

MAJOR AND TRACE ELEMENT CHEMISTRY OF THE MANTLE; Don L. Anderson,
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The constraint that the Earth retains the refractory elements in their cosmic or chondritic proportions is formalized into an inversion procedure which utilizes geochemical measurements on a variety of terrestrial samples as input. The basic building blocks are 1.) the continental crust which is a major reservoir of the incompatible elements, 2.) midocean ridge basalts (MORB) which are depleted in most of these elements, 3.) ultramafic rocks which are complementary to MORB and the continental crust in the major rock forming oxides, 4.) an orthopyroxene-rich component which is required to match chondritic ratios of the major elements, 5.) an optional enriched component such as kimberlite or ocean-island basalts. Approximately 400 models were calculated using three to five of the above components.

Two or three *à priori* compositions of the above components were compiled from the literature and 20 to 24 refractory lithophile elements were used in various combinations in the inversions. The target ratios were computed from recent estimates of cosmic and chondritic abundances and cosmochemical estimates of terrestrial chemistry.

The successful models are composed of 47 to 60% ultramafic rock, 36-42% orthopyroxenite, up to 14% MORB (the garnet-clinopyroxene rich component) and up to 0.1% kimberlite or 0.8% Hawaiian tholeiite (the enriched mantle components). When no allowance is made for a separate enriched component in the mantle, the trace elements can be matched with 0.7% continental crust, a value 25% higher than the amount of crust at the surface.

Important volatile-refractory ratios fall in the following ranges: Rb/Sr 0.027 - 0.042, K/U 0.48 - 1.22 ($\times 10^4$), Pb/U 6.7 - 12.2. Independent estimates of terrestrial Pb/U from Pb-isotope studies give 8.1. Using atmospheric ^{40}Ar to constrain the amount of K, and other volatiles, the above ranges are reduced to Rb/Sr 0.029 - 0.042, K/U 0.6 - 1.2 ($\times 10^4$), and Pb/U 8.8 - 12.2.

Abundances of moderately volatile elements relative to carbonaceous chondrites, are found to be Li (0.75), Mn (0.37), Na and K (0.2), Rb (0.16) and Cs (0.06). Other volatiles, relative to CI chondrites, are Zn (0.1), In (0.1), F (0.1), Pb (0.08), Bi (0.05), Tl (0.03), Cd (0.03) and Cl (0.02). The magnitude of the depletion generally correlates with volatility as defined on the basis of theoretical considerations and depletion of the various meteorite classes relative to CI. The compositions of the components and four derived primitive mantle models are given in the table. Two crustal compositions, two MORB compositions, two enriched mantle components, (kimberlite, KIMB, and a Hawaiian basalt, W998), three ultramafic rock compositions (UMR, BOYD and LHZD) and two orthopyroxenites are tabulated. These are compiled from references too numerous to list in this space. Mantle Matrix gives the percentages of each component for each of the form tabulated models. Cosmic abundances are from Anders, E. and Ebihara, M. (Geochim et Cosmochim. Acta, 46, 2363-2380, 1982).

