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The role and importance of chemical elements clarks in the practical expanded reproduction of mineral resources

M.Zh. Bitimbayev[1], K.B. Rysbekov[1], D.K. Akhmetkanov[1*], M.S. Kunayev[2], V.H. Lozynskyi[3], K.K. Elemesov[1]

[1]*Satbayev University, Almaty, Kazakhstan*
[2]*MK - Metals Holding LLP, Almaty, Kazakhstan*
[3]*Dnipro University of Technology, Ukraine*

**Corresponding author: d.akhmetkanov@satbayev.university*

Abstract. Mankind will always need metallic minerals. Despite of reduction of specific consumption, of increase both volumes of their reuse, and increase in strength qualities and wear resistance, of addition to metal alloys of synthetic materials, and also of transition to artificial atomic assembly of the necessary chemical elements from natural rocks and their constituent minerals and synthesis of metals from ocean water, offshore placers and bottom deposits in the future, extraction of ore from massif of earth crust will be the basic source of supply of demanded minerals. Based on these immutable postulates, we have made a comprehensive analysis of the existing geochemical patterns, the accumulation of mineral matter suitable for use as minerals. The origin of the planets of the Solar system with the condensation of the gas-dust cloud, which, in turn, as a result of adiabatic compression turned into planets of the Earth type and the asteroid belt with meteorites, was the reason for the same distribution of chemical elements in the Sun, in meteorites and in the Earth crust. We considered the anthropogenic-technical possibilities of mankind on the maximum depth of development of the continental part of the Earth's crust, the minimum industrial content (which will change over time towards reduction), the amount of minerals according to the clark in that part of the continental Earth's crust which is possible for industrial use with the objective restrictions, we determined the reserves of the demanded chemical elements. Calculations show their sufficiency for many years to come, but it will be the reserves in the deposits of a new type, created by objective geochemical regularities acting in nature, but not considered at present. Particular attention should be paid to the analytical generalization of mineral content at the micro- and nanoscale, which are currently not defined, being unaccounted reserves within well above the clark content at the minimum industrial level. The use of clarks and other geochemical patterns in the Earth's crust will require the creation of new analytical capabilities in exploration, new technological solutions for the extraction and processing of minerals from deposits of a new type, which are briefly described in the paper and are the subject of a more detailed and evidence-based description in the development of this article.

Keywords: *clark, solar system, planets and meteorites, geochemical regularities, mineral resources, complete depletion of reserves, reproduction of raw material base, new type deposits.*

1. Introduction

As is known, the clark of a chemical element as a system of averaged contents that characterize their distribution in a large geochemical system (in the crust, lithosphere, atmosphere, hydrosphere, biosphere, on Earth as a whole or in space), is called the concept of geochemical regularity, objectively existing in nature.

In the modern sense, clarks are the average concentrations of elements in the Earth's crust as the upper layer of the planet above the Mohorovich boundary, calculated in 1962 by A.P. Vinogradov, S.R. Taylor in 1964 and in 1967 by K.G. Vedepol (1, 2, 3). These average concentrations were determined from spectral analyses of the composition of the Sun, data on the chemical composition of rock meteorites, which correspond to crustal clarks, and numerous sample analyses of crustal rocks.

Research A.E. Fersman showed that the geochemical pattern of constancy of Clark in the system, which allows to fix any deviation from the norm, which is Clark, caused by concentration or dispersion, in turn explained by the migration of elements both on the surface, ie laterally extent, and vertically, creating a pattern of "zoning".

The next important point in the assessment of the chemical system is the practical application of clarks as benchmarks for comparing reduced or elevated levels of chemical elements in mineral deposits, rocks or entire regions for the purpose of prospecting and industrial evaluation of deposits. On the basis of this natural conclusion, quantitative indicators of the concentration of the elements in the process of migration, which in turn leads to the fixation of a certain dependence on the clarks of the total content of the elements in the geochemical systems, total reserves of certain metals and ores in the Earth's crust, the scale of deposits, the number of minerals of each element, the behavior of the elements in geochemical processes.

