A COMPARISON OF THE MOST PRIMITIVE SAMPLES FROM THE EARTH, THE MOON AND THE EUCRITE PARENT BODY.

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The Earth, the Moon and the eucrite parent body are differentiated planets. None of the samples analyzed from these planets has a chemical composition, resembling that of the bulk planet. But one can ask for the least differentiated samples. As a first measure for the degree of differentiation we have taken the ratio of the incompatible RE Yb to the relatively compatible Sc. Both these refractory elements do not separate during condensation (1); we should therefore expect a chondritic ratio in the bulk planets. Basalts from all three planets have similar high Yb/Sr ratios and similar high Yb contents (Fig.1).

By virtue of this ratio the Apollo 15 green glass (2,3) is the most primitive material, yet recovered from the Moon (Fig.1). The Yb/Sc ratios of a series of howardites decreases continually (from Le Teilleul, Kapoeta, Binda and Frankfort) to reach finally the chondritic ratio with Yamato (1), which is according to this criterium the least differentiated howardite (Fig 1) (4,5). A series of peridoditic nodules from Kapfenstein (Austria) approach the chondritic Yb/Sc ratio from the Yb deficient side (Fig.1). The lherzolite Ka 168 has practically a chondritic Yb/Sc ratio (6).

The Na-Mn plot (Fig.2) shows the range of analyzed samples from the three planets. Apparently, we are lacking samples from the lunar interior, low in Na (although the bulk Na content of the Moon is already quite low) and also with low Yb/Sc ratios counterbalancing the high ratios in KREEP and in mare basalts (Fig.1). The carbonaceous chondrites plotted in Fig.2 for comparison show a considerable scatter in Na contents. The "reduced" sub-group of C3V (7,8) has much lower Na and K contents than other C3 meteorites.

Fig.3 demonstrates how the series of peridoditic nodules approach chondritic (Si normalized) values for many elements. Vigarano would be a rather good match, except for still too low Mn and Zn concentrations.

The least fractionated lherzolite Ka 168 is compared to the hypothetical pyrolite (9) in Table 1. Ka 168 has essentially the same major element composition as the postulated primitive mantle material. Lherzolites with Ca and Al as high as Ka 168 are relatively rare, most analyzed peridodites are lower in Ca and Al than ~ 2 %. This value is, as one might expect, an upper limit (e.g.10-13). Highly incompatible elements such as K,Rb,Cs,U,Ba,Sr,and the light

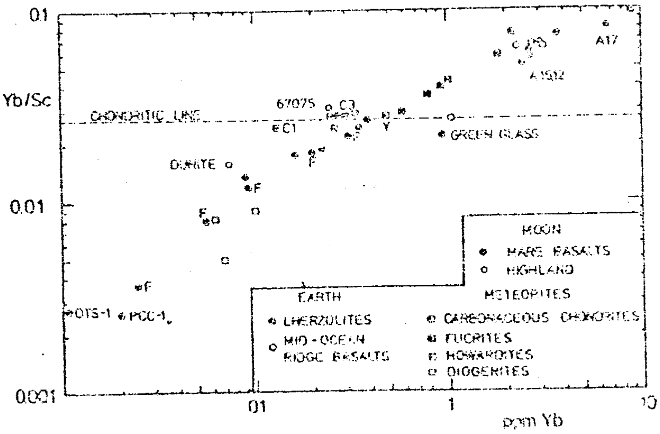

Fig.1; Y-Yamato(1), F-(13)

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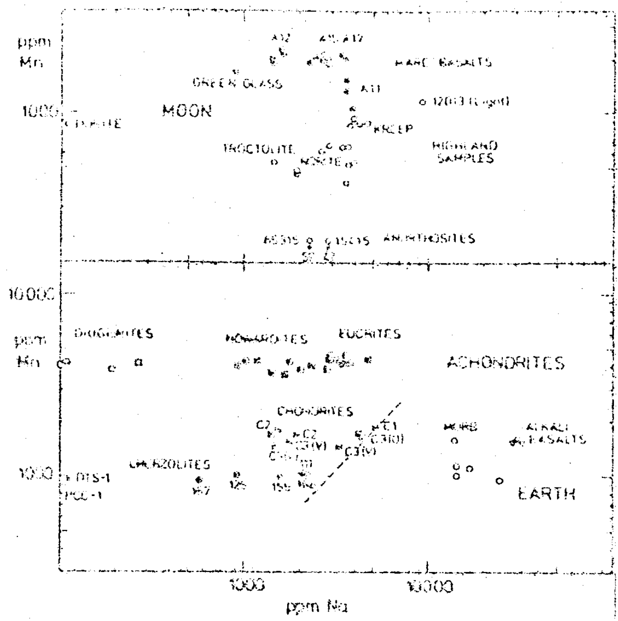

