LUNAR ROCK TYPES. B..M. Bansal[2], P.W. Gast[1], N.J. Hubbard[1], L.E. Nyquist[1], J. M. Rhodes[2], C.Y. Shih[3], and H. Wiesmann[2]. [1]NASA Manned Spacecraft Center, Houston, TX 77058, [2]Lockheed Electronics Corp., Houston, TX 77058, [3]National Research Council, NASA-MSC, Houston, TX 77058.

The data given in Table 1 are selected from a collection of over 40 new analyses of lunar rocks. Table 2 lists 10 new analyses of Apollo 16 rocks and soils. These analyses along with other published data suggest that lunar rocks can be categorized into four groups: 1) Mare and mare-like basalts, 2) KREEP basalts, with a subgroup centered around 14310 and perhaps containing Apollo 16 KREEP, 3) A newly recognized group of Very High Al_2O_3 basalts (VHA basalts) (such as 61156, 62295, 61016B, 15273,4,3, and 22007&6) with 20-24% Al_2O_3, and 4) Anorthositic rocks with greater than 24% Al_2O_3. The first three categories have clearly negative Eu and Sr anomalies. The fourth category usually has positive Eu and Sr anomalies. Definite examples of groups 2 and 3 occur at Apollo 15 and 16 sites, with one or more of these groups present at all sites. The REE, Ba, and U values in the VHA basalts are 1/3 to 1/4 those of KREEP basalts. The relative abundance of trivalent REE, Ba, and U is essentially identical with that of KREEP basalts. The grouping of these rock types in terms of Al_2O_3, Eu, and Sr is illustrated in Figures 1 and 2. Similar groups can be identified on FeO-MgO plots (Gast, this volume). REE, Ba, and U values for mare basalts (Figure 4 and Table 1) show that there are mare-like basalts with lower FeO and higher Al_2O_3 values than mare basalts that have REE, Ba, and U patterns above those of Apollo 15 and Apollo 12 (not shown) mare basalts. The chemical characteristics of the four categories described here have the following genetic constraints: 1) VHA basalts are not a mixture of KREEP basalts and anorthosite, 2) KREEP basalts cannot be a residuum from the formation of anorthosites or from crystallization of VHA basalts, 3) VHA basalts cannot be derived from the same source as KREEP basalts simply by increasing the extent of partial melting, and 4) anorthosites were derived from liquids with a wide range of trace element concentrations. Pure plagioclase anorthosites such as 15415 have the lowest Sr and Eu values, suggesting that they are the most primitive anorthosites yet analyzed. Anorthosites like 64423,13,1, but not anorthosites like 15415, may have been derived from VHA basalts. We suggest that the differences in composition observed in rocks with negative anomalies (groups 1-3) originated during partial melting; i.e., during the formation of these liquids. The VHA basalts do not correspond to "Highland" basalt or to "low-K Fra Mauro" basalts of Reid et al., (Meteoritics, 1972). A consideration of TiO_2 and REE values suggests that "Highland" basalt, if a true rock type, is to be associated with rocks like 15418 and 15415. Alternatively, "Highland" basalt may be a mechanical mixture of VHA basalts and materials more plagioclase rich than "Highland" basalt.

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Bansal, B. M.

Table 1. Chemical data for known or proposed primary lunar rock types. All data are from ion exchange procedures followed by colorimetry (Al_2O_3), atomic absorption (FeO, MgO, CaO and Na_2O) and stable isotope dilution mass spectrometry (all else).

	14143,3,100 9.2 mgms fragment	14152,5,102 11.1 mgms fragment	14161,35,7 27.3 mgms fragment	15076,21 61.1 mgms mare basalt	15256,22 60.2 mgms meta-mare basalt	15475,35 51.9 mgms mare basalt	15545,13 50.0 mgms mare basalt	15682,4 33.5 mgms mare basalt	15103,3,4 22.8 mgms fragment	15273,4,3 13.4 mgms fragment
TiO_2%	0.527	1.17	1.11	1.90	2.47	1.66	2.35	2.25	---	0.530
Al_2O_3%	---	21.3	---	---	---	---	---	---	12.5	23.2
FeO%	4.7	7.5	6.1	18.5	22.2	---	22.0	18.2	---	6.2
MgO%	4.8	6.4	6.2	7.75	9.03	8.31	9.45	7.94	6.45	10.9
CaO%	15.8	13.4	12.8	---	9.93	---	---	---	11.5	10.4
Na_2O%	0.63	0.79	0.74	0.30	0.26	0.33	0.283	0.39	0.34	0.61
Cr ppm	---	---	---	---	---	---	---	---	---	1020
K ppm	1,900	4,100	3,730	411	316	3.47	387	568	477	2126
Rb ppm	5.56	12.6	11.4	0.917	0.68	0.696	0.750	1.15	0.999	6.54
Sr ppm	157	202		112	100	111	104	130	114	149
Ba ppm	294	609	580	62.7	49.9	45.2	46.7	88.1	64.4	286
La ppm	23.7	56.6	55.1	7.38	4.82	4.01	4.93	8.04	6.54	23.9
Ce ppm	61.3	148	139	15.1	14.5	13.1	13.9	22.8	19.2	---
Nd ppm	37.6	85.4	83.0	10.6	10.5	8.87	9.92	16.3	13.4	38.3
Sm ppm	10.6	23.9	23.3	3.52	3.43	2.93	3.29	5.00	4.28	10.8
Eu ppm	1.34	2.28	2.04	0.970	0.893	0.481	0.895	1.51	1.03	1.34
Gd ppm	12.6	30.7	23.4	4.95	4.65	---	4.48	6.80	5.72	12.9
Dy ppm	14.3	34.0	32.1	5.60	4.98	4.59	4.68	7.26	5.58	14.9
Er ppm	8.80	19.3	19.1	3.40	2.75	2.70	2.67	4.28	3.33	9.21
Yb ppm	7.72	18.0	17.6	2.77	2.25	2.35	2.16	3.45	2.82	8.44
Lu ppm	1.16	2.59	2.56	0.326	0.330	0.350	0.308	---	---	1.25
U ppm	1.24	3.24	2.80	0.149	0.139	0.108	0.132	0.213	---	1.48
Li ppm	---	---	---	---	---	15.3	---	5.56	---	14.7