2. Materials and Methods

Thus, in the primary distribution of the planetary material, the metals demanded by the developing civilized

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world did not form, like rocks, clusters in the Earth's crust, but were dispersed in its constituent strata. The formation of any deposit required a secondary redistribution of metals, with a transition from dispersion to concentration. This transition could be carried out in a wide range of endogenous and exogenous conditions, but it was not infinite, because it was subject to "the law of direct proportionality for all metals: the scale of accumulation of any metal in ore deposits (reserves) is determined by the degree of occurrence (clark) of each of them in the Earth's crust" (2,3,4).

Academician L.N. Ovchinnikov determined a direct relationship between clarks, the total reserves of metals and the minimum industrial content of metals siderophilic-chalcophilic and lithophilic groups (Figure 1).

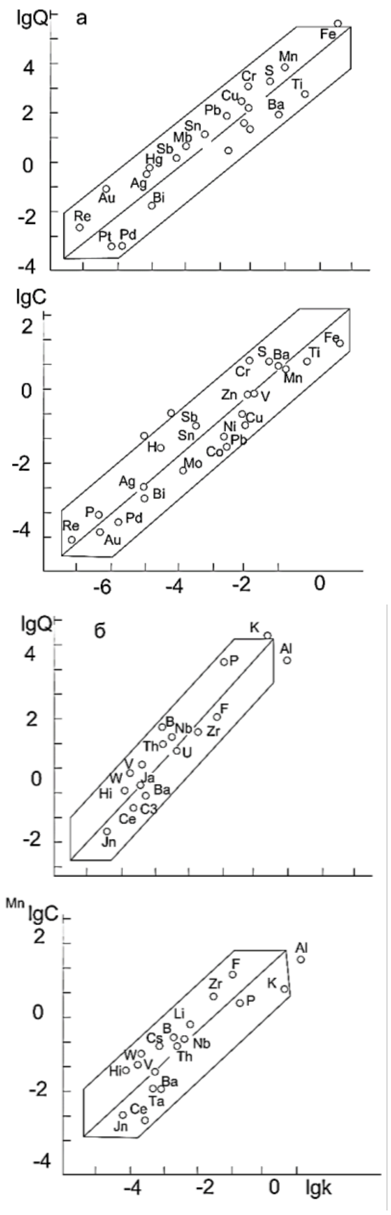

Figure 1. Relationship between clarks C and total reserves of metals in ore deposits Q, between clarks and the minimum commercial grade of metals C in ore deposits of siderophile-chalcophile (a) and lithophile (b) groups (prices and minimum commercial grade are given as of 01.01.1988)

On the basis of distribution of these elements and results of the full regression analysis, estimates of their interdependence were obtained (Table 1).

The data obtained in the results of calculations by the empirical formula of Academician L.N. Ochinnikov, which were published in 1988, maintaining a directly proportional relationship between clarks and reserves according to the minimum industrial grades on the planet as a whole or for its individual regions and states, will vary. This is facilitated by factors that depend on the technical feasibility of extraction and processing in different mining and geological and mining conditions, economic efficiency, and safety. But the pattern remains and allows us to make predictive calculations.

Table 1. Dependence of accumulation of chemical elements in ore deposits on their clark. According to A.P. Vinogradov

