Abundances of Chemical Elements in the Earth's Crust

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Abstract—The evaluation of the abundances of chemical elements in the Earth's crust is a pivotal geochemical problem. Its first solutions in the early 20th century formed the empirical groundwork for geochemistry and justified concepts about the unity of the material of the Universe, the genesis of the chemical elements, and the geochemical differentiation of the Earth. The accumulation of newly obtained data called for the revision of this problem, and a series of papers by A.P. Vinogradov, which were published in *Geokhimiya* in 1956–1962, presented reevaluated contents of elements in the continental crust. In these papers, A.P. Vinogradov relied on the classic idea of the geochemical balance of the sedimentary process. These generalizations provided the foundation for the quantitative characterization of the geochemical background of the biosphere and allowed Vinogradov to formulate the principles of the melting and degassing of material in the outer Earth's shells during the geologic history, a concept that became universally acknowledged in modern geochemistry and geology. The composition of the Earth's crust can also be evaluated based not on the principle of geochemical balance in the sedimentary process but on data on the actual abundances of major magmatic, metamorphic, and sedimentary rock types. The possibility of this solution was provided after the extensive research of A.B. Ronov, who managed to develop a quantitative model for the structure of the Earth's sedimentary shell. Based on these data, A.B. Ronov, A.A. Yaroshevsky, and A.A. Migdisov published a series of papers in *Geokhimiya* in 1967–1985 that presented a model for the chemical structure of the Earth's crust with regard for the material composing not only the upper part of the continental crust but also its deep-seated granulite–basite layer and the oceanic crust. The quantitative estimates thus obtained led the authors to important conclusions: first, it was demonstrated that the estimated abundances of elements in the granite–metamorphic layer of the continental crust presented in the classic works by A.P. Vinogradov are confirmed by independent materials, which are based on data on the actual abundance of rocks. Second, incredible as it was, the principle of geochemical balance in the sedimentary process in application to Ca and carbonates appeared to be invalid. This problem remains unsettled as of yet and awaits its resolution.

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The evaluation of the abundances of chemical elements in the Earth's crust is a pivotal problem of geochemistry. In fact, the very first accurate solutions of this problem in the early 1900s marked the establishment of geochemistry as a science on the natural history of the atoms of chemical elements. Papers by F.W. Clarke (United States), J. Vogt (Norway), V.I. Vernadsky (Russia), V.M. Goldschmidt and I. and W. Noddack (Germany), and G. Hevesy (Denmark) laid the empirical groundwork for geochemistry, which made it possible to propose the first solutions of the key scientific problems: the unity of the material of which the observable Universe consists, the origin of the chemical elements, and the geochemical zoning of the Earth. Ideas deduced from these solutions formed the fundamentals of modern geochemistry and acquired universal and philosophical significance.

The new tasks formulated during the solution of these problems were related, first of all, to the need for information on the abundances of trace, rare, and radioactive chemical elements. Interest in these elements rapidly grew in the middle of the last century due to the technological revolution. These tasks called for a radical modification of the analytical techniques. Progress in these methods was related to the fundamental modernization of, first of all, physical analytical methods. In the 1940s–1960s, the appearance and further development of X-ray diffraction analysis, mass spectrometry, and approaches of neutron activation analysis principally extended the empirical basis of geochemistry and made it possible to obtain extensive information, which appended preexisting tables and resulted in the revision of some earlier evaluations. This work was launched in the early 1940s and continued in the 1950s at the laboratory of Geochemical Problems and then at the Vernadsky Institute of Geochemistry and Analytical Chemistry, Russian Academy of Sciences, in Moscow. Its outcome allowed A.P. Vinogradov to publish a fundamental paper in the first issue of *Geokhimiya* (in the spring of 1956) that was the first publication of the then-latest data on the abundances of chemical elements in crustal magmatic rocks. This made it possible to quantify (on the basis of these data) the abundances of chemical elements in the classic object of geochemistry: the Earth's crust. The ever-growing accumulation of newly obtained data soon forced A.P. Vinogradov to return to this problem, and his paper published in 1962 [2] became the benchmark in geochemistry for several

years ahead. The simultaneous publications of analogous materials by Turekian and Wedepohl [2] and Taylor [4] appeared to be closely similar to the results published by A.P. Vinogradov: all of these reviews were based on the same base of empirical data.