Fig.2

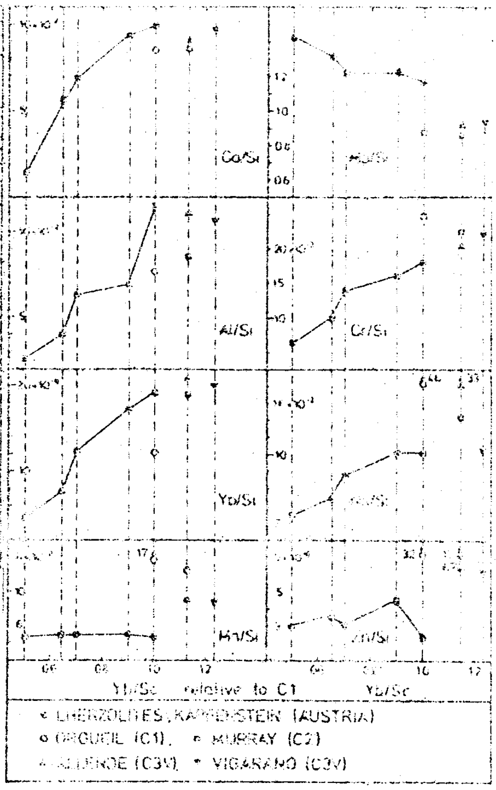

Fig.3

REE are known to be concentrated in very minor phases in the upper mantle (e.g.13). They are depleted in Ka 168. Peridoditic nodules from Victorian basanites (Australia) analyzed by Frey and Green (13) are very similar to the Kapfenstein nodules (6), with respect to major and some minor and trace elements.

In Table 2 the three primitive samples are compared with carbonaceous chondr.

Green glass: The low Fe/Si ratio and the generally low content of siderophiles indicate a prior stage of metal segregation. The low Mg/Si ratio in the green glass may be due to some olivine fractionation. A slight Sr and Eu anomaly (2) can be explained by some involvement of plagioclase. Finally, the low Cr and V contents (both elements do not enter olivine in significant amounts (6)) suggest also some separation of pyroxene, probably orthopyroxene, since the RE pattern is kept essentially flat.

Yamato (1): Again a metal phase must have been separated. The low Mg/Si ratio is also most easily explained by some earlier olivine fractionation. All other refractory elements (and Cr) have

Element	Ka 168	Pyrolite*)	Element	Ka 168	Pyrolite*)
Mg %	23.8	23.0	Sr ppm	6.9	
Al	2.3	2.1	Pd	0.02	0.012
Si	20.3	21.1	Cs	0.06	
Ca	2.2	2.2	Ba	2.3	
Ti	0.09	0.12	La	0.18	
Fe	6.2	6.1	Ce	0.66	
			Pr	0.11	
Na ppm	2040	4167	Sm	0.27	
S	300	317	Eu	0.10	
K	10		Gd	0.40	
Sc	14.7		Tb	0.70	
V	75		Dy	0.52	
Cr	3660	2524	Ho	0.12	
Mn	1010	1095	Er	0.37	
Co	106	98	Yb	0.39	
Ni	2250	1694	Lu	0.056	
Cu	6.4	36	Hf	0.15	
Zn	46.1	50	W	0.0089	
Ga	2.4	6	Re	≤0.01	0.0001
Ge	1.1	1.1	Os	≤0.01	0.005
As	0.18	1	Ir	0.006	0.002
Se	≤0.12	0.07	Pt	≤0.03	0.02
Rb	0.1		Au	0.00067	0.004
			U	9.1	

Table 1: *)-(9,10)

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within experimental error limits exactly the same element/Si ratios (Table 2). For this argument it is not relevant if the howardites ultimatley are of igneous origin or if they are mixtures between eucrites and diogenites as has been suggested by various authors (14-17). The position of Yamato(1) in the binary mixing diagram of Dreibus et al.(15) coincides exactly with the position of the eucrite parent body composition after loss of olivin. Assuming a chondritic Mg/Si ratio in the parent body, they calculated the loss of 47 % olivine (15).