No.	Chemical element	Clark C,%	Total world reserves Q, million tons	Minimum industrial content C,%	Concentration coefficient CC	Price on the world market P, $/kg
Siderophilic-Halcophilic group						
1	Iron (Fe)	4,65	$3,75 \cdot 10^{5}$	22,0	4,73	$9,1 \cdot 10^{-3}$
2	Titanium (Ti)	0,45	$4,86 \cdot 10^{2}$	7,0	16	$6,3 \cdot 10^{-2}$
3	Manganese (Mn)	0,10	$7,52 \cdot 10^{2}$	5,0	50	$5,7 \cdot 10^{-2}$
4	Barium (Ba)	$6,5 \cdot 10^{2}$	$1,1 \cdot 10^{-2}$	9,0	138	0,16
5	Sulfur (S)	$3,7 \cdot 10^{-2}$	$2,1 \cdot 10^{3}$	7,0	189	$3,9 \cdot 10^{-2}$
6	Vanadium (V)	$9,1 \cdot 10^{-3}$	22,0	0,7	77	4,2
7	Chromium (Cr)	$8,3 \cdot 10^{-3}$	$1,369 \cdot 10^{3}$	7,0	843	$6,9 \cdot 10^{-2}$
8	Zinc (Zn)	$8,3 \cdot 10^{-3}$	$2,01 \cdot 10^{2}$	0,7	84	0,356
9	Nickel (Ni)	$5,8 \cdot 10^{-3}$	54,4	0:1	17	2,4
10	Copper (Cu)	$4,7 \cdot 10^{-3}$	$3,42 \cdot 10^{2}$	0,2	43	1,34
11	Cobalt (Co)	$1,8 \cdot 10^{-3}$	3,24	$2,0 \cdot 10^{-2}$	11	4,8
12	Lead (Pb)	$1,6 \cdot 10^{-3}$	$1,07 \cdot 10^{2}$	0,3	188	0,36
13	Tin (Sn)	$2,5 \cdot 10^{-4}$	17,0	0,1	400	3,67
14	Molybden (Mo)	$1,1 \cdot 10^{-4}$	5,46	$5,0 \cdot 10^{-3}$	46	4,87
15	Antimony (Sb)	$5,0 \cdot 10^{-5}$	2,1	0,2	4000	3,12
16	Bismuth (Vi)	$9,0 \cdot 10^{-6}$	$2,5 \cdot 10^{2}$	$1,0 \cdot 10^{-3}$	111	9,9
17	Mercury (Hg)	$8,3 \cdot 10^{-6}$	0,8	$5,0 \cdot 10^{-3}$	6024	11,8
18	Silver (Ag)	$7,0 \cdot 10^{-6}$	0,46	$1,6 \cdot 10^{-3}$	228	57,0
19	Palladium (Pd)	$1,3 \cdot 10^{-6}$	$8,0 \cdot 10^{-4}$	$2,0 \cdot 10^{-4}$	194	$3,9 \cdot 10^{3}$
20	Platinum (Pi)	$7,0 \cdot 10^{-7}$	$8,0 \cdot 10^{-4}$	$2,0 \cdot 10^{-4}$	585	$4,3 \cdot 10^{3}$
21	Gold (Au)	$4,3 \cdot 10^{-7}$	0,14	$1,0 \cdot 10^{-4}$	233	1,125
22	Rhenium (Re)	$7,0 \cdot 10^{-8}$	$4,0 \cdot 10^{-3}$	$5,0 \cdot 10^{-5}$	714	$1,87 \cdot 10^{3}$
Lithophilic group						
23	Aluminum (Al)	8,05	$8,14 \cdot 10^{3}$	17,0	2	$3,4 \cdot 10^{-2}$
24	Potassium (K)	2,5	$5,5 \cdot 10^{4}$	2,5	1	$2,7 \cdot 10^{-2}$
25	Phosphorus (P)	$9,3 \cdot 10^{-2}$	$6,7 \cdot 10^{3}$	1,3	14,0	$4,0 \cdot 10^{-2}$
26	Fluorine (F)	$6,6 \cdot 10^{-2}$	$1,126 \cdot 10^{2}$	6,9	105	$5,3 \cdot 10^{-2}$
27	Zircon (Zr)	$1,7 \cdot 10^{-2}$	32,0	2,0	118	11,0
28	Lithium (Li)	$3,2 \cdot 10^{-3}$	8,25	0,33	103	1,29
29	Niobium (Nb)	$2,0 \cdot 10^{-3}$	19,82	0,14	70	2,58
30	Thorium (Th)	$1,3 \cdot 10^{-3}$	1,12	0,09	69	0,45
31	Boron (B)	$1,2 \cdot 10^{-3}$	54,0	0,16	133	0,43
32	Beryllium (Be)	$3,8 \cdot 10^{-4}$	0,243	$7,0 \cdot 10^{-3}$	18	91,6
33	Cesium (Cs)	$3,8 \cdot 10^{-4}$	0,230	0,1	270	99,0
34	Tantalum (Ta)	$2,5 \cdot 10^{-4}$	0,52	$6,5 \cdot 10^{-3}$	32	48,5
35	Uranium (U)	$2,5 \cdot 10^{-4}$	2,65	$2,0 \cdot 10^{-2}$	80	38,6
36	Germanium (Ge)	$1,4 \cdot 10^{-4}$	0,1	$1,0 \cdot 10^{-3}$	7	293,0
37	Tungsten (W)	$1,3 \cdot 10^{-4}$	1,36	$6,0 \cdot 10^{-2}$	44	16,6
38	Hafnium (Hf)	$1,0 \cdot 10^{-4}$	0,318	$3,0 \cdot 10^{-2}$	300	47,0
39	Indium (In)	$2,5 \cdot 10^{-5}$	$1,4 \cdot 10^{-2}$	$1,0 \cdot 10^{-3}$	40	88,0

