Abundance of chemical elements in the continental crust: a new table

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Abstract—The rare earth pattern in sedimentary rocks is nearly constant and is considered to represent the relative abundances of these elements in the continental crust. This pattern is derived principally from mixing of basic and acidic igneous rock patterns. Preliminary calculations indicate that approximately equal contributions of basic and acid patterns are required to give the observed rare earth abundance pattern in sedimentary rocks.

A table of element abundances in the continental crust, calculated on the basis of a 1:1 mixture of granite and basalt abundances, is presented. Attention is drawn to differences from previous estimates.

> *It is exceedingly difficult to estimate in any reliable way* . . . . *the mean composition of the surface region of the Earth.*
>
> (SUESS and UREY, 1956, p. 54)

1. INTRODUCTION

THE overall abundance of the chemical elements in the Earth's crust is a basic problem in geochemistry. The crust, the region above the Mohorovičić discontinuity comprises only 0·4 per cent, and the continental crust only 0·29 per cent of the mass of the Earth (MACDONALD, 1959), but it is the only part at present accessible to direct sampling. The upward concentration of many elements gives the crust an importance greater than its bulk alone would justify, when considering the composition of the Earth as a whole. A knowledge of its composition is crucial for geochemical and geophysical Earth models, and it is a factor of increasing importance in geological hypotheses dealing with the formation of volcanoes, mountain building, origin of granite etc.

At the outset, it is desirable to consider separately the continental and oceanic crust. The purpose of this paper is to provide data for the composition of the continental crust. The oceanic crust, although less well sampled, is probably close in composition to average basalt. The data given in Table 3 under that heading could be used as a first approximation to the composition of the oceanic crust.

The methods of producing a table of element abundances in the continental crust are of interest. A massive sampling programme, using some surface grid, with as much deep drilling as practicable, represents an obvious, if uneconomical and unimaginative approach. Easier solutions are possible. The most imaginative proposal was that of GOLDSCHMIDT (1933) who used analytical data from glacial clays, the product of a natural sampling process (see next section).

To a first approximation, the composition of the continental rocks can be obtained from the element abundances in the common rock types. Most workers have used various proportions of granite and basalt. The justification for this

procedure is based on the well-known frequency diagram of silica percentage in igneous rocks (BARTH, 1962) and the large amount of data available for these rock types. A substantial measure of agreement exists for the abundances of the major elements (Table 1) and a principal objective is to provide abundance data for the rarer elements.

Table 1. Various estimates of the abundance of the major elements in the continental crust. Data expressed as oxides in weight per cent

	1	2	3	4	5
SiO_2	60·18	61·90	63·1	59·4	60·3
Al_2O_3	15·61	16·66	15·2	15·6	15·6
Fe_2O_3	3·14	3·44	—	2·3	—
FeO	3·88	3·87	6·0[a]	5·0	7·2[a]
MgO	3·56	3·50	3·1	4·2	3·9
CaO	5·17	3·35	4·1	6·6	5·8
Na_2O	3·91	2·15	3·4	3·1	3·2
K_2O	3·19	4·15	3·0	2·3	2·5
TiO_2	1·06	0·83	0·8	1·2	1·0
$\lessgtr$	99·70	99·85	98·7	99·7	98·8
FeO[a]	6·71	6·97	6·0	7·1	7·2

[a] Total Fe expressed as FeO.

1. CLARKE and WASHINGTON (1924).
2. GOLDSCHMIDT (1954, Table 17). Average of 68 primary zone glacial clays (water free).
3. VINOGRADOV (1962). Two parts felsic to one part basic rock.
4. POLDERVAART (1955, Table 20). Average of continental shield and folded belts regions.
5. Average of one part basic and one part felsic rock.

2. PREVIOUS ESTIMATES

These are dealt with under the two headings of major elements and general abundance tables.

Major elements

CLARKE and WASHINGTON (1924) made an extensive survey of the composition of the continental crust,* using the average composition of 5159 analyses of igneous rocks as the basis for the estimate. The resulting average was criticised on the grounds of inadequate sampling, over-emphasis on rarer species and the lack of areal or volume estimates. Their values are given in Table 1, column 1. Despite the objections to their procedure, no more satisfactory method was proposed and their estimate is in fact very close to more recent averages. The next constructive step was taken by GOLDSCHMIDT (1933). He proposed that a large scale sampling of Scandinavia had been carried out during the Pleistocene glaciation. Erosion by the ice sheet was largely mechanical and chemical weathering was at a minimum. The products of this process were represented by the glacial clay deposits derived from rock flour, and well mixed before deposition from melt water. This interesting proposal provided values (Table 1, column 2) close to those of CLARKE and

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* 138 analyses of oceanic rocks were included. These do not seriously affect the average.

WASHINGTON (1924) except that sodium and calcium were lower due to the aqueous environment.