The paper published by A.P. Vinogradov in 1962 undoubtedly marked a new stage in the evolution of knowledge about the chemistry of the continental crust. This paper does not lose its both historical and scientific importance for geochemistry, and its summarizing table is worth reproducing in this publication (Table 1). The corrections introduced with time into the estimated abundances of chemical elements in the Earth's crust cannot significantly modify the conclusions that have been drawn from these data. The comprehension and use of these values led to the formulation of at least three key points of geochemistry. First, they clarified the problem of mineral resources, first and foremost, the resources of rare elements, which were "offered" by nature and formed the basis for technological progress. Second, these data made it possible to quantitatively characterize the geochemical background of the biosphere and the natural levels of the concentrations of chemical elements in the habitats of living organisms. They also led to the first correct formulation of the problem of the geochemical heterogeneity of the biosphere and made it possible to identify the boundary conditions for distinguishing natural and anthropogenic geochemical anomalies and to justify the formulation of the problem of the geochemical zoning of the biosphere. Finally, when compared with data on the concentrations of chemical elements in the cosmic matter [5], these data led A.P. Vinogradov to formulate his well-known concept of melting and degassing as the fundamental differentiating processes of the Earth's deep-seated rocks and the origin of the crust, hydrosphere, and atmosphere [6, 7], a concept that appeared in place of V.M. Goldschmidt's idea about the primary differentiation of the completely molten Earth and is now universally recognized in geochemistry and geology.

Early in the evolution of geochemistry, the solution of the problem of the crustal abundances of chemical elements encountered certain principal difficulties, which were of dualistic character. First, the problem of the precise determination of the concentrations of, in the end, all chemical elements (with several of them contained in trace amounts) appeared to be nontrivial in itself. The solution of this problem was further complicated by the diversity of materials that had to be analyzed (rocks, minerals, soils, waters, gases, living matter, with the complete analysis of each of them being a separate experimental problem). Second, the geological object—the Earth's crust—was complex and extremely heterogeneous. The incredible diversity of rocks and mineral deposits, the differences between the crustal abundances of some rocks as great as several orders of magnitude, and the absence of acceptable quantitative estimates of these differences required an

idea that would be instrumental in bypassing this "geological" complexity of the problem. Such an idea was found and justified by V.M. Goldschmidt as a concept of the geochemical balance of the sedimentary process. According to this idea, the average composition of secondary sedimentary rocks should be identical to the average composition of primary magmatic rocks. In his famous paper "Grundlagen der Quantitativen Geochemie" (*Fundamentals of Quantitative Geochemistry*) [8], Goldschmidt convincingly demonstrated that the composition of the chemically least altered clays is practically identical to the average composition of magmatic rocks (except only for the concentrations of the most mobile Ca, Na, and volatiles) calculated by F.W. Clarke and G.S. Washington. The validation of the plausibility of this balance provided the possibility of using the average concentrations of chemical elements in clayey rocks as a measure of the contributions of the most widespread rock types (granites and basalts) to the structure and composition of the Earth's crust. It was exactly this balance that was utilized by Vinogradov and Taylor to evaluate the average composition of the continental crust. These estimates of the two researchers appeared somewhat different: using data on a great number of elements, Vinogradov assumed the proportion of granites to basalts in the continental crust equal to 2 : 1, whereas Taylor relied on his own evaluations of the REE abundances in schists and assumed this ratio equal to 1 : 1. This explains the differences (which are generally insignificant) in the final values.