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		CRUST		MORB										MANTLE MODELS				COSMIC
		1	2	1	2	KIMB	W998	UMR	BOYD	LHZD	OPX4	OPX2	1	2	3	4		
MG	pct	2.11	1.49	5.89	5.92	16	5.76	23.1	26.5	25.48	19.1	21.1	21.1	21.2	21.3	21	21.3	
AL	pct	9.5	8.53	8.48	9.2	1.89	6.92	2.1	0.83	1.04	1.08	0.4	1.86	1.88	1.93	1.91	1.89	
SI	pct	27.1	29.5	23.2	23.35	14.7	23.9	21.2	20.6	20.62	26	26.9	22.9	23.1	23.4	23.1	23.1	
CA	pct	5.36	3.34	8.48	9.16	7.04	6.16	2.5	0.99	1.48	0.87	0.4	1.99	2.01	1.95	2.04	2.02	
SC	ppm	38	6.5	37.3	39	15	23.8	14	14	15	22	4	20	17.6	13.8	17.5	12.6	
TI	pct	0.48	0.36	0.55	0.47	1.18	1.16	0.1	0.08	0.042	0.02	0.02	0.08	0.08	0.12	0.08	0.1	
SR	ppm	400	503	110	52	740	450	13	0.5	8.9	0.5	4.5	13.3	11.6	16.6	13.4	17.3	
Y	ppm	22	14	23	20	22	24	2	1.4	4.6	0.02	0.02	4.42	1.68	3.77	1.84	3.4	
ZR	ppm	100	210	70	35	250	146	2.2	2.2	11	11	11	14.2	6.76	12.1	8.36	8.04	
NB	ppm	11	13	2	1	110	8.4	0.4	0.4	0.9	1.4	1.4	1.36	0.86	1.03	0.89	0.55	
BA	ppm	350	707	5	4	1000	196	7	2.3	2.3	2	2	6.17	7.43	7.47	8.91	4.93	
LA	ppm	19	28	1.38	0.9	150	13.8	0.57		0.18	0.04	0.04	0.59	0.5	0.44	0.54	0.51	
CE	ppm	38	57	5.2	3.5	200	34.7	1.71		0.69	0.1	0.1	1.31	1.38	1.17	1.49	1.34	
ND	ppm	16	23	5.61	5.3	85	21.3	1.31		0.56	0.04	0.04	1.05	0.99	1.06	1.06	1	
SM	ppm	3.7	4.1	2.06	1.48	13	5.5	0.43		0.27	0.01	0.01	0.33	0.31	0.28	0.33	0.32	
EU	ppm	1.1	1.09	0.81	0.63	3	1.98	0.19		0.1	0	0	0.12	0.13	0.11	0.14	0.12	
TB	ppm	0.64	0.53	0.52	0.46	1	0.86	0.14		0.075	0	0	0.09	0.1	0.08	0.1	0.08	
YB	ppm	2.2	1.53	2.11	1.67	1.2	1.93	0.46		0.37	0.02	0.02	0.37	0.32	0.27	0.34	0.35	
LU	ppm	0.3	0.23	0.34	0.35	0.16	0.27	0.08		0.056	0.01	0.01	0.07	0.06	0.05	0.06	0.05	
HF	ppm	3	4.7	1.4	1.16	7	3.3	0.34	0.04	0.15	0.17	0.17	0.28	0.31	0.3	0.33	0.26	
TA	ppm	2	2	0.1	0.07	9	0.53	0.03	0.01	0.03			0.05	0.03	0.04	0.03	0.03	
TH	ppm	4.8	5.1	0.03	0.028	11.4	0.6	0.09		0.025			0.06	0.09	0.06	0.08	0.06	
U	ppm	1.25	1.3	0.022	0.02	3.1	0.22	0.03		0.009			0.02	0.02	0.02	0.02	0.02	
F	ppm	625	625	211	100	1900	300	21					16.3	18.5	22.1	21.1	132	
CL	ppm	1074	1074	23	17	300	190	1					0.85	0.31	14.6	7.08	1522	
P	ppm	1050	817	390	390	3880	1600	61					49.3	50	75.8	50.3	2572	
S	ppm	260	24	600	600	2000	1375	8					60.8	16.3	94.3	19.9		
LI	ppm	10	10	9	12	25	12.8	1.5	1.5	1.5			2	1.16	2.52	1.17	3.44	
NA	pct	2.6	3.11	1.59	0.44	0.2	0.18	0.22	0.04	0.13			0.12	0.16	0.14	0.19	1.08	