POLDERVAART (1955) has provided quantitative estimates of the volumes and composition of the various major geological divisions of the crust. His average composition of the continental shield, and young folded belt regions, which together comprise the continental crust is given in Table 1, column 4. VINOGRADOV (1962) has given the most recent estimate and his calculation of the abundances of the major elements in the continental crust is given in Table 1, column 3. He used a ratio of two parts felsic to one part basic rock.

For reasons discussed in the next section, abundances based on a mixture of equal proportions of basaltic and granitic data have been adopted in this paper. The data given in Table 1, column 5 are based on this procedure. They are very close to the values of POLDERVAART (1955).

General abundance tables

CLARKE and WASHINGTON (1924, Table 11) gave a comprehensive table of the abundance of the chemical elements in igneous rocks. Except for the major elements noted above, the main result was to demonstrate the paucity of knowledge about the rarer elements. GOLDSCHMIDT (1937) presented the first modern compilation of trace elements abundances in igneous rocks. This table has been the basis for all subsequent attempts. RANKAMA and SAHAMA (1950, Table 2.3), FLEISCHER (1953), GOLDSCHMIDT (1954), RANKAMA (1954, Table 9.1) and MASON (1958, Table 9) published revisions of this basic table. AHRENS and TAYLOR (1961, Table 8.2) gave a further revision, with references, using, where available, data from granite and basalt in a 2:1 weight ratio. VINOGRADOV (1956), GREEN (1959) and TUREKIAN and WEDEPOHL (1961) provided valuable compilations of the abundance of the elements in common rock types. VINOGRADOV (1962) revised his earlier table and gave a compilation of abundances in the continental crust, based on a 2:1 weight ratio of felsic to basic rock abundances.

3. SIGNIFICANCE OF RARE EARTH ABUNDANCE DATA

HASKIN and GEHL (1962) have provided determinations of the rare earth elements in several sedimentary rocks, including shales, sandstones and limestones. The *relative* abundance patterns for the rare earths were similar, with minor exceptions, for these varied sediments. The relative abundances were also similar to those observed for three composite shale samples by MINAMI (1935). Different relative patterns are observed in chondrites, basaltic and granitic rocks. These are shown in Fig. 1. For simplicity, only the patterns for the rare earths of odd atomic number are given. Similar patterns are observed for the even numbered rare earths. The abundance data are normalised to La = 1·00 (weight ratio) and are plotted against the elements arranged in order of decreasing ionic radii (AHRENS, 1952). Several conclusions, significant for crustal abundance studies, follow from a study of these patterns.

(1) The occurrence of similar relative abundances in sedimentary rocks of diverse origin and of differing ages indicates that no significant fractionation of rare earths occurs during sedimentary processes.

(2) The uniformity of the sedimentary patterns indicates both large scale sampling and thorough mixing of the distinctly different igneous patterns.

(3) The uniform patterns indicate that sampling is on a large enough scale to assume that the sedimentary rare earth pattern gives the relative abundances of the rare earth elements in the crust exposed to weathering.

(4) It is accordingly possible, in principle, to compute the contributions to the relative abundances of the rare earths in sedimentary rocks from those in igneous
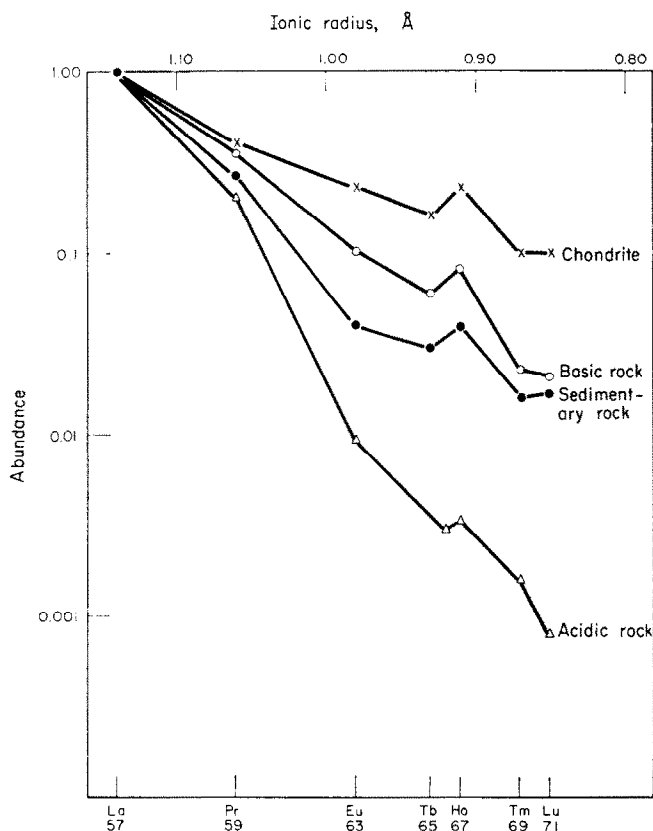

Fig. 1. The abundances of the rare earth elements of odd atomic number, normalized to La $= 1 \cdot 00$ (weight ratio), in basic, acid and sedimentary rocks (data from Table 2) and in chondrites (SCHMITT et al., 1963). The elements are arranged in order of decreasing ionic radius (values from AHRENS, 1952), which is also the order of increasing atomic number.

rocks. The major contribution will be from basic and acid igneous rocks (BARTH, 1962). For the present purpose, the basalt and granite rare earth abundance patterns can be used in this way to provide the ratio of basalt to granite in the continental crust.

