TRACE ELEMENT EVIDENCE FOR A TWO STAGE ORIGIN OF HIGH-TITANIUM MARE BASALTS. A.R. Duncan, A.J. Erlank, J.P. Willis, M.K. Sher and L.H. Ahrens. Department of Geochemistry, University of Cape Town, Rondebosch, South Africa.

We have previously noted (1,2) near constant ratios of certain pairs of elements (K/Zr, K/Ba, Zr/Nb, Zr/Ba) in Apollo 12, 14 and 15 samples, and have indicated (3) that samples which are cumulates or are derived from cumulates (e.g. Apollo 16 anorthosites) are liable to show greater variation in these ratios.

Our data for Apollo 17 materials show perturbation of the inter-element relationships previously observed, exhibiting a systematic variation of many inter-element ratios with TiO_2 content (Fig.1, Table 2). The trends shown in Fig.1 clearly represent mixing lines between a low TiO_2 component with what we have come to call "normal" lunar inter-element ratios and a high TiO_2 basaltic component with severely perturbed ratios. It is apparent that the perturbed ratios must be characteristic either of the basaltic liquids or of a cumulus phase in the basalts. Since basalt 70215 has strongly perturbed ratios, and cannot texturally be a cumulate, we consider that in the general case it must be the Apollo 17 basaltic liquids which have the perturbed ratios.

Perturbations of many of the inter-element ratios (K/Zr, Zr/Nb, Zr/Ba) could be explained if high-Ti basaltic liquids were extensive melts of ilmenite-rich cumulates, assuming the high Zr contents of lunar ilmenites (5) and Zr/Nb ratios of approximately 1 such as those in kimberlite ilmenites (6). Kimberlitic ilmenites seem relevant in view of their high Zr content ($\sim$ 1000 ppm) and the presence of armalcolite in kimberlite (7). However, the perturbation of K/Y and Zr/Y ratios in high-Ti basaltic liquids cannot be a consequence of their derivation from ilmenite cumulates since the Y content of lunar (8) and kimberlitic (6) ilmenites is very low. Armalcolite cumulates do not seem a suitable alternative in view of the low Zr content of most armalcolites (9). Other reported phases that are rich in Ti, Zr, Nb and Y (e.g. phase β, phase X, phase Y, etc.) do not seem suitable cumulus minerals in view of their trivial abundance and very late stage of crystallization in lunar rocks. We conclude that there is strong evidence for derivation of high-Ti basalts by extensive melting or assimilation of an earlier Ti-rich cumulate but that the exact cumulus assemblage cannot as yet be determined.

Available data for Apollo 11 low-K, high-Ti basalts (10) also show perturbed ratios and a comparable two stage model is applicable. The presence of a similar Ti-rich cumulate below two widely separated sites on the moon leads us to speculate that such cumulates may have formed as a complement to the early anorthositic crust of the moon. Philpotts et al. (11) have derived a similar model from data for other elements and using a different interpretive framework.

