2	Quartz	2.6
Al_2O_3	8.35	Ilmenite	3.8	Al_2O_3	9.62	Ilmenite	2.8
TiO_2	2.65	Orthoclase	0.5	TiO_2	2.0	Orthoclase	0.5
MnO	0.283	Albite	2.5	MnO	0.269	Albite	3.0
FeO	22.9	Anorthite	22.4	FeO	20.4	Anorthite	25.8
MgO	10.3	Diopside	22.4	MgO	8.62	Diopside	20.2
CaO	9.74	Hypersthene	38.2	CaO	9.86	Hypersthene	44.8
Na_2O	0.271	Olivine	10.1	Na_2O	0.334	Olivine	-
K_2O	0.049			K_2O	0.065		
Sum	100.3				100.4		

Table 1 (Continued)

	Olivine basalts	Quartz basalts	KREEP basalts
La	4.87	6.11	81.5
Ce	13.5	16.8	198
Nd	10.4	11.6	132
Sm	3.53	4.11	38.4
Eu	0.893	1.02	2.81
Gd	5.1	5.5	43.5
Tb	0.80	0.90	7.3
Dy	5.38	6.03	49.8
Ho	1.0	1.2	10.6
Er	3.1	3.5	27
Yb	2.27	2.73	24.9
Lu	0.319	0.394	3.82
Co	52.6	46.7	27
Sc	45.2	43.4	29
Hf	2.6	2.8	29
Cr	4430	3480	-
Mn	2190	2130	-

[1] Helmke P. A. and Haskin L. A. (1973) Rare-earth elements, Co, Sc, Hf in the Steens Mountain basalts. Geochim Cosmochim. Acta. In Press.

[2] Kay, R., Hubbard, N. J., and Gast, P. W. (1970) Chemical characteristics and origin of oceanic ridge volcanic rock. J. Geophys. Res. 75, 1585-1614.

[3] Humphries D. J., Biggar G. M., and O'Hara M. J. (1972) Phase equilibria and origin of Apollo 15 basalts, etc. In The Apollo 15 Lunar Samples (ed. J. W. Chamberlain and C. Watkins) 103-107, Lunar Science Institute.

[4] Albee A. L., Chodoa A. A., and Gancarz A. J. (1972) Petrology of Apollo 15 sample 15486. In The Apollo 15 Lunar Samples (ed. J. W. Chamberlain and C. Watkins) 20-25, Lunar Science Institute.

[5] Weigand P. W. (1972) Petrology of pyroxene vitrophyre 15597. In The Apollo 15 Lunar Samples (ed. J. W. Chamberlain and C. Watkins) 187-188, Lunar Science Institute.