Several difficulties emerge at this stage.

(1) There are few data on which to establish typical or average rare earth abundance patterns in granite or basalts.

(2) The variations seen in rare earth abundances in individual basalts and granites mean that a large number of analyses will probably be required to firmly establish averages (FREY and HASKIN, 1964; SCHMITT *et al.*, 1963; HASKIN and GEHL, 1963; GAVRILOVA and TURANSKAYA, 1958).

(3) Some basalts from the mid-Atlantic ridge and the Experimental Mohole have a chondritic rare earth abundance pattern (FREY and HASKIN, 1964). These may not be restricted to the oceanic crust (TAYLOR, 1962) but are unlikely to be quantitatively important in the continental crust (see below).

Despite these difficulties, it is worthwhile to make a preliminary calculation since the method appears to be valid in principle. It is hoped that such an attempt will encourage more determinations of the rare earths in common crustal rocks. The need for a table of element abundances in the crust, as stated in the introduction, is a further reason.

Accordingly, a preliminary calculation has been made. The average rare earth abundance pattern in granites has been derived from the data given for the Kirovograd granite (GAVRILOVA and TURANSKAYA, 1958) and the standard granite, G-1 (HASKIN and GEHL, 1963).

The average rare earth abundance pattern for basic rocks has been derived from the data for Kilauea-iki basalt (SCHMITT *et al.*, 1963) and the standard diabase, W-1 (HASKIN and GEHL, 1963). The data from the mid-Atlantic ridge, and the Experimental Mohole basalts, which possess chondritic rare earth abundance patterns (FREY and HASKIN, 1964) have been excluded, since the chondritic rare earth pattern does not seem to be typical of the upper mantle and crust (SCHMITT *et al.*, 1963). Calculations based on a chondritic rare earth pattern for basalts require a ratio of five basalt to one granite to give the sedimentary rare earth pattern. This estimate seems to be at variance with the major element data. The weighting to be given to these basalts is uncertain and possibly they are balanced by more fractionated basalts.

Using the adopted averages, Table 2 gives the results of the calculations. The first three columns give respectively sedimentary, basic and acidic rock rare earth abundance patterns, normalized to La $= 1\cdot00$ (weight ratio). In columns 4 and 5, the basic and acidic patterns are divided by the sedimentary pattern.

The ratio of basic to acidic rare earth abundance patterns required to give the sedimentary pattern is given by

$$x \text{ basic rock pattern} + y \text{ acidic rock pattern} = \text{sedimentary pattern}$$

or
$$\frac{x \text{ basic rock pattern}}{\text{sedimentary pattern}} + \frac{y \text{ acidic rock pattern}}{\text{sedimentary pattern}} = 1\cdot00$$

Preliminary calculations indicated that x and y were commonly both about $0\cdot5$. Column 6 in Table 2 gives the result for $x = y = 0\cdot5$ for the various elements. The average value for the sum is $1\cdot03$ with a relative deviation of $\pm21\%$. This result is shown graphically in Fig. 2. (Europium is excluded from the calculation because of the ease of reduction to Eu^{2+}.) Allowing for the paucity of data, and a precision of about $\pm5\%$ in the analytical data, a mixture of equal parts of the

Table 2. Calculation of ratio of basic to acid igneous rock rare earth patterns to give sedimentary rock rare earth pattern. All data normalized to La = 1·00 (weight ratio)

		1	2	3	4	5	6
57	La	1·00	1·00	1·00	1·00	1·00	1·00
58	Ce	2·0	2·73	1·58	1·37	0·79	1·08
59	Pr	0·27	0·35	0·20	1·28	0·72	1·00
60	Nd	0·90	1·47	0·62	1·63	0·69	1·16
61	Pm	—	—	—	—	—	—
62	Sm	0·20	0·36	0·10	1·78	0·52	1·15
63	Eu	0·040	0·10	0·0094	2·50	0·27	1·39[a]
64	Gd	0·18	0·39	0·057	2·17	0·32	1·25
65	Tb	0·030	0·060	0·0030	1·98	0·10	1·04
66	Dy	0·12	0·30	0·018	2·50	0·15	1·33
67	Ho	0·040	0·081	0·0034	2·02	0·084	1·05
68	Er	0·090	0·18	0·0090	1·95	0·10	1·02
69	Tm	0·016	0·023	0·0016	1·94	0·10	1·02
70	Yb	0·10	0·13	0·0035	1·30	0·035	0·68
71	Lu	0·017	0·021	0·0008	1·25	0·050	0·65
							1·03 av.[a]

[a] Eu is excluded from average because of possible reduction to Eu^{2+}.