Geological observations, first of all, gradually amassing information on the actual abundances of the major rock types in the crust made the researchers consider more closely the idea of geochemical balance in the sedimentation process. The data of R.O. Daly and, later, S.P. Solov'ev on the actual occurrence frequencies of various magmatic rocks and the first quantitative results obtained by A.B. Ronov on the sedimentary shell demonstrated that the problem of geochemical balance can be revised. Poldervaart [9] was the first to propose in 1955 a new evaluation of the average chemical composition of the Earth's crust on the basis of the hypothetical abundance of the major types of magmatic, sedimentary, and metamorphic rocks in it (the abundances were "hypothetical" because no actual values were known at that time). The average crustal composition assayed by Poldervaart differed from the classic model of Clarke–Goldschmidt. However, the problem of the average chemical composition of the Earth's crust was actually solved in such a way only after A.B. Ronov had accomplished a vast volume of work on reconstructing the structure of the Earth's sedimentary shell. These estimates laid the groundwork for the estimation of the composition of the crust, which was first published in a paper by Ronov and the author of this paper in 1967 [10]. That paper summarized all then-available factual materials, but the likely most interesting result presented in it was the geochemical paradox, which was illustrated by quantitative data, of

Table 1. Abundances (10^{-4} wt %) of chemical elements in the major rock types and the upper continental crust (after [Vinogradov, 1962])

Element	Stony meteorites	Ultrabasic rocks	Basic rocks	Intermediate rocks	Acid rocks	Earth's crust
1	2	3	4	5	6	7
1 H	–	–	–	–	–	–
3 Li	3	0.5	15	20	40	32
4 Be	3.6	0.2	0.4	1.8	5.5	3.8
5 B	2	1	5	15	15	12
6 C	400	100	100	200	300	230
7 N	1	6	18	22	20	19
8 O	350000	425000	435000	460000	487000	470000
9 F	28	100	370	500	800	660
11 Na	7000	5700	19400	30000	27700	25000
12 Mg	140000	259000	45000	21800	5600	18700
13 Al	13000	4500	87600	88500	77000	80500
14 Si	180000	190000	240000	260000	323000	295000
15 P	500	170	1400	1600	700	930
16 S	20000	100	300	200	400	470
17 Cl	70	50	50	1100	240	170
19 K	850	300	8300	23000	33400	25000
20 Ca	14000	7000	67200	46500	15800	29600
21 Sc	6	5	24	2.5	3	10
22 Ti	500	300	9000	8000	2300	4500
23 V	70	40	200	100	40	90
24 Cr	250	2000	200	50	25	83
25 Mn	2000	1500	2000	1200	600	1000
26 Fe	250000	98500	85600	58500	27000	46500
27 Co	800	200	45	10	5	18
28 Ni	13500	2000	160	55	8	58
29 Cu	100	20	100	35	20	47
30 Zn	50	30	130	73	60	83
31 Ga	3	2	18	20	20	19
32 Ge	10	1	1.5	1.5	1.4	1.4
33 As	0.3	0.5	2	2.4	1.5	1.7
34 Se	10	0.05	0.05	0.05	0.05	0.05
35 Br	0.5	0.5	3	4.5	1.7	2.1
37 Rb	5	2	45	100	200	150
38 Sr	10	10	440	800	300	340
39 Y	0.8	–	20	–	34	29
40 Zr	30	30	100	260	200	170
41 Nb	0.3	1	20	20	20	20
42 Mo	0.6	0.2	1.4	0.9	1	1.1
44 Ru	1	–	–	–	–	–
45 Rh	0.19	–	–	–	–	–
46 Pd	1	0.12	0.019	–	–	–
47 Ag	0.094	0.05	0.1	0.07	0.05	0.07

Table 1. (Contd.)

