IMPLICATIONS OF ZR AND HF ABUNDANCES AND THEIR RATIOS IN LUNAR MATERIALS, Lindgren L. Chyi and William D. Ehmann, Department of Chemistry, University of Kentucky, Lexington, Kentucky 40506.

In continuation of our studies of Zr and Hf abundances in lunar materials we have directed our attention to their modest fractionation among various lunar rock types. Our 17 new analyses are listed in Table 1. These analyses along with our other published data (1) are plotted as Figure 1.

The four major rock types which include mare basalt, KREEP basalt, very high aluminum basalt, and anorthosite (2) can be readily distinguished based on Zr and Hf abundances and Zr/Hf ratios. Mare basalts have moderate Zr-Hf contents grouped according to missions from an average of 111 ppm for Apollo 15 up to 534 ppm for Apollo 11, and low Zr/Hf ratios ranging from 38.8 for Apollo 15 down to 33.9 for Apollo 11. KREEP basalts are characterized by very high Zr contents (Zr mean=1380 ppm) and high Zr/Hf ratios (mean=48.2). Very high aluminum (VHA) basalts have an average Zr content of 296 ppm which is much lower than that for the KREEP basalts, but their mean Zr/Hf ratio of 46.8 is very similar to that of KREEP basalts. Hence, our Zr-Hf data do not reveal whether the VHA materials represent an independent magma type (2,3), or are related to KREEP basalts (4). Anorthosites have very low Zr and Hf contents. Owing to the difficulty of measuring the Zr content at this low level, we cannot report a reliable Zr/Hf ratio at the present time. However, if Apollo 16 soils are derived from anorthosite, VHA basalts, and KREEP basalts, the Zr/Hf ratio in typical anorthosites must be lower than 45.5 which is the average ratio for Apollo 16 soils. It is worth noting that Apollo 14 rock 14053 with Al_2O_3, FeO and MgO contents intermediate between those of typical mare basalts and those of VHA basalts (5) has a Zr/Hf ratio also intermediate between the ratios for these two rock types. The orange soil from the Apollo 17 mission has a very low Zr/Hf ratio (32.6) which is lower than for any lunar rock types discovered. This indicates that the orange soil cannot be produced by simple mechanical mixing of any identified rock types for which data are presently available. We have previously suggested that these modest Zr-Hf fractionations may be due to a Zr-Hf charge disparity under extremely reducing conditions, where Zr exists as 3+ while Hf remains as 4+ (1).

Because of the geochemical coherence of Zr and Hf, their improbability of forming volatile complexes in the lunar environment, and their very low abundances in both chondritic and iron meteorites, the Zr/Hf ratios in lunar rocks should be representative of their original magmas, and relatively independent of cooling rates, release of volatiles, and surface processes. Although the Zr contents in ilmenite and ulvöspinel are a function of temperature and may change due to subsolidus redistribution if the magma has been cooled slowly enough (6), the Zr/Hf ratios as established by bulk chemical analyses should always represent the original ratios at the time the rock was first solidified.

IMPLICATIONS OF ZR AND HF ABUNDANCES

Chyi, L. L. et al.

Table 1. Additional Zr and Hf abundances in lunar materials.

Sample	Description	Zr (ppm)	Hf (ppm)	Zr/Hf (weight)	
10003,36	Mare basalt	336	10.1	33.3	[34.3]
		367	10.4	35.3	
10022,32	Mare basalt	596	17.6	33.8	[33.8]
		617	18.3	33.7	
10024,20	Mare basalt	598	18.0	33.3	[33.5]
		689	20.5	33.6	
12051,46	Mare basalt	141	4.17	33.8	[34.0]
		147	4.30	34.2	
12063,60	Mare basalt	137	4.23	32.4	[32.2]
		141	4.41	32.0	
15016,31	Mare basalt	93.9	2.48	37.9	[38.1]
		98.5	2.58	38.2	
60015,65B	Anorthosite	<4	0.020	-	
		<4	0.015	-	
60025,72	Anorthosite	<4	0.015	-	
		<4	0.012	-	
60335,33	VHA basalt ?	359	7.62	47.1	[47.0]
		343	7.32	46.9	
61016,133B	VHA basalt	235	5.06	46.4	[46.5]
		244	5.24	46.6	
61501,11	<1 mm fines	194	4.27	45.4	[45.0]
		193	4.34	44.5	
64421,20A	<1 mm fines	183	4.14	44.2	[44.0]
		198	4.52	43.8	
64501,10B	<1 mm fines	173	3.84	45.1	[46.4]
		187	3.93	47.6	
65015,54	Metaclastic rock	920	19.8	46.5	[46.8]
	with high KREEP	1010	21.4	47.1	
71500,5	Unsieved fines	212	6.95	30.5	[31.0]
		229	7.28	31.5	
73235,54	Blue gray breccia	n.d.*	0.21*	-	
		365**	8.03**	45.5**	
74220,90	Orange soil	203	6.07	33.4	[32.6]
		193	6.08	31.7	

* Separated white inclusions. ** Basaltic clast. [ ]= mean value

Note: Other data discussed in the text have been published previously (1).

IMPLICATIONS OF ZR AND HF ABUNDANCES

Chyi, L. L. et al.

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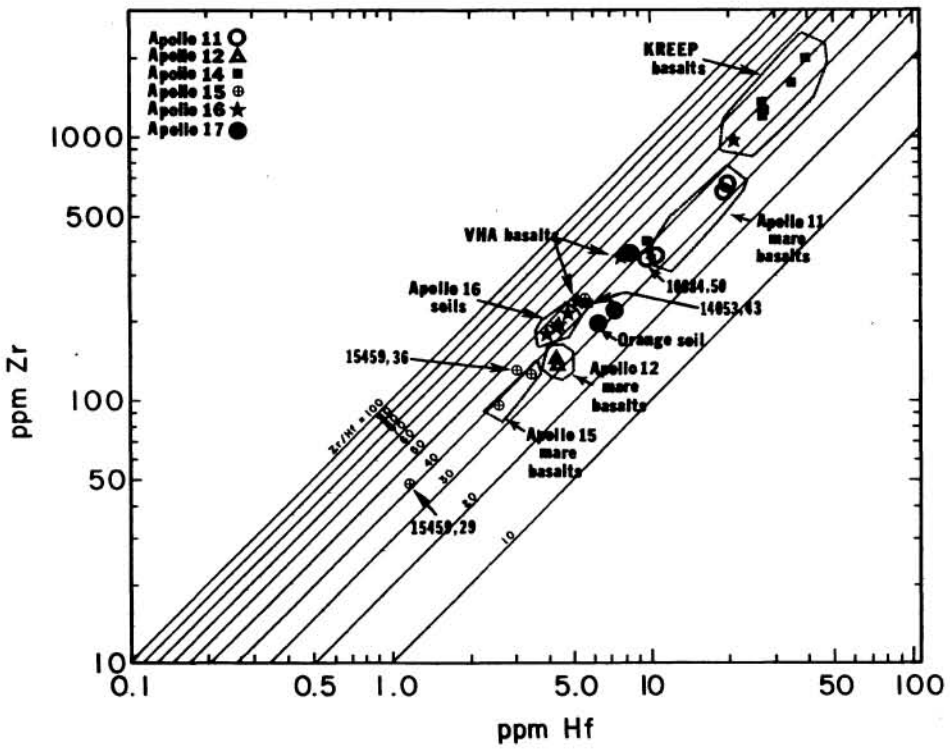

Fig. 1. Zr and Hf abundances and weight ratios in lunar materials.