1. Average rare earth sedimentary rock pattern (HASKIN and GEHL, 1962). Ce value is based on comparison with MINAMI's (1935) data. The Dy value is calculated assuming a straight line relation for Gd–Dy–Er.
2. Average basic rock pattern. Average of W-1 values (HASKIN and GEHL, 1963) and Kilauea-iki (SCHMITT et al., 1963a).
3. Average acidic rock pattern. Average of G-1 (HASKIN and GEHL, 1963) and Kirovograd granite (GAVRILOVA and TURANSKAYA, 1958).
4. Average basic pattern (col. 2) divided by average sedimentary pattern (col. 1).
5. Average acidic pattern (col. 3) divided by average sedimentary pattern (col. 1).
6. Addition of 0·5 × col. 4 and 0·5 × col. 5.

basic and acidic rock rare earth patterns gives a good approximation to the relative abundances of rare earths in sedimentary rocks. From the considerations given above, this provides the ratio of basic to acidic rocks in the crust exposed to weathering. *This study indicates that the composition of the continental crust can be represented by a mixture of equal quantities of basic and acidic rock.*

This result may be checked against other estimates. This is carried out for the major elements in Table 1, where column 5 gives the average composition resulting from a 1:1 mixture of basic and acidic rocks. The values obtained are very close to the other estimates, in particular to POLDERVAART (1955) and CLARKE and WASHINGTON (1924). The fact that the calculations based on the rare earth model are not significantly different from previous estimates based on different premises is an indication of the validity of the method employed here.

4. CONTINENTAL CRUSTAL ELEMENT ABUNDANCES

The general agreement of the present estimate for the *major* elements with previous ones has encouraged the preparation of a table of abundances for as many elements as possible. The data are given in Table 3, together with the

average abundances of elements in basalt and granite which were used for the calculation of the crustal values. A reference is given for each value and a list of these is given following the table. Full details are given in the list of references at the end of the paper. An attempt has been made to survey the current literature to December 1963. The abundances of several elements given here differ from previous estimates and call for comment.
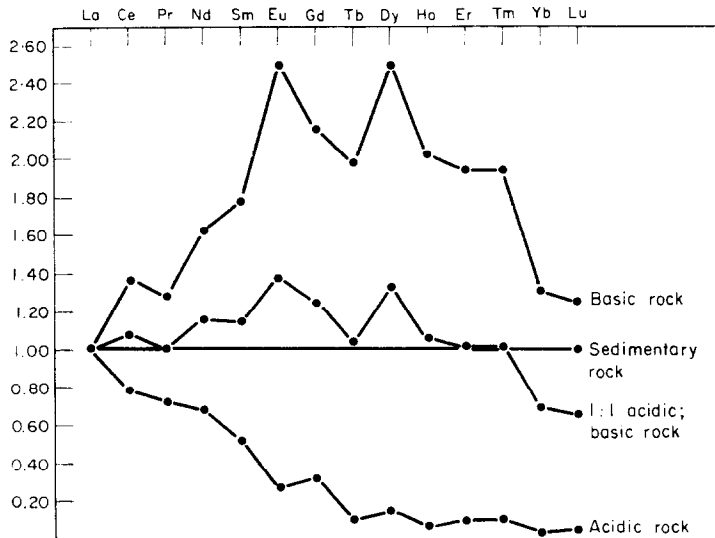

Fig. 2. Plots of lanthanum normalised basic and acidic rock distribution patterns divided by the sedimentary rock distribution. The abundance pattern resulting from addition of 0·5 × basic rock + 0·5 × acidic rock pattern is shown. This line should be compared with the horizontal line representing the sedimentary rock abundances.

3. *Lithium.* The value of 20 ppm is much lower than previous estimates of 32 ppm (AHRENS and TAYLOR, 1961). This is due to the lowering of the basalt and granite averages by HEIER and ADAMS (1964).

4. *Beryllium.* The work of BEUS (1956, 1961) indicates a granite average of 5 ppm, changing the crustal abundance to 2·8 ppm from 2 ppm (AHRENS and TAYLOR, 1961).

5. *Boron.* The data of HARDER (1959a,b) and SHIMA (1963) have changed the crustal abundance to 10 ppm from earlier estimates of 3 ppm (AHRENS and TAYLOR, 1961).

16. *Sulphur.* The data of RICKE (1960) have reduced the estimate by about one-half.

21. *Scandium.* The granitic average is based on the geometric mean of 45 granites (KOLBE, 1964).