Element	Stony meteorites	Ultrabasic rocks	Basic rocks	Intermediate rocks	Acid rocks	Earth's crust
1	2	3	4	5	6	7
48 Cd	0.1	0.05	0.19	–	0.1	0.13
49 In	0.001	0.013	0.022	–	0.26	0.25
50 Sn	1	0.5	1.5	–	3	2.5
51 Sb	0.1	0.1	1	0.2	0.26	0.5
52 Te	0.5	0.001	0.001	0.001	0.001	0.001
53 I	0.04	0.01	0.5	0.3	0.4	0.4
55 Cs	0.1	0.1	1	–	5	3.7
56 Ba	6	1	300	650	830	650
57 La	0.3	–	27	–	60	29
58 Ce	0.5	–	45	–	100	70
59 Pr	0.1	–	4	–	12	9
60 Nd	0.6	–	20	–	46	37
62 Sm	0.2	–	5	–	9	8
63 Eu	0.08	0.01	1	–	1.5	1.3
64 Gd	0.4	–	5	–	9	8
65 Tb	0.05	–	0.8	–	2.5	4.3
66 Dy	0.35	0.05	2	–	6.7	5
67 Ho	0.07	–	1	–	2	1.7
68 Er	0.2	–	2	–	4	3.3
69 Tm	0.04	–	0.2	–	0.3	0.27
70 Yb	0.2	–	2	–	4	3.3
71 Lu	0.035	–	0.6	–	1	0.08
72 Hf	0.5	0.1	1	1	1	1
73 Ta	0.02	0.018	0.48	0.7	3.5	2.5
74 W	0.15	0.1	1	1	1.5	1.3
75 Re	0.0008	–	0.00071	–	0.00067	0.0007
76 Os	0.5	–	–	–	–	–
77 Ir	0.48	–	–	–	0.0063	–
78 Pt	2	0.2	0.1	–	–	–
79 Au	0.17	0.005	0.004	–	0.0045	0.0043
80 Hg	3	0.01	0.09	–	0.08	0.083
81 Tl	0.001	0.01	0.2	0.5	1.5	1
82 Pb	0.2	0.1	8	15	20	16
83 Bi	0.003	0.001	0.007	0.01	0.01	0.009
90 Th	0.04	0.005	3	7	18	13
92 U	0.015	0.003	0.05	1.8	3.5	2.5

the absence of Ca balance between the magmatic and sedimentary material of the continental crust. This problem was somehow "felt" in geochemistry before: beginning with papers by Clarke and Goldschmidt devoted to quantitative geochemistry, it became evident enough that the theoretically evaluated abundances of carbonates in the sedimentary shell (as was calculated from the average Ca concentrations in magmatic rocks) significantly (by factors of two to three) exceeded the analogous values that seemed to follow from geological observations. The validation of these observations by the measured volumes of the major rock types compos-

ing the sedimentary shell (these calculations were conducted by Ronov) highlighted these discrepancies and made them obvious. Although numerous papers have been published since then in attempt to solve this paradox, up to the negation of evident data, it remains unsettled as of yet.

However, several geochemical parameters of the Earth's crust could not be evaluated in that research reliably and accurately enough. First of all, this applies to the average composition of the crystalline constituent of the continental crust, which was assayed based on the earlier rough evaluations made by J. Sederholm in 1925 for the Baltic Shield and by F. Grout in 1938 for the Canadian Shield. Second, there were no data on the composition of the oceanic crust, which was not considered at all by classic geochemistry. Third, the problem of the composition of the lower portion of the continental crust, the so-called basaltic layer, remained obscure. The adequate solution of this problem required further studying. The decisive role belongs there to the following works:

(1) In the late 1960s, Ronov and Migdisov completed their extensive research of the average chemical composition of the crystalline basement of the upper continental crust: its granitic–metamorphic layer. This task was accomplished largely with the use of factual materials that were obtained by scrupulous measurements conducted in specially designed maps to characterize the abundances of the main types of metamorphic and magmatic rocks in the Baltic and Ukrainian shields and the crystalline basement of the Russian Platform. Published in 1970, these results [11] enabled the modern evaluation of the composition of the upper continental crust. The roughly coeval data of D. Show *et al.* on the Canadian Shield; the materials of K. Ida and W. Fahring and of I. Lambert and K. Heier on the Australian Shield; the data of E.A. Kulish on the Aldan Shield; and the somewhat later extensive materials of B.A. Gorlitskii on the Ukrainian Shield appeared not only generally closely similar to the results of Ronov and Migdisov but also provided insight into the heterogeneity of the crust (although it was left uncertain as to how these variations might depend on the amounts of the input data and the methods used to assay the average compositions; the reader can find an illustrative explanation of the essence of this problem in Table 36 in the book by Ronov *et al.* [12]).

