CLASSIFICATION AND PETROGENESIS OF APOLLO 15 MARE BASALTS. J. M. Rhodes[1], W. I. Ridley[2], R. Brett[3]. [1]Lockheed Electronics Company, Houston, TX 77058; [2]Lunar Science Institute, Houston, TX 77058; [3]NASA Manned Spacecraft Center, Houston, Tx 77058.

On the basis of bulk chemistry, it has been shown that two distinct basalt types have been sampled at the Apollo 15 site[1-3]. Additional data[4-6] confirm this subdivision. The types are an olivine normative group (norm. ol. 4-19%) characterized by high FeO (>21%) and low SiO_2 (<46%), and a quartz normative group (norm. qtz. 0.4-2.1%) with higher SiO_2 (>47%) and lower FeO (<20.5%) concentrations. These two groups are clearly resolved by MgO-TiO_2 relationships (Fig. 1), the equation TiO_2=3.62-0.157 MgO providing an effective discriminant. The quartz normative basalts have markedly higher Sr and lower Ni concentrations than the olivine normative basalts (Table 4)[5,7]. K/U ratios[8] are higher for the quartz normative basalts than the olivine normative rocks, 3095 (std. dev. = 163) and 2551 (std. dev. = 109), respectively. Similarly, Rb, Y, Zr, Nb tend to be higher in the quartz normative group (Table 4).

These two chemically defined basalt types can be correlated with the petrographic groups proposed by LSPET[9] and Brown[10] (Table 2). On the basis of both petrographic and chemical criteria, 15065, a pigeonite gabbro, belongs to the quartz normative group. However, it is slightly olivine normative and cannot be related to other members of the group by addition or subtraction of reasonable liquidus phases such as pigeonite, olivine or spinel. This sample may, therefore, belong to a third, as yet undefined, basalt group.

Textural studies, supplemented by phase equilibria experiments[11-13], have established a crystallization sequence that can generally be applied to the Apollo 15 mare basalts. The sequence in order of onset of crystallization is chromite, Fe-Ni, and (olivine); ulvöspinel, ilmenite, troilite and pyroxene; plagioclase; tridymite and/or cristobalite; mesostasis. This sequence is essentially identical to that of the Apollo 12 basalts, except that troilite crystallizes earlier.

Vitrophyres from Dune Crater (15499, 15485, 15486) contain liquidus pigeonite varying from En_{70} to En_{66}, and highly magnesian chromite, preserved by extremely rapid cooling. In addition, two of these samples contain highly forsteritic olivine that appears to be metastable. These vitrophyres, which are the best candidates for liquid compositions in the quartz normative group, are also the most primitive (high MgO/MgO+FeO) and may be parental to other members of this group. 15058, which is a coarse-grained rock, isochemical with the olivine bearing vitrophyre 15499, contains no olivine. Starting with an inferred parental magma similar to 15499, the small chemical variation observed for the quartz normative basalts can be accounted for by removal of small amounts (<7%) of pigeonite (En_{68}) and olivine (Fo_{72}) ±chromite[1]. This model is consistent with experimental data, which show that liquidus olivine reacts with near-liquidus pigeonite and liquid[11].

The composition of early formed chromite in the olivine normative basalts is extremely sensitive to cooling rates. Similarly, the ratio ulvöspinel/chromite appears to be a sensitive indicator of cooling rates, on the basis that rapidly cooled assemblages have little time for the peritectic reaction between chromite, ulvöspinel and liquid[14] to occur.

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For many of the olivine normative basalts, the common discrepancy between experimentally determined and theoretically calculated liquidus olivine compositions on the one hand and the more fayalitic measured composition of the naturally-occurring olivines on the other, strongly indicates that most rocks have been modified by addition or subtraction of mineral phases accompanied by sub-liquidus crystal-liquid reactions. Among the MgO-rich members of this series, 15016 shows a consistency between experimental liquidus and natural olivine compositions (Fo_{72})[13], and appears to be the most likely candidate for a parental liquid of the olivine normative group. Starting with a magma of this composition, it is possible to derive all the members of the olivine normative group by up to 14% crystal fractionation involving olivine ±spinel [1-3]. The small increase in Sr, Zr, Nb, Y contents, with decreasing MgO/MgO+FeO for both basalt groups (Table 4)[5], provides qualitative support for the two models presented here.