Table 1 (continued). *These values may be up to 5% low.

	15273,4,9 9.8 mgms fragment	15273,4,10 16.0 mgms fragment	15382,9,1 12.0 mgms fragment	64422,13,20 71.2 mgms fragment	64423,13,1 35.7 mgms fragment	62295,34 47.6 mgms	61156,2 52.2 mgms	62235,4 51.9 mgms A-16 KREEP	60315,3 49.4 mgms A-16 KREEP	65015,45 53.9 mgms Near KREEP
TiO_2%	2.05	2.12	2.17	0.191	0.142	0.685	0.645	1.18	1.26	1.10
Al_2O_3%	---	---	14.9	29.0	29.4	20.3	22.9	18.5	17.7	23.2
FeO%	10*	9.7*	9.2*	2.5	0.39	5.84	8.0	9.4	10.3	8.71
MgO%	7.8	7.6	7.4	5.07	0.23	14.3	9.3	10.0	13.3	9.5
CaO%	9.6	6.5	7.1	16.0	18.3	10.6	13.3	11.5	10.1	12.0
Na_2O%	0.93	0.76	0.85	0.84	0.61	0.46	0.38	0.46	0.55	0.59
Cr ppm	---	---	---	400	50	773	852	1,309	1,477	2,350
K ppm	4,767	5,300	5,270	249	320	605	1,009	2,926	3,000	2,830
Rb ppm	14.6	17.1	16.1	0.206	0.18	4.59	2.46	9.32	9.80	9.09
Sr ppm	191	189	195	235	183	139	154	161	156	164
Ba ppm	740	788	793	37.2	54.2	187	193	568	445	492
La ppm	73.1	80.2	79.5	1.29	2.31	18.6	20.5	60.1	45.5	49.5
Ce ppm	195	207	212	2.1	7.06	45.9	51.8	153	113	125
Nd ppm	118	125	127	2.46	2.76	29.0	33.1	94.3	71.3	78.0
Sm ppm	32.4	35.3	35.2	0.664	0.619	8.30	9.37	27.1	20.1	22.2
Eu ppm	2.69	2.71	2.77	1.39	0.929	1.18	1.31	2.03	1.89	1.91
Gd ppm	---	43.6	42.9		0.645	10.1	11.8	32.2	23.8	26.6
Dy ppm	---	45.4	45.7		0.556	10.8	12.2	35.0	26.3	28.8
Er ppm	24.0	26.8	28.1		---	6.85	7.09	21.2	15.5	16.8
Yb ppm	21.9	25.1	24.0		0.257	6.06	6.50	18.7	14.0	15.3
Lu ppm	3.21	3.56	3.43		0.0426	0.879	---	---	---	2.24
U ppm	3.39	3.92	3.72	---	---	0.882	0.943	2.53	2.05	3.42
Li ppm	---	---	---	---	5.1					

Table 2. X-ray fluorescence analyses of Apollo 16 samples.