(2) The "discovery" of the oceanic floor and the accumulation of newly obtained data not only on the composition of modern deep-sea sediments (the first information on their geochemistry became available as early as the late 19th century, when collections of samples taken during the first world-encircling tours were processed, including dredges of marine bottom sediments) but also on one of the most important component of the oceanic crust: its volcanic rocks. The very first results on the chemistry and geochemistry of seven deep-sea basalts published by A. Engel *et al.* in 1965 had demonstrated how geochemically unusual were these basalts, which were even placed in a distinct "cell" in the rock systematics and for which a new term was coined: oceanic tholeiitic basalts. However incredible, the volcanic rocks composing the upper layer of the oceanic crystalline crust appeared to be so geochemically homogeneous that the increase in the number of the samples from seven to a few thousands practically did not affect the evaluation of their chemical composition that was derived from the data of Engel. Together with geophysical information, these data allowed Ronov to measure the actual volume of the oceanic crust and its contribution to the structure of unconsolidated sediments and magmatic material and formed the basis for the modern evaluations of the average chemical composition of the oceanic crust (it is worth mentioning that the description and geochemical examination of metamorphic rocks, which were found, although not very often, among seafloor rocks, did not modify the evaluation of the average composition: these rocks appeared to be of relatively low metamorphic grades and practically indistinguishable geochemically from their protolithic magmatic rocks).

The solution of these problems forced Ronov and the author of this paper to return to the evaluation of the chemical structure of the crust, which was accomplished in a paper published in 1976 [13]. In contrast to the model of 1967, this publication proposed new evaluations for the compositions of the most widespread rocks of the granitic–metamorphic layer of the continental crust, the average composition of this layer as a whole, and that of the oceanic crust; as well as the reevaluated composition of the deep-seated and practically unknown continental crustal layer: the granulite–basite layer (this problem will be discussed below).

The last step toward the solution of problems related to the chemical composition of the Earth's crust was made in the late 1980s. These results were published in a book by A.B. Ronov, the author of this paper, and A.A. Migdisov [12] in 1990. This latter model was based on refined data on the abundances of rocks in the sedimentary shell, which were published in the final papers by A.B. Ronov. The most important of these results were quantitative data on the abundances and compositions of the main types of volcanic rocks [14]. The evaluations obtained by Ronov for the proportions of these rocks and data on the abundances of intrusive rocks, which were also based on the materials of Ronov and Migdisov [11], made it possible to continue the differentiated assessment of the average chemical composition of the magmatic material of the crust depending on its geotectonic (geodynamic) setting [15].

In this, the latest model for the chemical structure of the Earth's crust, we tried to approach the solution of the problem of the unknown composition of the lower part of the continental crust, its granulite–basite layer. As is known, geophysical data provide no unambiguous

Table 2. Mass (10^{24} g) and average chemical composition (wt %) of the Earth's crust and its layers (after [12])