	Orgueil*) C 1	Vigarano*) C 3 (V)	Ka 168 Lherzolite	Yamato(1)**) Howardite	Green Glass***) Apollo 15
Si %	10.65	15.4	20.3	23.76	21.3
Fe/Si	1.73 = 1	0.63	0.17	0.32	0.41
Mg/Si	0.88 = 1	1.06	1.33	0.61	0.53
Cr/Si (10^{-2})	2.56 = 1	0.87	0.70	1.14	0.51
Ca/Si (10^{-2})	8.6 = 1	1.13	1.26	1.41	3.53
Al/Si (10^{-2})	7.5 = 1	1.38	1.52	1.75	2.49
Ti/Si (10^{-3})	4.1 = 1	1.02	1.07	1.44	2.00
Sc/Si (10^{-5})	5.6 = 1	1.16	1.79	1.36	3.61
V/Si (10^{-4})	5.2 = 1		0.71	1.0	1.34
Sr/Si (10^{-5})	8.1 = 1	1.12	0.54	1.14	1.40
Ba/Si (10^{-5})	2.25 = 1	1.38	0.49	1.54	3.56
La/Si (10^{-6})	2.1 = 1	1.61	0.42	1.36	3.12
Sm/Si (10^{-6})	1.25 = 1	1.61	1.06	1.42	2.66
Yb/Si (10^{-6})	1.35 = 1	1.64	1.42	1.52	3.24
Mn/Si (10^{-2})	1.72 = 1	0.52	0.29	0.99	0.44
Na/Si (10^{-2})	4.65 = 1	0.22	0.22	0.08	0.09
K /Si (10^{-3})	4.22 = 1	0.29	0.01	0.07	
Zn/Si (10^{-3})	3.28 = 1	0.19	0.09	<0.004	0.03
Ga/Si (10^{-5})	7.8 = 1	0.41	0.21	0.03	
Ge/Si (10^{-4})	2.9 = 1	0.37	0.02		0.0006
Co/Si (10^{-3})	4.77 = 1	0.86	0.14	0.02	0.07
Ni/Si (10^{-1})	9.95 = 1	0.92	0.15	0.0009	0.008
W /Si (10^{-7})	8.4 = 1	1.5	0.07	0.08	
Ir/Si (10^{-6})	4.3 = 1	1.1	0.09		0.002
Au/Si (10^{-6})	1.3 = 1	0.7	0.003	0.001	0.0007

Table 2: *)-(5), **)-(4), ***)-(2,3,18).

Ka 168: The major and minor element composition is (except for Fe and Mn) quite similar to the C3V meteorite Vigarano. The removal of iron and the extraction of highly incompatible elements may have been the only processes affecting these samples. The very small degree of partial melting, which is responsible for the low contents of K, Ba etc. may also be responsible for the still slightly too high Mg/Si ratio. There are indications that other trace elements (less or not incompatible) in Ka 168 are fairly representative for the upper mantle.

References: 1) Grossman L. and Larimer J.W.(1974) Rev.Geophys.&Space Sci.12, 71. 2) Taylor S.R. et al.(1972) In Apollo 15 Lunar Samples,p. 262. The Lunar Sci.Inst.,Houston. 3) Ridley W.T. et al.(1973) PEPI 7, 133. 4) Wänke H. et al. (1977) PLSC 8th,2191. 5) unpublished data, this laboratory. 6) Kurat G. et al. in preparation. 7) McSween H.Y. and Richardson S.M.(1977) GCA 41, 1145. 8) McSween H.Y.(1977) GCA 41, 1777. 9) Ringwood A.E. and Ringwood A.E. and Kesson S.E.(1976) Publ.Nos.1221 and 1222, Research School of Earth Sciences A.N.U. 10) Ringwood A.E.(1975) Composition and Petrology of the Earth's Mantle,McGraw Hill 11) Rhodes J.M. and Dawson J.B.(1975) Physics and Chemistry of the Earth 9,545. 12) Hutchison R. et al.(1970) Mineralog.Mag.37,726. 13) Frey F.A. and Green D. H.(1974) GCA 38,1023. 14)Jérome D.J. and Goles G.G.(1971) Activation analyis in Geochem. and Cosmochem.,p.261,Universitetsforlarget,Oslo. 15)Dreibus G.et al. (1977) PLSC 8th,211. 16) Miyamoto M. et al.(1977) In Lunar Science-VIII,p. 670 The Lunar Sci.Inst., Houston. 17) Fukuoka T. et al.(1977) PLSC 8th, 187. 18) Baedecker P.A. et al.(1973) PLSC 4th, 1177.