28. *Nickel.* New values by TUREKIAN (1963) and TUREKIAN and CARR (1960) have revised the abundances in basalt and granite. Because nickel is concentrated in basic rocks, the crustal abundance is particularly sensitive to the

Table 3. Abundance of chemical elements in the continental crust, together with basalt and granite averages

Atomic number	Element	Crustal average		Basalt average	Reference	Granite average	Reference
1	H	—					
2	He	—					
3	Li	20	ppm	10	(1)	30	(1)
4	Be	2·8	ppm	0·5	(2)	5	(2)
5	B	10	ppm	5	(3)	15	(4)
6	C	200	ppm	100	(5)	300	(5)
7	N	20	ppm	20	(6)	20	(6)
8	O	46·4	%				
9	F	625	ppm	400	(6)	850	(6)
10	Ne	—					
11	Na	2·36	%	1·94	(5)	2·77	(5)
12	Mg	2·33	%	4·5	(5)	0·16	(7)
13	Al	8·23	%	8·76	(5)	7·70	(5)
14	Si	28·15	%	24·0	(5)	32·3	(5)
15	P	1050	ppm	1400	(5)	700	(5)
16	S	260	ppm	250	(8)	270	(8)
17	Cl	130	ppm	60	(6)	200	(6)
18	A	—					
19	K	2·09	%	0·83	(5)	3·34	(5)
20	Ca	4·15	%	6·72	(5)	1·58	(5)
21	Sc	22	ppm	38	(9)	5	(10)
22	Ti	0·57	%	0·90	(5)	0·23	(5)
23	V	135	ppm	250	(6)	20	(10)
24	Cr	100	ppm	200	(5)	4	(11)
25	Mn	950	ppm	1500	(6)	400	(6)
26	Fe	5·63	%	8·56	(5)	2·70	(5)
27	Co	25	ppm	48	(12)	1	(12)
28	Ni	75	ppm	150	(13, 14)	0·5	(15)
29	Cu	55	ppm	100	(5)	10	(6)
30	Zn	70	ppm	100	(16)	40	(6)
31	Ga	15	ppm	12	(17)	18	(17)
32	Ge	1·5	ppm	1·5	(5)	1·5	(5)
33	As	1·8	ppm	2	(6)	1·5	(6)
34	Se	0·05	ppm	0·05	(6)	0·05	(6)
35	Br	2·5	ppm	3·6	(6)	1·3	(6)
36	Kr	—					
37	Rb	90	ppm	30	(1, 18)	150	(1, 18)
38	Sr	375	ppm	465	(19)	285	(19)
39	Y	33	ppm	25	(20)	40	(6)
40	Zr	165	ppm	150	(21)	180	(6)
41	Nb	20	ppm	20	(6)	20	(6)
42	Mo	1·5	ppm	1	(22, 23, 24)	2	(22, 23, 24)
43	Tc	—					
44	Ru	—					
45	Rh	—					
46	Pd	—					
47	Ag	0·07	ppm	0·1	(6)	0·04	(6)
48	Cd	0·2	ppm	0·2	(25, 26)	0·2	(25, 26)
49	In	0·1	ppm	0·1	(27)	0·1	(27)

Table 3 *cont.*

Atomic number	Element	Crustal average		Basalt average	Reference	Granite average	Reference
50	Sn	2	ppm	1	(28)	3	(28)
51	Sb	0·2	ppm	0·2	(6)	0·2	(6)
52	Te	—					
53	I	0·5	ppm	0·5	(6)	0·5	(6)
54	Xe	—					
55	Cs	3	ppm	1	(1, 29)	5	(1)
56	Ba	425	ppm	250	(13, 30)	600	(10, 30)
57	La	30	ppm	10	(31, 32)	40	(10, 31, 32)
58	Ce	60	ppm				
59	Pr	8·2	ppm				
60	Nd	28	ppm				
61	Pm	—	ppm				
62	Sm	6·0	ppm				
63	Eu	1·2	ppm				
64	Gd	5·4	ppm				
65	Tb	0·9	ppm				
66	Dy	3·0	ppm				
67	Ho	1·2	ppm				
68	Er	2·8	ppm				
69	Tm	0·48	ppm				
70	Yb	3·0	ppm				
71	Lu	0·50	ppm				
72	Hf	3	ppm	2	(33)	4	(34)
73	Ta	2	ppm	0·5	(5)	3·5	(5)
74	W	1·5	ppm	1	(6)	2	(6)
75	Re	—					
76	Os	—					
77	Ir	—					
78	Pt	—					
79	Au	0·004	ppm	0·004	(6)	0·004	(6)
80	Hg	0·08	ppm	0·08	(6)	0·08	(6)
81	Tl	0·45	ppm	0·10	(26)	0·75	(26)
82	Pb	12·5	ppm	5	(6)	20	(6)
83	Bi	0·17	ppm	0·15	(26)	0·18	(26)
84	Po	—					
85	At	—					
86	Rn	—					
87	Fr	—					
88	Ra	—					
89	Ac	—					
90	Th	9·6	ppm	2·2	(35)	17	(36)
91	Pa	—					
92	U	2·7	ppm	0·6	(35)	4·8	(36)