Based on the definition of the mentioned ratios in ore deposits for 35 metals and for B, S, P and F by Ovchinnikov L.N. $\sum Q=KA$, where K is average content of elements in the Earth's crust, or "clark" by Vinogradov A.P., %; A is average proportionality factor, equal to $2.8\text{x}10^{10}$ at the accuracy of 0.58 and standard deviation 3.18. Then the total world reserves in the fields are expressed by the formula.

$\sum Q=K[(2.8\pm0.6)\pm6.4]\cdot10^{10}$ tons

The emerging negative situation with the availability of mineral raw materials for civilization, the destruction of the natural balance in the stability of the massif of subsoil, which composes the earth's surface, and the impossibility of human society existence without mining and processing mineral raw materials were the reason for the emergence of the task of finding sources of conservation and expanded reproduction based on the use of all rocks as minerals.

The term of such decisions should not exceed the term of change of one generation, given the need for a huge complex of research and practical work to create a mineral resource base in the new interpretation and the complete depletion of traditional mineral reserves by the end of the XXI century.

Deposits of minerals in the traditional interpretation are formed over time, the duration of which is commensurate with the geological time of formation of various complexes of rocks.

The theoretical basis, which determined the focus of our search and formulation of the basics of reproduction of mineral resources in the new interpretation, sounds as follows: "The measure of scientific content for mining production should also become the degree of implementation of a variety of resource-producing technologies that affect the mineral environment. It is they are now called to provide "reclamation" of the subsoil within the spatial boundaries of the transformed area of the lithosphere, considering its properties, requirements and environmental standards. In these technologies should be used new knowledge about the properties of natural and man-made geosystems" [1].

As the Academician of the Russian Academy of Sciences N.P. Laverov says in the Preface to the above-mentioned work: " Particular in the mining sciences is expressed in the fact that the transformation of the bowels is carried out in the historical, but not in the geological time scale". We interpret this concept as the need to create a practical technological possibility of transformation during one generation, i.e. on a historical scale, georesources in any of its contents into useful commodity products.

On the basis of the task and having studied empirical formula of Academician Ovchinnikov L.N., we believe that:

1) total world stocks do not depend only on the correlation coefficient. On the contrary, the correlation coefficient is a derivative of the value of minimum industrial content, which, in its turn, depends on the level of development of mineralogy in all its technological diversity and on the needs of the market, which dictate prices. In this case the market will be able to dictate the prices from a certain historical time depending on the mining-geological and mining-technical conditions of extraction and processing and on the need in each produced chemical element;

2) Moreover, the formula itself cannot be considered reliable at the present time, since the actual reserves of almost all chemical elements given in Table 1 are much higher than the calculated ones. Such a difference can be explained by two reasons:

- The clarks were not determined accurately enough and need to be recalculated;
- L.N. Ovchinnikov's formula needs reassessment;

3) the dependence of the value of total world reserves on clark, preserving its paramount and correct value for the assessment of metal reserves in the Earth's crust, should be subject to correlation with these conditions;

4) taking the maximum depth of operations to extract chemical elements from massive rocks (traditional mining or other methods), depending on the anthropogenic and technical capabilities, 5 km, we can calculate the projected reserves of them in the continental part of the crust in the range from the surface to this depth;

5) The established regularity between reserves of metal in deposits and its average content in the Earth's crust can be used for the prediction of reserves not only of the Earth's crust as a whole, but also its separate representative areas on a separate state, ore provinces and separate ore formations, and also taking into account genetic relationships on differentiation of chemical elements depending on differentiators;

