LUNA 16 REVISITED: THE CASE FOR ALUMINOUS MARE BASALTS. Arch M. Reid, NASA Johnson Space Center, Houston, TX 77058 and P. Jakeš, Lunar Science Institute, Houston, TX 77058 and Geological Survey, Prague, Czechoslovakia.

Lunar soils in the mare basins have compositions that are more aluminous than the local mare basalts. The aluminium excess reflects the admixture of material more aluminous (more feldspathic) than the returned mare basalt samples. One source of this material is undoubtedly the highly feldspathic rocks from the lunar highlands. We suggest that a second source may be mare basalts with higher Al and lower Fe than most of the returned mare basalt samples. Aluminous mare basalts may be present at several sites and may be a common lunar rock type. Evidence for the existence of aluminous mare basalts is provided by basalt samples at the Apollo 12 and 14 sites, by basalt fragments at the Luna 16 site and by glass compositions at each mare site. These samples are described below and evidence that they are not secondary melts is presented.

The basalt samples are the ophitic basalt 12038, the subophitic basalts 14053 and 14072 and the basaltic clasts in 14321. Figures 1 and 2 show that those samples form a group distinct from the other mare basalt samples. Basalt fragments from Luna 16 plot with the high Al group as do preferred glass compositions from the mare soils. The aluminous mare basalts, relative to other mare basalts have lower Ca/Al ratios (close to meteoritic), lower Fe but comparable Mg/Fe ratios and higher Si. TiO_2 varies from 2 to 5 wt. percent (Table 1). Large ion lithophile trace element abundances are high (e.g. Ba) and siderophile trace elements low. REE abundances are 50 to 80 times chondritic but with Sm/Eu ratios lower than for mare basalts with comparable total REE abundances (Table 2).

Pyroxene is the major mineral with a wide range of pigeonite and augite compositions, Ti/Al near 0.5, extreme Fe-enrichment and no orthopyroxene. Pyroxenes more magnesian than Mg/Mg+Fe 0.7 are rare, in contrast to other lunar basalts. Feldspar is more abundant than in most mare basalts and is mostly anorthitic but ranges from An_{97} to An_{75}. A variety of olivine compositions are found (Fo 76 to 43) with Fo 65 most abundant; high Mg varieties are very rare. In comparison to other mare basalts the Cr content is low (0.1 wt. percent), only slightly higher than in olivines from highland rocks. Opaque phases are ilmenite and lesser chrome spinel and troilite. Metallic iron is rare and is low in Ni. Experimental studies on these compositions indicate somewhat lower liquidus temperatures than most mare basalts, with a narrow temperature range for the precipitation of the major silicate phases (plagioclase, olivine, pyroxene). Sample 12038, for example, was shown to be a low pressure, relatively low temperature, cotectic liquid (1).

Surveys of glass compositions in mare soils have shown that glasses with the composition of the dominant mare basalt samples are rare and that at each site there is a prominent glass group with the composition of the aluminous mare basalts (Table 3). The high Al content of these mare glasses must be due, in part, to the mixing of Fe-rich mare basalt with more aluminous material. The glass data are also consistent with the hypothesis that the larger samples may not adequately represent the mare basalt population and that aluminous mare basalts are common rock types in the mare basins (2).

ALUMINOUS MARE BASALTS

Reid, A. M. et al.

Aluminous mare basalts range in age from 3.28 AE for 12038 through 3.42 for a Luna 16 fragment to 3.99 for 14053. The basalt component in 14321 has been dated at 4.05 and is probably pre-Imbrian.

Several regions of the Moon apparently contain aluminous mare basalts, e.g. Mare Fecunditatis, Oceanus Procellarum. Mare Crisium and parts of Mare Nubium have Al/Si ratios that may indicate similar material. The low Ni content and low siderophile element content of at least some of these basalts rules out substantial meteoritic contamination and origin of these rocks by impact melting of the lunar regolith. The high Cr contents are incompatible with extensive near surface fractionation involving pyroxene. Intermediate in composition between the mare basalts and highland rocks, the aluminous mare basalts may be primary melts derived from a source region transitional between the aluminous lunar crust and a mafic lunar mantle. The mare basalts sampled by the Apollo missions may represent the highest levels and youngest portions of mare filling. Aluminous mare basalts though rare as surface samples, may be important in the total volume of mare fill.