	60315,57	62235,56	65015,45	62295,34	68416,33	66095,37	68501,27	64801,18	64421,22	63501,21
	KREEP-like rocks			WHA basalts	gabbroic anorthosites		soils			
SiO_2	46.84	47.05	47.18	44.73	45.04	44.07	45.18	45.03	44.68	45.02
TiO_2	1.39	1.19	1.04	0.68	0.33	0.18	0.58	0.61	0.55	0.53
Al_2O_3	17.24	18.88	19.98	20.28	28.75	30.02	26.65	27.37	27.63	27.72
FeO	8.86	9.45	7.91	6.29	4.27	3.03	5.48	5.36	4.90	4.72
MnO	0.12	0.13	0.12	0.10	0.07	0.05	0.07	0.08	0.08	0.07
MgO	13.81	10.16	10.34	15.06	4.49	4.72	6.28	5.66	5.33	5.25
CaO	10.50	11.60	12.03	11.78	16.31	16.65	15.35	15.64	15.69	15.87
Na_2O	0.51	0.42	0.44	0.43	0.34	0.35	0.47	0.36	0.47	0.46
K_2O	0.39	0.33	0.32	0.08	0.08	0.08	0.11	0.13	0.11	0.09
P_2O_5	0.48	0.39	0.40	0.13	0.08	0.06	0.12	0.13	0.11	0.10
S	0.14	0.10	0.13	0.07	0.05	0.14	0.08	0.08	0.07	0.06
Total	100.28	99.70	99.89	99.63	99.81	99.55	100.37	100.45	99.62	99.89

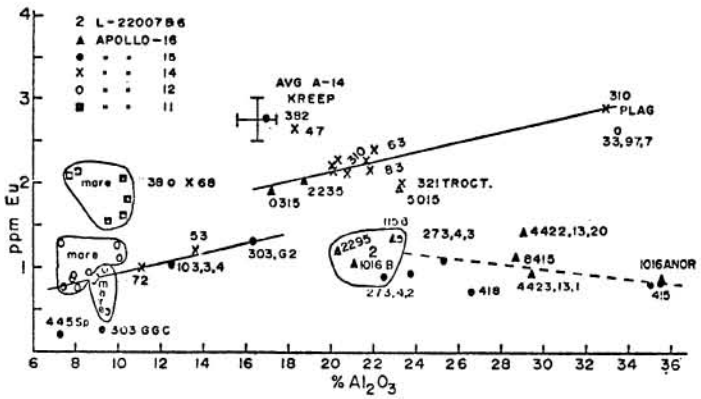

Fig. 1. Eu and Al_2O_3 data for lunar rock types. Highland basalt (Reid et.al, 1972) has $Al_2O_3 \sim$ 26% and thus may be a mixture of very high Al_2O_3 basalts and more aluminous materials.

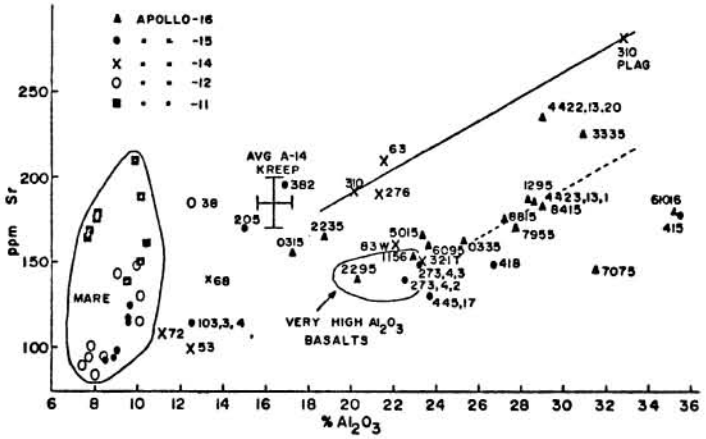

Fig. 2. Sr and Al_2O_3 data for lunar rock types. Note the wide range in Sr and Eu (Fig. 1) values for samples with more than 26% Al_2O_3.

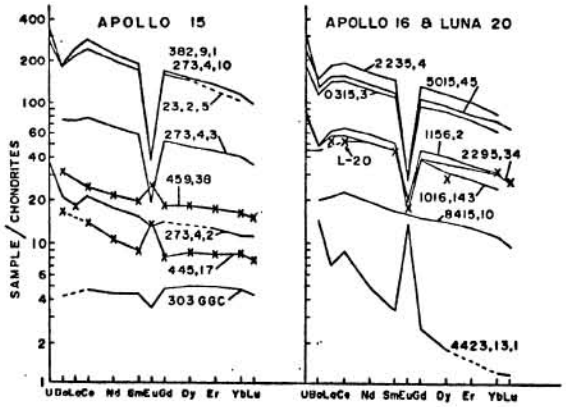

Fig. 3. REE, Ba and U data for several lunar samples with more than 16% Al_2O_3 and a green glass clod (15303 GGC). Note the general similarity in slope for the aluminous samples.

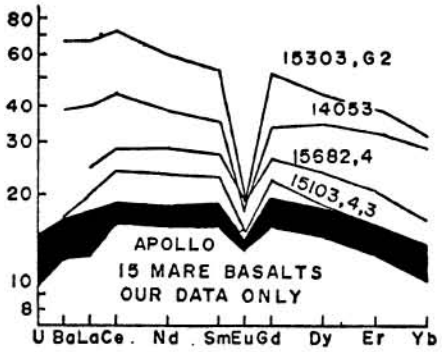

Fig. 4. REE, Ba and U data for A-15 mare basalts and four examples of mare-like basalts. Note that the slope of the pattern approaches that of the aluminous samples in Fig. 3.