It has been shown earlier[1] that the quartz normative basalts cannot be derived from the olivine normative basalts or, vice versa, by near-surface crystal fractionation. Similar arguments also apply to sample 15065. It is suggested, therefore, that the chemical variation observed within each basalt group is the product of near-surface crystal fractionation, and that the between-group differences reflect either inhomogeneity in the lunar mantle or differences in degrees of partial melting of similar sources. If the latter, then the higher trace element abundances in the quartz-normative basalts indicate that they have been derived by slightly lower degrees of partial melting than the olivine normative basalts. Both basalt types, although similar in bulk chemistry to the Apollo 12 olivine and pigeonite basalts[15], are characterized by lower concentrations of TiO_2, K_2O, Rb, Zr and Y for a given MgO/MgO+FeO ratio. If the Apollo 15 basalts derive by partial melting from a source similar to that postulated for the Apollo 12 mare basalts, then the extent of melting must have been slightly greater for both Apollo 15 groups.

REFERENCES

1) Rhodes, J. M. (1972) in The Apollo 15 Lunar Samples, 250-254, Lunar Science Institute.
2) Chappell, B. W., and D. H. Green (1972) pers. comm.
3) Mason, B., et al.,(1972) Geochim. Cosmochim. Acta Suppl. 3, 785-796.
4) Strasheim, A., et al., (1972) in The Apollo 15 Lunar Samples, 257-259.
5) Willis, J. P., et al., ibid., 486-489.
6) Christain, R. P., et al., ibid., 206-209.
7) Compston, W., et al., ibid., 347-351.
8) O'Kelley, G. D., et al., ibid., 244-249.
9) Apollo 15 LSPET (1972) Science 175, 363-375.
10) Brown, G. M., et al. (1972) in The Apollo 15 Lunar Samples, 40-44.
11) Humphries, D. J., et al., ibid., 103-107.
12) Longhi, J., et al., ibid., 131-134.
13) Kushiro, I., ibid., 128-130.
14) Kushiro, I., et al., (1970) Amer. Geophys. Union Trans. 51, 585.
15) James, O. B., and T.L. Wright (1972) Geol. Soc. America Bull. 83,2357-2382.

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Table 1. X-ray fluorescence analyses of Apollo 15 mare basalts.

	Quartz normative basalts.						Previous missions.		
	15475,35	15499,2	15058,5	15076,2	15076,21	Mean	Mean Apollo 12	Mean Apollo 11 (low-K)	Mean Apollo 11 (high-K)
SiO_2	47.82	47.62	47.81	48.80	48.06	47.83	44.9	49.6	40.3
TiO_2	1.96	1.81	1.77	1.46	2.01	1.89	3.36	10.2	11.5
Al_2O_3	9.52	9.27	8.87	9.30	9.63	9.32	8.95	10.2	8.72
FeO	19.95	20.26	19.97	18.62	20.22	20.10	20.8	19.0	19.6
MnO	0.29	0.28	0.28	0.27	0.29	0.29	0.27	0.28	0.25
MgO	8.28	8.54	9.01	9.46	7.80	8.51	11.2	6.92	7.64
CaO	10.65	10.40	10.32	10.82	10.74	10.53	9.70	11.6	11.5
Na_2O	0.24	0.29	0.28	0.26	0.29	0.27	0.27	0.41	0.52
K_2O	0.04	0.06	0.03	0.03	0.05	0.04	0.06	0.08	0.30
P_2O_5	0.07	0.08	0.08	0.03	0.08	0.08	0.11	0.09	0.18
S	0.07	0.07	0.07	0.03	0.08	0.07	-	-	-
Total	98.89	99.08	98.49	99.08	99.25	98.93	99.6	99.4	100.5