6) the rate of chemical reactions contributing to and creating the ore-forming process is extremely small and comparable with the duration of the leading geological process and its individual stages and phases. Hence, it follows that on a historical scale, waiting for the collection and mobilization of metals for the transport of ore matter in the area of ore deposition in the historical time interval is useless, i.e. we cannot talk about replenishment of reserves as a result of natural ore-forming process in the traditional deposits;

7) comparison of the data on total world reserves and prices in the world market, given in the reviewed literature [12,13] with transformation for 2018-2020 and the value of clarks from various sources shows changes in some cases of clarks and in all cases of data on reserves and world prices. These facts indicate, first, the considerable scientific work to continually refine the value of clarks; second, the intensive exploration carried out around the world using new technologies; third, the market impact on metal prices due to growth and changes in demand for metals and depending on inflation; fourth, the need to verify and continually refine the average proportionality ratio, accuracy and standard deviation.

On the basis of this comparative analysis, we may conclude that the empirical formula of Ovchinnikov L.N. determines the existence of this dependence accurately, but it is applied in 1987-1988, and gives erroneous results in 2020-2021, while maintaining its logic. This tendency will apparently continue until the possible practical limits on reserves and on the minimum industrial content are reached.

3. Results and discussion

In order to study and use in the practical activities of the mining industry pattern of dependence of metal accumulation in deposits on their clarks, which makes it possible to find and create new sources of minerals, the authors conducted calculations for the formation of the mineral resource base on the background of the depletion of traditional reserves of minerals.

Input data for the calculations: [9]

- Average radius of the Earth R=6371.032 km;

- Volume of the Earth's globe on the surface $V_1=4/3\pi R^3 \cdot 4/3\pi \cdot 6371.032^3= 1.083 \cdot 10^2 km^3$

- the depth of spreading of the Earth's crust in the continental part is on average 33 km;

- volume of the part of the Earth's ball with radius reduced by 33 km, $V_2=4/3\pi(6371.032-33)^3= 1.0666 \cdot 10^{12} km^3$

- volume of the globular layer between the Earth's surface and the lower surface of the continental crust $V_3=1.083 \cdot 10^{12}-1.0666 \cdot 10^{12} =16.3838 \cdot 10^9 km^3$

- continental crust C_c of the total surface area of the globe is 148.1/509.1=0.2909, and the volume of continental crust in the 33 km high globe layer will then be $V_4=C_C \cdot V_3=4.766 \cdot 10^9 km^3$

- coefficient of human civilization's use of the continental crust $C_{ICC}=5/33=0.15$ (15), where 5 km is the height of the continental crust from the surface, which is determined by the anthropogenic-technical possibility of developing the subsurface;

- volume of the continental crust, which is possible to use as a target for exploration and production of mineral resources $V=4.766 \cdot 10^9 \cdot 0.15(15)=0.722 \cdot 10^9 km^3$

- volume weight γ of the Earth's crust rocks in the continental part is on average $2.7 \cdot 10^9 t/km^3$;

-is the mass of the rock of the continental part of the Earth's crust, which theoretically can be extracted in order to obtain mineral raw materials from it (or in which the average clark of a chemical element can be determined through its content in that part of the Earth's crust, which according to the anthropogenic-technical possibility can be used as a mineral raw material): $Q=\gamma \cdot V=2.7 \cdot 10^9 \cdot 0.722 \cdot 10^9=1.95 \cdot 10^9$ billion tons.

The next step in our work is to calculate the number of chemical elements depending on the clarks of the continental part of the Earth to a depth of 5 km from the surface, which is determined by the anthropogenic and technical capabilities of humans H_{ATB}. It should be noted that we make calculations based on the currently accepted limiting conditions, which consist of two requirements - the clark of the chemical element and ensuring a safe depth of mining, at which it is technically possible to extract minerals with their lifting and transfer for processing. Economic efficiency will be determined by the technology used and market demand.

Following the above and using the dependences of accumulation of chemical elements in ore deposits, we determine the expected amounts of chemical elements in the continental crust in the layer from the surface to a depth of 5 km (Table 2).