K	pct	1.25	1.75	0.066	0.032	1.76	0.46	0.01		0.042	0		0.04	0.01	0.02	0.02	0.12	
RB	ppm	42	61	0.34	0.17	65	0.32	0.4	0.05	0.05	0.04		0.41	0.55	0.54	0.6	4.97	
CS	ppm	1.7	1.7	0.005	0.002	2.3	0.7	0.01	0	6E-04	0		0.02	0.02	0.02	0.01	0.41	
U	ppm	175	175	210	190	120	202	77	77	77	60	60	81.6	73.1	87.8	74.4	124	
CR	ppm	55	56	441	900	1100	490	2500	2500	2500	2500	3200	2336	2457	2538	2433	5777	
MN	ppm	1100	1100	1080	1080	1100	1100	1040	1010	1010	1010	853	1017	1030	962	1029	4319	
FE	pct	5.83	3.81	6.52	6.37	7.16	7.89	6.08	6.46	5.1	6.08	3.55	5.6	6.08	5.36	6.07	48.4	
CO	ppm	25	25	53	50	77	68	105	105	105	105	50	99.4	104	75.8	103	1110	
NI	ppm	20	35	152	320	1050	416	2110	2110	2110	2110	700	1931	2067	1304	2047	2.4E4	
CU	ppm	60	60	77	130	80	65	15	15	15	30	5	31.7	22.9	27.5	22.4	244	
ZN	ppm	52	52	74	74	80	109	60	60	60	20	20	46.1	45	47.1	45.2	671	
GA	ppm	18	18	18	14	10	19	4	4	4	3	3	4.64	3.88	5.23	4.05	22	
GE	ppm	1.5	1.5	1.5	1.5	0.5	1.28	1.1	1	1	1.1	1.1	1.09	1.11	1.11	1.11	70.2	
SE	ppm	0.05	0.05	0.181	0.181	0.15	0.08	0.02	0.02	0.02	0.01	0.01	0.03	0.02	0.04	0.02	39.7	
AG	ppm	0.07	0.07	0.019	0.019	0.02	0.04	0	0	0.003	0	0	0	0	0.01	0	480	
CD	ppm	0.2	0.2	0.129	0.129	0.07	0.07	0.03	0.03	0.03	0.01	0.01	0.03	0.02	0.04	0.02	1467	
IN	ppm	0.1	0.02	0.072	0.072	0.1	0.09	0	0	0.002	0	0	0.01	0	0.01	0	170	
SN	ppm	2	2	1.36	1.36	15	15	0.52	0.52	0.52	0.52	0.52	0.63	0.54	0.77	0.55	3662	
W	ppm	1.5	1.5	0.005	0.002	1	0.2	0.01	0	0.009			0.01	0.02	0.02	0.01	0.21	
RE	ppb	1	1	1.1	1.1	1	0.8	0.01	0.1	0.1	0.08	0.1	0.19	0.06	0.25	0.07	80.4	
OS	ppb	5	5	0.04	0.04	3.5	0.1	5	5	5	3.1	3.1	3.82	4.2	3.58	4.15	1524	
IR	ppb	1	1	0.001	0.04	7	0.3	5	5	5	3.2	3.2	3.84	4.21	3.58	4.17	1031	
AU	ppb	4	0.6	0.34	1	4	1	0.8	0.8	0.8	0.49	0.49	0.72	0.71	0.74	0.67	316	
TL	ppb	0.25	0.25	0.01	0.007	0.22	0.02	0.01					0	0.01	0	0.01	312	
PB	ppm	7	15	0.08	0.08	10	4	0.2	0.2	0.2			0.17	0.17	0.21	0.2	5.45	
BI	ppb	0.2	0.2	0.007	0.007	0.03	0.05	0.01	0.01	0.005			0	0	0.01	0	0.24	

MODEL MATRIX				AL/SI				
	1	2	3	4	0.08	0.08	0.08	0.08
CRUST	0.55	0.69	1		0.92	0.92	0.91	0.91
CRUST2				0.55	1.07	1.07	1.01	1.07
MORB				2.5	11.4	11.3	11	11
MORB2	9.28	1.63	13.4		8.85	8.73	8.01	9.16
KIMB	0.19				3.55	4.24	4.34	4.38
W998				0.81	3.21	3.2	3.73	3.18
UMR		59.7			3.29	3.67	3.44	3.66
OPX4	38	38			1.59	1.55	1.63	1.59
OPX2			37.6		1.83	0.56	1.22	0.68
BOYD			47		0.03	0.05	0.03	0.04
LHZD	52.2				0.11	0.14	0.08	0.11