1. HEIER and ADAMS (1964). 2. BEUS (1956, 1961). 3. SHIMA (1963). 4. HARDER (1959 a, b). 5. VINOGRADOV (1962). 6. TUREKIAN and WEDEPOHL (1961). 7. BARTH (1962). 8. RICKE (1960). 9. FRYKLUND and FLEISCHER (1963). 10. Average of 45 granites. KOLBE (1964). 11. CARR and TUREKIAN (1962). 12. CARR and TUREKIAN (1961). 13. NOCKOLDS and ALLEN (1956). 14. TUREKIAN (1963). 15. TUREKIAN and CARR (1960). 16. RADER *et al.* (1963). 17. BURTON *et al.* (1959). 18. Based on K/Rb ratio of 270 for basalt and 220 for granite. 19. TUREKIAN and KULP (1956). 20. HASKIN and GEHL (1963). 21. CHAO and FLEISCHER (1960). 22. ISHIMORI (1951). 23. KURODA and SANDELL (1954). 24. VINOGRADOV *et al.* (1958). 25. VINCENT and BILEFIELD (1960). 26. BROOKS and AHRENS (1961). 27. SHAW (1957). 28. ONISHI and SANDELL (1957). 29. Based on K/Cs ratio of 7500 in basalt. 30. GAST (1960). 31. HASKIN and GEHL (1962). 32. Absolute rare earth abundances in basalts and granites are uncertain at present and require more data. A tentative figure of 30 ppm for La is suggested, and the other rare earth abundances are computed on this basis using the sedimentary abundance pattern. 33. Based on Zr/Hf ratio of 75. 34. Based on Zr/Hf ratio of 45. 35. HEIER and CARTER (1963). 36. HEIER and ROGERS (1963). Average of 750 granites.

basalt: granite ratio, and the value of 75 ppm is about double the earlier estimate.

31. *Gallium.* The data of BURTON *et al.* (1959) have lowered the average in basic rocks, resulting in a decrease in the crustal average from 19 ppm (AHRENS and TAYLOR, 1961) to 15 ppm.

37. *Rubidium.* The new average of 90 ppm is derived from the survey of HEIER and ADAMS (1964) and is lower than the previous value of 120 ppm due to the lowered value of potassium. The rubidium:strontium ratio is 0·24.

55. *Cesium.* The survey of HEIER and ADAMS (1964) has been used to provide the granite average. For basalts, a K/Cs ratio of 7500 has been used to calculate the abundance (AHRENS *et al.*, 1960). The crustal average of 3 ppm is lower than the 5 ppm adopted by AHRENS and TAYLOR (1961).

56. *Barium.* The crustal abundance of barium is uncertain due to the lack of a modern survey of the geochemistry of this important element. GAST (1960) reports an average of 620 ppm for two composite granite samples. KOLBE (1964) finds a geometric mean of 600 ppm for 45 granites and this value is adopted here. The average of 250 ppm Ba for basalts is obtained by averaging the values of GAST (1960) for three composite samples, and that of NOCKOLDS and ALLEN (1956). The crustal average of 425 ppm is considerably lower than previous estimates. This is sensitively dependent on the granite average and the granite:basalt ratio adopted.

57–71. *The rare earths.* It is difficult to decide on *absolute* rare earth abundances in basalt and granite because of the paucity of data. However, for crustal averages, it is only necessary to determine the abundance of one element and the abundances of the others may be derived by calculation from the relative abundances in sedimentary rocks. A value of 10 ppm La has been selected as the basalt average (SCHMITT *et al.*, 1963; HASKIN and GEHL, 1963). KOLBE (1964) obtains an average of 45 ppm La for 45 granites. The data were obtained by emission spectrography, employing G-1 and W-1 as standards with the values reported by HASKIN and GEHL (1963). TUREKIAN and WEDEPOHL (1961) report an older average of 55 ppm. A value of 50 ppm La has been selected as the granite average. A value of 30 ppm La results for the continental crust, and the remaining rare earths are calculated from the sedimentary rock abundance patterns on this basis.

72. *Hafnium and Zr/Hf ratios.* More data are needed for hafnium in common rock types. The present values are calculated on the basis of the Zr/Hf ratio in zircons. KOSTERIN *et al.* (1958) and other workers report a fall in the Zr/Hf ratio in zircons from about 75 in basic rocks to 45 in granites. These ratios are used to calculate hafnium abundances. For comparison, the Zr/Hf ratio in chondrites is 175 (EHMANN and SETSER, 1963).

81, 83. *Thallium and bismuth.* Data are from BROOKS and AHRENS (1960). There is still some uncertainty about the absolute value for bismuth.

90, 92. *Thorium and uranium.* The data for basic rocks are from an extensive survey by HEIER and CARTER (1963). The granite average for thorium is based on the geometric mean of Th abundances in 166 granitic rocks. The

uranium average is based on the geometric mean of U abundances in 750 granitic rocks (HEIER and ROGERS, 1963).