Using the values of the minimum industrial concentrations of 39 chemical elements, adopted by Academician L.N. Ovchinnikov in his work "Formation of ore deposits", published in 1988. [2], it is possible to compare total world stocks of the same chemical elements determined by L.N.Ovchinnikov's empirical formula with the confirmed world stocks given in the official statistics in the second decade of the XXI century (in different years for different elements). Such a comparison and the number of accumulated elements in the continental crust at a depth of H_ATB will allow us to make sufficiently correct conclusions about the state of the mineral resource base of minerals (Table 3).

Table 2. Accumulation of chemical elements depending on their clarks (by A.P. Vinogradov), comparing it with statistically confirmed reserves and with the amount by clark in the continental part of the Earth's crust

Item	Chemical element	Clark C, %		Total world reserves of chemical elements, million tons		Minimum industrial content C, % (by L.N. Ovchinnikov)	Concentration factor CF=C/C$_1$	The total amount of chemical elements in the continental part of the Earth's crust, calculated by the authors, billion tons, at a depth of H_{ATB}=5 km	
		According to A.P. Vinogradov, C$_1$	According to the average values of other authors, C$_2$	Q$_1$ by the clarks of A.P. Vinogradov	Q$_1$ confirmed by 2018-2020 statistics			Full amount by clark	30% of the quantity according to the minimum industrial content by L.G. Ovchinnikov
1	2	3	4	5	6	7	8	9	10
	Siderophilic-Halcophilic group								
1	Iron (Ft)	4,65	5,33	$3,75 \cdot 10^5$	$0,84 \cdot 10^5$	22,0	4,73	$90,675 \cdot 10^6$	$5,75 \cdot 10^6$
2	Titanium (Ti)	0,45	0,53	$4,86 \cdot 10^2$	$9,40 \cdot 10^2$	7,0	16	$8,775 \cdot 10^6$	$164,5 \cdot 10^3$
3	Manganese (Mn)	0,10	0,09	$7,52 \cdot 10^3$	$5,2 \cdot 10^2$	5,0	50	$1,950 \cdot 10^6$	$11,7 \cdot 10^3$
4	Barium (Ba)	$6,5 \cdot 10^{-2}$	$4,7 \cdot 10^{-2}$	$1,1 \cdot 10^2$	$3,00 \cdot 10^2$	9,0	138	$1,267 \cdot 10^6$	$2,755 \cdot 10^3$
5	Sulfur (S)	$3,7 \cdot 10^{-2}$	$3,3 \cdot 10^{-2}$	$2,1 \cdot 10^3$	-	7,0	189	$721,5 \cdot 10^3$	$1,145 \cdot 10^3$
6	Vanadium (V)	$9,1 \cdot 10^{-3}$	$1,2 \cdot 10^{-3}$	22,0	-	0,7	77	$177,45 \cdot 10^3$	$0,69 \cdot 10^3$
7	Chrome (Cr)	$8,3 \cdot 10^{-3}$	$9,3 \cdot 10^{-3}$	$1,369 \cdot 10^3$	$1,6 \cdot 10^3$	7,0	843	$161,85 \cdot 10^3$	57,6
8	Zinc (Zn)	$8,3 \cdot 10^{-3}$	$6,8 \cdot 10^{-3}$	$2,01 \cdot 10^2$	$2,62 \cdot 10^2$	0,7	84	$161,85 \cdot 10^3$	578
9	Nickel (Ni)	$5,8 \cdot 10^{-3}$	$7,0 \cdot 10^{-3}$	54,4	75,9	0:1	17	$114,1 \cdot 10^3$	$1,996 \cdot 10^3$
10	Copper (Cu)	$4,7 \cdot 10^{-3}$	$5,3 \cdot 10^{-3}$	$3,42 \cdot 10^2$	$8,3 \cdot 10^2$	0,2	43	$91,65 \cdot 10^3$	$0,639 \cdot 10^3$
11	Cobalt (Co)	$1,8 \cdot 10^{-3}$	$2,3 \cdot 10^{-3}$	3,24	7,5	$2,0 \cdot 10^{-2}$	11	$35 \cdot 10^3$	$0,95 \cdot 10^3$
12	Lead (Pb)	$1,6 \cdot 10^{-3}$	$1,3 \cdot 10^{-3}$	$1,07 \cdot 10^2$	$1,17 \cdot 10^2$	0,3	188	$31,2 \cdot 10^3$	$0,05 \cdot 10^3$
13	Tin (Sn)	$2,5 \cdot 10^{-4}$	$2,3 \cdot 10^{-4}$	17,0	5,5	0,1	400	$4,875 \cdot 10^3$	3,656
14	Molybdenum (Mo)	$1,1 \cdot 10^{-4}$	$1,2 \cdot 10^{-4}$	5,46	15,0	$5,0 \cdot 10^{-3}$	46	$2,145 \cdot 10^3$	13,99
15	Antimony (Sb)	$5,0 \cdot 10^{-5}$	$3,0 \cdot 10^{-5}$	2,1	1,5	0,2	4000	975	0,073