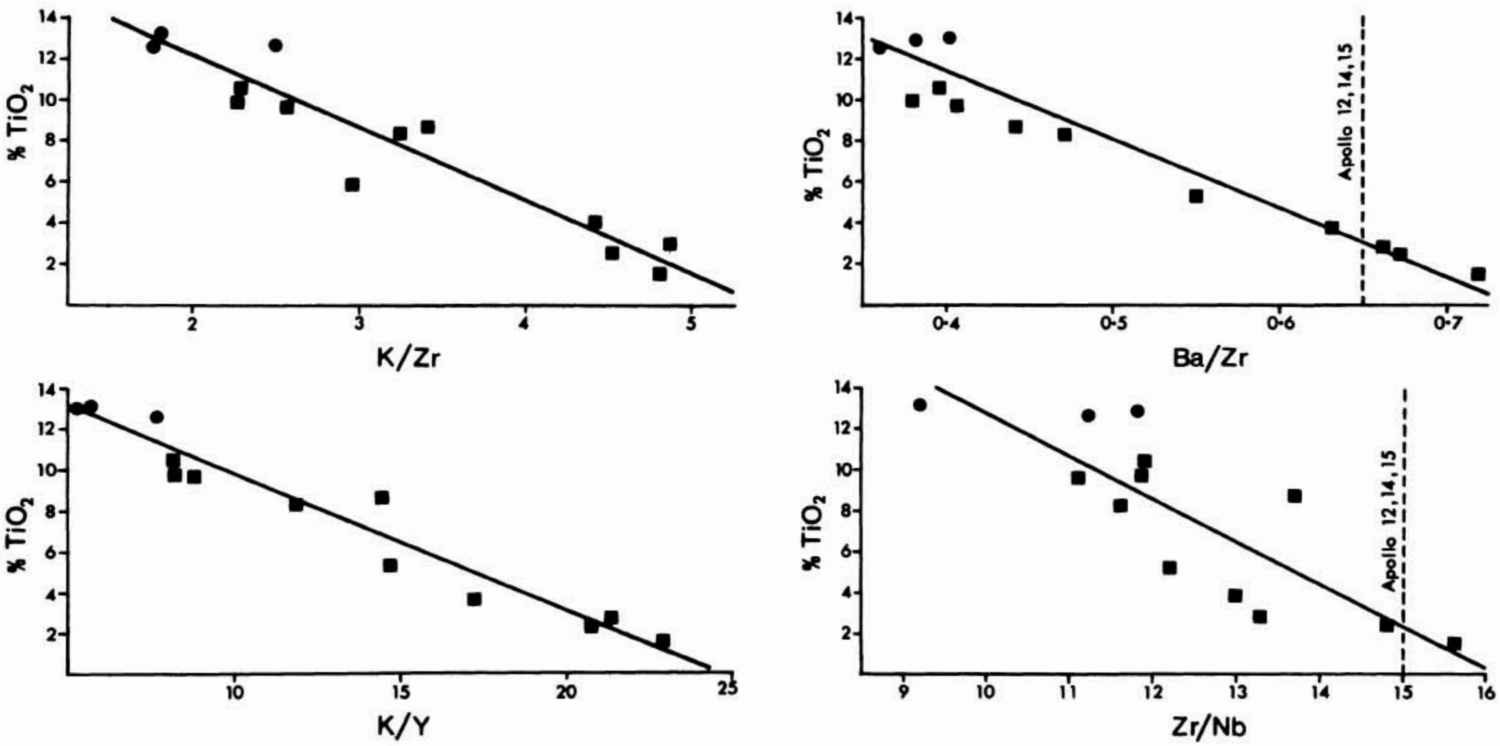

Fig. 1 Variation of selected inter-element ratios with TiO_2 content in Apollo 17 samples. Symbols ● = basalt, ■ = soil. Data are from Table 1 and Duncan et al (4)

References: (1) A.J.Erlank et al.(1972) Lunar Science III, 239. (2) J.P.Willis et al. (1972) The Apollo 15 Lunar Samples, 268. (3) A.R.Duncan et al. Proc.4th Lunar Sci. Conf. (in press.) (4) A.R.Duncan et al.,Compositional Characteristics etc. (this volume). (5) G.Arrhenius et al. (1971) Proc. 2nd Lunar Sci. Conf. 1, 169. (6) A.J. Erlank, unpublished data. (7) S.E.Haggerty (1973) Extended Abstracts, Int. Conf. on Kimberlites, Cape Town, 147. (8) C.A.Anderson and J.R.Hinthorne (1972) Science 175, 853. (9) A.El.Goresy et al. (1973) EOS 54, 591. (10) W. Compston et al. (1970) Proc. 1st Lunar Sci. Conf. 2, 1007. (11) J.A. Philpotts et al. (1973) EOS 54, 603.

TABLE 1. CHEMICAL ANALYSES OF APOLLO 17 BASALTS

MAJOR ELEMENTS (%)

	70017,18 Basalt	70215,55 Basalt	74275,58 Basalt
SiO_2	38.37	37.91	38.43
TiO_2	12.83	13.08	12.66
Al_2O_3	8.78	8.86	8.51
FeO	18.71	19.96	18.25
MnO	0.247	0.264	0.247
MgO	9.41	7.99	10.26
CaO	10.43	10.77	10.38
Na_2O	0.43	0.38	0.37
K_2O	0.047	0.041	0.075
P_2O_5	0.052	0.114	0.074
Cr_2O_3	0.577	0.431	0.639
S	0.175	0.188	0.141
Sub total	100.058	99.988	100.036
O= S	0.088	0.094	0.071
Total	99.970	99.894	99.965

TRACE ELEMENTS (ppm)

	70017,18 Basalt	70215,55 Basalt	74275,58 Basalt
Nb	18.5	20.8	22.1
Zr	218	192	248
Y	71.2	63.6	81.5
Sr	166	122	158
Rb	1.2	<1	1.9
Zn	<2	<2	<2
Cu	<3	<3	<3
Ni	<3	<3	<3
Co	18	23	24
V	146	50	79
Ba	83	77	89

TABLE 2. INTER-ELEMENT RATIOS OF APOLLO 17 SAMPLES

	70017,18 Basalt	70215,55 Basalt	74275,58 Basalt	72701,12 Soil	74121,2 Soil	74220,31 Soil	76321,3 Soil	78221,1 Soil	78501,12 Soil	75081,66A Soil	75081,66B Soil	75081,66C Soil	75081,66D Soil
Zr/Nb	11.8	9.23	11.2	15.6	14.8	13.7	13.3	13.0	12.2	11.9	11.9	11.1	11.6
Zr/Y	3.06	3.02	3.04	4.83	4.54	4.25	4.32	3.84	3.69	3.27	3.30	3.32	3.63
Ba/Zr	0.380	0.401	0.359	0.720	0.672	0.441	0.662	0.630	0.548	0.394	0.379	0.406	0.471
K/Zr	1.79	1.77	2.51	4.84	4.56	3.44	4.90	4.42	4.02	2.31	2.30	2.63	3.24
K/Y	5.48	5.35	7.63	23.4	20.7	14.6	21.2	16.9	14.8	7.54	7.58	8.76	11.8
K/Ba	4.70	4.42	6.99	6.73	6.78	7.79	7.40	7.01	7.32	5.85	6.07	6.48	6.89
Ni/Co	-	-	-	7.70	7.43	1.20	6.33	6.50	5.53	2.74	3.37	3.87	5.35

Acknowledgements: We acknowledge analytical assistance from Dr. J. Gurney and support from the University of Cape Town and the C.S.I.R.