REFERENCES

AHRENS L. H. (1952) The use of ionization potentials. Part I: Ionic radii of elements. *Geochim. et Cosmochim. Acta* **2**, 155–169.

AHRENS L. H., EDGE R. A. and TAYLOR S. R. (1960) The uniformity of concentration of lithophile elements in chondrites with particular reference to cesium. *Geochim. et Cosmochim. Acta* **20**, 260–272.

AHRENS L. H. and TAYLOR S. R. (1961) *Spectrochemical Analysis* (second edition). Addison-Wesley, Reading, Mass.

BARTH T. F. W. (1962) *Theoretical Petrology* (second edition). John Wiley, New York.

BEUS A. A. (1956) Geochemistry of beryllium. *Geokhimiya* **1956,** (5) 511–531.

BEUS A. A. (1961) Distribution of beryllium in granites. *Geokhimiya* **1961,** (5) 432–437.

BROOKS R. R. and AHRENS L. H. (1961) Some observations on the distribution of thallium, cadmium and bismuth in silicate rocks and the significance of covalency on their degree of association with other elements. *Geochim. et Cosmochim. Acta* **23**, 100–115.

BURTON J. D., CULKIN F. and RILEY J. P. (1959) The abundances of gallium and germanium in terrestrial materials. *Geochim. et Cosmochim. Acta* **16**, 151–180.

CARR M. H. and TUREKIAN K. K. (1961) The geochemistry of cobalt. *Geochim. et Cosmochim. Acta* **23**, 9–60.

CARR M. H. and TUREKIAN K. K. (1962) Chromium in granitic rocks. *Geochim. et Cosmochim. Acta* **26**, 411–416.

CHAO E. C. T. and FLEISCHER M. (1960) Abundance of zirconium in igneous rocks. *Rep. Int. Geol. Congress XXI Session (Norden)* **1**, 106–131.

CLARKE F. W. and WASHINGTON H. S. (1924) The composition of the Earth's crust. *U.S.G.S. Prof. Paper* 127.

EHMANN W. D. and SETSER J. L. (1963) Zirconium and hafnium in stone meteorites. *Science* **139**, 594–595.

FLEISCHER M. (1953) Recent estimates of the abundances of the elements in the Earth's crust. *U.S. Geol. Surv. Circ.* **285**, 1–7.

FREY F. A. and HASKIN L. (1964) Rare earths in oceanic basalts. *J. Geophys. Res.* **69**, 775–780.

FRYKLUND V. C. and FLEISCHER M. (1963) Abundance of scandium in volcanic rocks, a preliminary estimate. *Geochim. et Cosmochim. Acta* **27**, 643–664.

GAST P. W. (1960) Limitations on the composition of the upper mantle. *J. Geophys. Res.* **65**, 1287–1297.

GAVRILOVA L. K. and TURANSKAYA N. V. (1958) Distribution of rare earths in rock-forming and accessory minerals of certain granites. *Geokhimiya* **1958**, (2) 163–170.

GOLDSCHMIDT V. M. (1933) Grundlagen der quantitativen Geochemie. *Fortsch. Min. Krist. Petrog.* **17**, 112.

GOLDSCHMIDT V. M. (1938) Geochemische Verteilungsgesetze der Elemente. IX. Die Mengenverhaltnisse der Elemente und Atom-Arten. *Norske Videnskaps-Akad. Skrifter. M-N.* Kl. **4**, 1–148.

GOLDSCHMIDT V. M. (1954) *Geochemistry* (Ed. A. Muir). Oxford University Press, London.

GREEN J. (1959) Geochemical table of the elements for 1959. *Bull. Geol. Soc. Amer.* **70**, 1127–1184.

HARDER H. (1959a) Beitrag zur Geochemie des Bors. I. Bor in Mineralen und Magmatischen Gesteinen. *Akad. Wiss. Gottingen Math-phys.* Kl. **5**, 67–122.

HARDER H. (1959b) Beitrag zur Geochemie des Bors. II. Bor in Sedimenten. *Akad. Wiss. Gottingen Math-phys.* Kl. **6**, 123–183.

HASKIN L. and GEHL M. A. (1962) The rare earth distribution in sediments. *J. Geophys. Res.* **67**, 2537–2541.

HASKIN L. and GEHL M. A. (1963) The rare-earth contents of G-1 and W-1. *J. Geophys. Res.* **68**, 2037–2043.

HEIER K. S. and ADAMS J. A. S. (1964) The geochemistry of the alkali metals. *Physics and Chemistry of the Earth.* Vol. V, pp. 253–381.

HEIER K. S. and CARTER J. L. (1963) Uranium, thorium and potassium contents in basic rocks. Proceedings of the International Symposium on *The Natural Radiation Environment.* Rice University Semi-Centennial Series, University of Chicago Press (in press).

HEIER K. S. and ROGERS J. J. W. (1963) Radiometric determination of thorium, uranium and potassium in basalts and in two magmatic differentiation series. *Geochim. et Cosmochim. Acta* **27**, 137–154.