Item	Chemical element	Clark C, %		Total world reserves of chemical elements, million tons		Minimum industrial content C, % (by L.N. Ovchinnik	Concentra tion factor $CF=C/C_1$	The total amount of chemical elements in the continental part of the Earth's crust, calculated by the authors, billion tons, at a depth of H_{ATB}=5 km	
16	Bismuth (Bi)	$9,0\cdot10^{-6}$	$1,9\cdot10^{-5}$	$2,5\cdot10^{-2}$	-	$1,0\cdot10^{-3}$	111	175,5	0,474
17	Mercury (Hg)	$8,3\cdot10^{-6}$	$7,2\cdot10^{-6}$	0,8	-	$5,0\cdot10^{-2}$	6024	161,85	0,008
18	Silver (Ag)	$7,0\cdot10^{-6}$	$7,3\cdot10^{-6}$	0,46	0,84	$1,6\cdot10^{-3}$	228	136,5	0,179
19	Palladium (Pd)	$1,3\cdot10^{-6}$	$9,0\cdot10^{-7}$	$8,0\cdot10^{-4}$	0,76	$2,0\cdot10^{-4}$	194	25,39	0,0495
20	Platinum (Pt)	$7,0\cdot10^{-7}$	$5,7\cdot10^{-7}$	$8,0\cdot10^{-4}$		$2,0\cdot10^{-4}$	585	13,69	0,0144
21	Gold (Au)	$4,3\cdot10^{-7}$	$3,5\cdot10^{-7}$	0,14	0,058	$1,0\cdot10^{-4}$	233	8,385	0,0108
22	Rhenium (Re)	$7,0\cdot10^{-8}$	$8,0\cdot10^{-8}$	$4,0\cdot10^{-3}$	-	$5,0\cdot10^{-5}$	714	1,365	0,00057
Lithophilic group									
23	Aluminum (Al)	8,05	8,07	$8,14\cdot10^{3}$	$14,7\cdot10^{3}$	17,0	2	$15,697\cdot10^{7}$	$2,35\cdot10^{7}$
24	Potassium (K)	2,5	2,13	$5,5\cdot10^{4}$	$6,56\cdot10^{4}$	2,5	1	$4,875\cdot10^{7}$	$1,46\cdot10^{7}$
25	Phosphorus (P)	$9,3\cdot10^{-2}$	0,1	$6,7\cdot10^{3}$	$11,13\cdot10^{3}$	1,3	14,0	$18,135\cdot10^{5}$	$38,86\cdot10^{3}$
26	Fluorine (F)	$6,6\cdot10^{-2}$	$6,4\cdot10^{-2}$	$1,126\cdot10^{2}$	$1,09\cdot10^{2}$	6,9	105	$259,65\cdot10^{3}$	$0,742\cdot10^{3}$
27	Zircon (Zr)	$1,7\cdot10^{-2}$	$1,6\cdot10^{-2}$	32,0	-	2,0	118	$33,15\cdot10^{3}$	84,2
28	Lithium (Li)	$3,2\cdot10^{-3}$	$2,5\cdot10^{-3}$	8,25	18,79	0,33	103	$62,4\cdot10^{3}$	$0,182\cdot10^{3}$
29	Niobium (Nb)	$2,0\cdot10^{-3}$	$2,1\cdot10^{-3}$	19,82	4,3	0,14	70	$39,0\cdot10^{3}$	$0,167\cdot10^{3}$
30	Thorium (Th)	$1,3\cdot10^{-3}$	$1,0\cdot10^{-3}$	1,12	-	0,09	69	$25,3\cdot10^{3}$	$0,110\cdot10^{3}$
31	Boron (B)	$1,2\cdot10^{-3}$	$9,0\cdot10^{-4}$	54,0	-	0,16	133	$23,4\cdot10^{3}$	$0,053\cdot10^{3}$
32	Beryllium (Be)	$3,8\cdot10^{-4}$	$2,0\cdot10^{-4}$	0,243	-	$7,0\cdot10^{-3}$	18	$7,41\cdot10^{3}$	$0,1235\cdot10^{3}$
33	Cesium (Cs)	$3,8\cdot10^{-4}$	$4,3\cdot10^{-4}$	0,230	-	0,1	270	$7,41\cdot10^{3}$	8,23
34	Tantalum (Ta)	$2,5\cdot10^{-4}$	$2,2\cdot10^{-4}$	0,52	$1,5\cdot10^{2}$	$6,5\cdot10^{-3}$	32	$4,875\cdot10^{3}$	45,7
35	Uranium (U)	$2,5\cdot10^{-4}$	$2,6\cdot10^{-4}$	2,65	7,33	$2,0\cdot10^{-2}$	80	$4,875\cdot10^{3}$	18,28
36	Germanium (Ge)	$1,4\cdot10^{-4}$	$1,4\cdot10^{-4}$	0,1	-	$1,0\cdot10^{-3}$	7	$2,73\cdot10^{3}$	95,5
37	Tungsten (W)	$1,3\cdot10^{-4}$	$1,4\cdot10^{-4}$	1,36	3,3	$6,0\cdot10^{-2}$	444	$2,535\cdot10^{3}$	1,713
38	Hafnium (Hf)	$1,0\cdot10^{-4}$	$2,4\cdot10^{-4}$	0,318	-	$3,0\cdot10^{-2}$	300	$1,95\cdot10^{3}$	1,95
39	Indium (In)	$2,5\cdot10^{-5}$	$4,7\cdot10^{-3}$	$1,4\cdot10^{-2}$	-	$1,0\cdot10^{-3}$	40	487,5	3,656