	Olivine normative basalts.						
	15556,5	15256,15	15256,22	15668,2	15545,13	15016,4	15555,8	Mean
SiO_2	45.11	44.93	45.12	45.48	45.02	43.97	44.24	44.84
TiO_2	2.76	2.54	2.51	2.56	2.33	2.31	2.26	2.47
Al_2O_3	9.43	8.89	8.95	9.09	8.77	8.43	8.48	8.86
FeO	22.25	22.21	22.52	22.22	22.02	22.58	22.47	22.32
MnO	0.29	0.29	0.32	0.31	0.30	0.33	0.29	0.30
MgO	7.73	9.08	9.32	9.19	10.36	11.14	11.19	9.72
CaO	10.83	10.27	10.14	10.23	9.89	9.40	9.45	10.03
Na_2O	0.26	0.28	0.25	0.26	0.21	0.21	0.24	0.24
K_2O	0.03	0.03	0.04	0.05	0.03	0.03	0.03	0.03
P_2O_5	0.08	0.06	0.07	0.08	0.05	0.07	0.06	0.07
S	0.08	0.08	0.07	0.08	0.07	0.07	0.05	0.07
Total	98.94	98.66	99.31	99.55	99.05	99.54	99.46	98.69

Table 2. Chemical and petrographic classification of Apollo 15 mare basalts.

I. QUARTZ NORMATIVE BASALTS

SiO_2 > 47%; FeO < 20.5%; TiO_2 < 3.62 - 0.157 MgO.

A. Porphyritic clinopyroxene basalts - 15058; 15065; 15076; 15117(?); 15475; 15495.
B. Porphyritic clinopyroxene basalt vitrophyre - 15499; 15597.

II. OLIVINE NORMATIVE BASALTS

SiO_2 < 46%; FeO > 21%; TiO_2 > 3.62 - 0.157 MgO.

C. Porphyritic olivine basalt - 15379(?); 15535; 15545; 15555; 15557; 15607; 15643(?); 15659(?); 15676.
D. Vesicular olivine basalt - 15016; 15556; 15668; 15672(?).
E. Recrystallized basaltic breccia - 15256.

(?) Thin sections unavailable for these samples.

Table 3. Modal analyses of Apollo 15 mare basalts.

	Quartz normative basalts			Olivine normative basalts			
	15475,16	15595,35	15485,5	15555,35	15556,136*	15606,5	15668,2
No. points	483	800	1159	1800	700	800	369
Pyroxene	64	46	53	65	57	65.5	59.6
Plagioclase	24	-	-	25	38	23	31.2
Olivine	-	-	-	5	0.1	2.6	0.8
Ilmenite	1.2	tr.	tr.	1	2.1	2.7	1.1
Cr-spinel	0.5	tr.	tr.	0.5	0.4	0.8	0.3
Ulvö-spinel	1.2	-	tr.	2	0.6	0.9	3.5
Metal	tr.	-	tr.	tr.	tr.	tr.	-
Troilite	tr.	-	tr.	tr.	0.1	tr.	-
Tridymite	0.6	-	-	-	-	-	-
Cristobolite	-	-	-	0.3	0.8	0.3	-
Mesostasis	1.7	-	-	0.4	1.0	1.2	3.0
Groundmass	-	43	42	-	-	-	-
Vesicles, vugs	6.4	11	5	-	-	2.9	0.5
Total	100	100	100	99	100	100	100

Table 4. Trace element data for some Apollo 15 mare basalts.

	Olivine normative		Quartz normative	
	15256,22	15555,8	15076,21	15475,35
Sr (ppm)	98	92	120	117
Rb (ppm)	0.6	0.6	1.1	1.2
Zr (ppm)	89	76	97	89
Nb (ppm)	5.3	4.3	6.2	5.9
Y (ppm)	25	23	29	29
Th (ppm)	<1	<1	<1	<1
Ni (ppm)	48	42	11	9

Fig. 1. MgO-TiO_2 variation in Apollo 15 mare basalts.

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