ISHIMORI T. (1951) Gehalt an Molybdän in japanischen vulkanischen Gesteinen. *Bull. Chem. Soc. Japan* **25**, 251–252.

KOLBE P. (1964) Geochemistry of some African and Australian granitic rocks. Ph.D. Thesis, Australian National University.

KOSTERIN A. V., ZUEV V. N. and SHEVALEEVSKII I. D. (1958) Zr/Hf ratio in zircons in some igneous rocks of Northern Kirgizia. *Geokhimiya* **1958**, (1) 116–119.

KURODA P. K. and SANDELL E. B. (1954) Geochemistry of molybdenum. *Geochim. et Cosmochim. Acta* **6**, 35–63.

MACDONALD G. J. F. (1959) Chondrites and the chemical composition of the Earth. *Researches in Geochemistry,* pp. 476–494. John Wiley, New York.

MASON B. H. (1958) *Principles of Geochemistry* (second edition). John Wiley, New York.

MINAMI E. (1935) Gehalte an seltenen Erden in europäischen und japanischen Ton-Schiefern. *Nach. Gessellschaft. Wiss. Gott. Math-phys. Kl. Fach.* IV. N.F. **1**, (14).155–170.

NOCKOLDS S. R. and ALLEN R. (1956) The geochemistry of some igneous rock series. III. *Geochim. et Cosmochim. Acta* **9**, 34–77.

ONISHI H. and SANDELL E. B. (1957) Meteoritic and terrestrial abundance of tin. *Geochim. et Cosmochim. Acta* **12**, 262–270.

POLDERVAART A. (1955) The chemistry of the Earth's crust. *Geol. Soc. Amer. Special Paper* **62**, 119–144.

RADER L. F., SWADLEY W. C., HUFFMAN C. and LIPP H. H. (1963) New determinations of zinc in basalts and rocks of similar composition. *Geochim. et Cosmochim. Acta* **27**, 695–714.

RANKAMA K. and SAHAMA TH. G. (1950) *Geochemistry.* University of Chicago Press, Chicago.

RANKAMA K. (1954) *Isotope Geology.* Pergamon Press, New York.

RICKE W. (1960) Ein Beitrag zur Geochemie des Schwefels. *Geochim. et Cosmochim. Acta* **21**, 35–80.

SCHMITT R. A., SMITH R. H., LASCH J. E., MOSEN A. W., OLEHY D. A. and VASILEVSKIS J. (1963) Abundances of the fourteen rare-earth elements, scandium and yttrium in meteoritic and terrestrial matter. *Geochim. et Cosmochim. Acta* **27**, 577–622.

SCHMITT R. A., SMITH R. H. and OLEHY D. A. (1963) Cadmium abundances in meteoritic and terrestrial matter. General Atomic Report GA-4167.

SHAW D. M. (1957) The geochemistry of gallium, indium and thallium—a review. *Physics and Chemistry of the Earth,* Vol. 2 (Chap. 6), pp. 164–211.

SHIMA M. (1963) Geochemical study of boron isotopes. *Geochim. et Cosmochim. Acta* **27**, 911–913.

SUESS H. E. and UREY H. C. (1956) Abundances of the elements. *Rev. Mod. Phys.* **28**, 53–74.

TAYLOR S. R. (1962) Meteoritic and terrestrial rare earth abundance patterns. *Geochim. et Cosmochim. Acta* **26**, 81–88.

TUREKIAN K. K. and KULP J. L. (1956) The geochemistry of strontium. *Geochim. et Cosmochim. Acta* **10**, 245–296.

TUREKIAN K. K. and CARR M. H. (1960) The geochemistries of chromium, cobalt and nickel. *Int. Geol. Congress XXI Session (Norden)* **1**, 14–26.

TUREKIAN K. K. and WEDEPOHL K. H. (1961) Distribution of the elements in some major units of the Earth's crust. *Bull. Geol. Soc. Amer.* **72**, 175–192.

TUREKIAN K. K. (1963) The chromium and nickel distribution in basaltic rocks and eclogites. *Geochim. et Cosmochim. Acta* **27**, 835–846.

VINCENT E. A. and BILEFIELD L. I. (1960) Cadmium in rocks and minerals from the Skaergaard intrusion, East Greenland. *Geochim. et Cosmochim. Acta* **19**, 63–69.

VINOGRADOV A. P. (1956) Regularities of distribution of chemical elements in the Earth's crust. *Geokhimiya* **1956**, 1–43.

VINOGRADOV A. P. (1962) Average contents of chemical elements in the principal types of igneous rocks of the Earth's crust. *Geokhimiya* **1962**, (7) 641–664.

VINOGRADOV A. P., VAINSHTEIN E. E. and PAVLENKO L. I. (1958) Tungsten and molybdenum in igneous rocks (as related to the geochemistry of tungsten). *Geokhimiya* **1958**, (5) 497–509.