Component	Continental crust				Oceanic crust				Earth's crust as a whole
	sedimentary shell	granite-meta-morphic shell	granulite-basite shell	crust as a whole	sedimentary layer	volcanic layer	basaltic layer	crust as a whole	
SiO_2	51.82	63.81	48.69	54.55	39.72	50.16	50.20	49.89	53.54
Al_2O_3	12.89	14.92	17.74	16.17	9.51	14.97	14.97	14.81	15.87
Fe_2O_3	2.50	1.75	–	0.92	3.34	1.79	1.73	1.79	1.11
FeO	2.91	3.68	10.84	7.32	1.31	8.82	8.82	8.60	7.6
MgO	3.32	2.83	6.70	4.91	2.13	7.53	7.54	7.38	5.44
CaO	9.93	4.08	11.69	8.72	19.18	11.62	11.73	11.93	9.41
Na_2O	1.96	3.02	2.71	2.74	1.43	2.43	2.41	2.38	2.66
K_2O	2.23	2.84	0.07	1.32	1.51	0.22	0.19	0.23	1.09
TiO_2	0.659	0.537	0.12	0.855	0.563	1.44	1.40	1.381	0.970
MnO	0.115	0.086	0.22	0.159	0.260	0.180	0.180	0.181	0.164
P_2O_5	0.162	0.141	0.25	0.201	0.198	0.150	0.140	0.143	0.189
C_{org}	0.48	0.05	–	0.07	0.11	–	–	–	0.06
CO_2	7.21	0.90	–	1.14	14.29	–	–	0.42	0.99
SO_3	0.219	0.105	–	0.063	0.355	–	–	0.010	0.052
S	0.221	0.066	–	0.049	0.038	–	–	0.001	0.039
F	0.046	0.053	–	0.025	0.052	–	–	0.002	0.020
Cl	0.539	0.022	–	0.068	0.136	–	–	0.004	0.055
H_2O	3.04	1.17	–	0.77	5.94	0.69	0.69	0.85	0.78
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Mass	2.52	8.12	11.68	22.32	0.18	1.05	4.91	6.14	28.46

solution of this problem. Although an attempt to systematically compare experimental data on the physical characteristics of the main types of magmatic and metamorphic rocks at various temperatures and pressures with geophysical data seemed to led the researchers to return to the classic model for the composition of the continental crustal material as corresponding to the composition of mafic rocks, these models were generalized as fairly primitive schemes (Fig. 2 in [13], which was then reproduced in [12]) and did not look convincing enough. It appeared, however, to be interesting to test such a model based on the idea of geochemical balance for the material of the continental crust as a whole. The key point of the idea was the assumption (which looked self-evident for nonvolatile components) that the average composition of the continental crust should be identical to the average chemical composition of magmatic crust-forming rocks of mantle provenance. This idea definitely follows from the modern paradigm of geology, as is expressed, for example, in the principle of the derivation of crustal material from the mantle, and was explicitly formulated by A.P. Vinogradov. S.R. Taylor addressed this idea and proposed his well-known "andesitic" model for the composition of the continental crust [16, 17]. However, the identification

of the average composition of crust-forming magmatic material with andesites (in the restricted sense of this term) was at variance with natural observations. This was in conflict not only with the abundances of various types of volcanic rocks in ancient foldbelts but also with the actual abundances of volcanic rocks composing young island arcs of different types and various stages of maturity. In this sense, Ronov's data are undoubtedly more representative. According to them, the average proportions of basalts, andesites, and more acid volcanics among the volcanic rocks of island arcs and foldbelts are close to 5.5 : 3.5 : 1.

The average composition of the crust-forming magmatic material estimated on the basis of these values was slightly more mafic than that in Taylor's andesitic model. Assuming this composition as an average for the crust as a whole and subtracting (in compliance with the measured volumetric proportions) the composition of the upper crust (in fact, that of continental shields) from it, we developed a model for the granulite–basite layer [18], whose silica content (49.7%) was close to those in mafic magmatic rocks. In fact, some details of this composition appeared to be "not good enough" in the sense that the concentrations of other components

Table 3. Abundances (10^{-4} wt %) of some chemical elements in the upper continental crust

Element	Vinogradov, 1962	Ronov *et al.*, 1990
O	470000	479000
Si	295000	296300
Al	80500	79000
Fe	46500	40600
Ca	29600	29200
K	25000	23600
Na	25000	22400
Mg	18700	17100
Ti	4500	3220
C	230	2960
S	470	1080
Mn	1000	670
P	930	620
F	660	530
Cl	170	220

did not exactly correspond to the analogous values for natural mafic magmatic and metamorphic rocks (this applies, first of all, to the underestimated content of potassium), but it is hardly reasonable now to expect any "better" estimates.