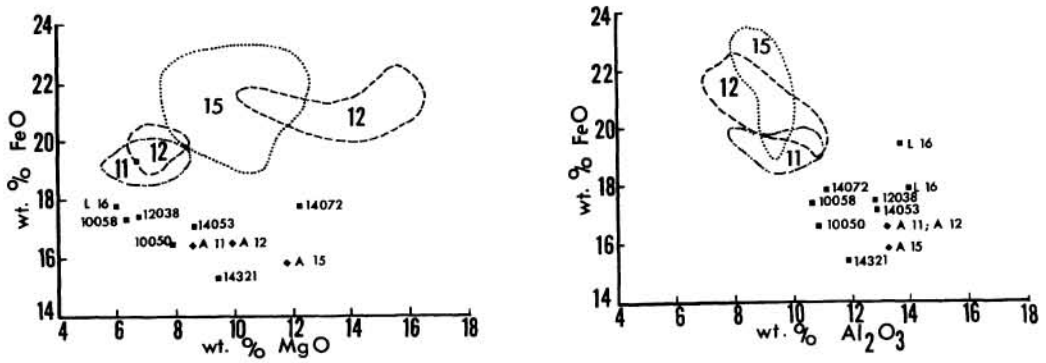

Figure 1. FeO-MgO and FeO-Al_2O_3 plots of aluminous mare basalts (squares). Circled areas define the compositional fields of mare basalts from different Apollo missions. Diamonds represent the averages of preferred glass compositions in mare soils.

Table 1. Compositions of aluminous mare basalts.

	12038	14053	14072	14321, basalt	Luna 16 basalt	
SiO_2	46.56	46.18	45.15	48.06	45.50	43.8
TiO_2	3.31	2.94	2.57	2.42	4.04	4.9
Al_2O_3	12.53	12.84	11.07	11.91	13.95	13.65
Cr_2O_3	0.27	0.26	0.51	0.21		
FeO	17.99	17.09	17.82	15.31	17.77	19.35
MnO	0.27	0.26	0.27		0.26	0.20
MgO	6.71	8.59	12.16	9.42	5.95	7.05
CaO	11.62	11.18	9.84	10.87	11.96	10.4
Na_2O	0.66	0.44	0.32	0.64	0.63	0.38
K_2O	0.77	0.11	0.08	0.18	0.21	0.15

ALUMINOUS MARE BASALTS

Reid, A. M. et al.

Table 2. Selected trace elements in aluminous mare basalts.

	12038	14053	14072	14321, basalt	Luna 16
La	11.8	13.0	8.7	28	29
Ce	29.1	34.5	27	84	29
Pr			3.3	12	
Nd	22	21.9	13	46	27.4
Sm	7.57	6.56	4.4	14	8.23
Eu	1.969	1.21	1.00	1.50	2.2
Gd	10.1	8.59	5.9	17	10.4
Tb	1.61		.91	2.5	
Dy	9.73	10.5	6.1	15	
Ho	1.99		1.8	3.7	
Er	5	6.51	4.6	9.8	5.95
Tm			.78	1.5	
Yb	4.80	6.00	4.0	7.7	5.4
Y			38	74	
Lu	.689				0.75
Sr		98	108	120	303
Ba		146	128	280	215
Rb		2.19	1.4	5.7	2.1
U		.60			

Table 3. Preferred compositions of mare glass groups.

Mission	11	12	15	17
SiO_2	40.2	43.7	45.70	48.22
TiO_2	7.2	3.3	1.60	1.09
Al_2O_3	13.2	13.2	12.39	12.93
Cr_2O_3			.33	.37
FeO	16.5	16.5	15.83	15.55
MgO	8.5	9.9	11.72	8.69
CaO	12.0	11.1	10.41	12.38
Na_2O	0.3	0.2	.30	.45
K_2O	0.10	0.16	.10	.02

REFERENCES:

(1) Biggar G.M., O'Hara M.J., Peckett A. and Humphries D.J. (1971) Proc. 2nd Lunar Sci. Conf. 1, 617-643.

(2) Reid A.M., Warner J., Ridley W.I., Johnston D.A., Harmon R.S., Jakes P. and Brown R.W. (1972) Proc. Third Lunar Sci. Conf. 1, 363-378.

(3) Data sampled from rather numerous sources and generally available in Warner J.L. (1974) Unpublished compilation of Apollo chemical, age and modal information on file in the Curator's Office, NASA-JSC, Houston, TX.