The final results are summarized in Table 2. The likely most significant outcome of this work is the practical validation of the estimated abundances of major elements in the upper continental crust, the only geologic object that was then accessible for geochemical examination, by the values published in the classic work by A.P. Vinogradov [2] (Table 3). This means that the actual geochemical parameters of the continental crust have long been known, and this problem, which was approached and attacked by geochemists over a long period of time, with the use of different methods, can be considered solved.

The latest evaluations of the abundances of all chemical elements in the upper continental crust seem to be the data published by Wedepohl [19] in 1995. These values are listed in this paper in Table 4. It can be seen that Wedepohl's estimates of the abundances of

Table 4. Abundances (10^{-4} wt %) of chemical elements in the upper continental crust (after [Wedepohl, 1995])

Element	Abundance	Element	Abundance	Element	Abundance
1 H	–	30 Zn	52	59 Pr	6.3
3 Li	22	31 Ga	14	60 Nd	25.9
4 Be	3.1	32 Ge	1.4	62 Sm	4.7
5 B	17	33 As	2.0	63 Eu	0.95
6 C	3240	34 Se	0.083	64 Gd	2.8
7 N	83	35 Br	1.6	65 Tb	0.50
8 O	–	37 Rb	110	66 Dy	2.9
9 F	611	38 Sr	316	67 Ho	0.62
11 Na	25670	39 Y	20.7	68 Er	–
12 Mg	13510	40 Zr	237	69 Tm	–
13 Al	77440	41 Nb	26	70 Yb	1.5
14 Si	303480	42 Mo	1.4	71 Lu	0.27
15 P	665	44 Ru	–	72 Hf	5.8
16 S	953	45 Rh	–	73 Ta	1.5
17 Cl	640	46 Pd	–	74 W	1.4
19 K	28650	47 Ag	0.055	75 Re	–
20 Ca	29450	48 Cd	0.102	76 Os	–
21 Sc	7	49 In	0.061	77 Ir	–
22 Ti	3117	50 Sn	2.5	78 Pt	–
23 V	53	51 Sb	0.31	79 Au	–
24 Cr	35	52 Te	–	80 Hg	0.056
25 Mn	527	53 I	1.4	81 Tl	0.75
26 Fe	30890	55 Cs	5.8	82 Pb	17
27 Co	11.6	56 Ba	668	83 Bi	0.123
28 Ni	18.6	57 La	32.3	90 Th	10.3
29 Cu	14.3	58 Ce	65.7	92 U	2.5

chemical elements differ somewhat form those obtained by Ronov *et al.* These differences can be explained by the fact that Wedepohl proceeded from slightly different proportions of major rock types in the crust. The reasons for these changes are not fully clear, and it is pertinent to mention that, with regard for the generally not very high accuracy of even modern estimates (their inaccuracies can hardly be less than ±10%), there are no grounds to consider these discrepancies principal. The abundances of chemical elements in the lower continental crust and, correspondingly, in the continental crust as a whole published by Wedepohl are even more problematic and are not quoted here.

There seem to be good reasons to believe that our estimates of the average compositions of the upper continental crust, sedimentary shell, and continental crust are fairly realistic. This makes it possible to proceed to the solution of another problem: an accurate quantitative evaluation of the regional geochemical heterogeneity of the Earth's crust, in particular, in relation to its geotectonic (geodynamic) heterogeneity and the different ages of its rocks. Much information devoted to this problem is already published, for example in *Geochemistry International* (see, for instance, [20–25]), but the solution of this problem is only in its early stages and requires so much effort and time that it is hard to expect any appreciable results in the foreseeable future.

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