Note: The data in paragraph 10 of Table 2 need further recalculation, since the dependence of the amount of metals calculated by the minimum industrial content, in fact, is not directly proportional to the calculated clark and is fit to the exponential function.

4. Conclusions

The practical use of the essence of our Discovery depends on the following objective provisions. The content of the continental part of the Earth's crust in the layer H_ATB, calculated by the clark, shows gigantic numbers.

But for a realistic estimate of the amount of these elements, the following limitations must be considered. Not all of the territory of the Earth's continental part can be used as an object of extraction of minerals, even if their quantity and quality will allow them economically justified extraction and processing:

- Territory covered by highlands and other relief boundaries will be excluded from subsoil use;

- Territories along the national and international infrastructure, settlements, natural boundaries (rivers, lakes, coasts of seas and oceans, etc.) will be withdrawn from subsoil use for a historically long period;

- As mentioned above, the amount of chemical element(s) accounted for in the balance as a mineral resource will depend on the adopted cost-effective level of minimum industrial content. It will depend on creation of workable new technologies of extraction (we can say in the future "extraction in solution without disturbing the integrity of the massif") and processing, as well as the use as a useful raw material of the whole extracted mass with its separation into components, which will reduce sharply the cost of production due to complete gross extraction and complete wasteless processing. This fact will limit the use of reserves of the continental crust and set the order of commissioning depending on the technical and economic opportunities (Table 4).

- Based on this condition, the object of subsoil use will be the areas of primary and secondary halos on the forms of migration and deposition of chemical elements in the lateral (subhorizantal) zoning, in the zoning of near-ore rock changes in hydrothermal systems, in the latitudinal geochemical zone on the earth's surface and in the vertical zoning associated with changes in chemical composition and properties in subvertical direction, typical of ore veins, weathering crust.

- Separately, the concepts of technogenic geochemical anomalies, technogenic dispersion halos, technogenic barriers, as well as the model of technogenic migration associated with technogenic landscapes and geochemistry of cities should be considered and used.

Thus, the reserves of mineral resources of a new type, which mankind creates in connection with the full depletion of reserves in mineral deposits, explored and transferred to exploitation in accordance with the currently accepted interpretation, will be composed of the determination of objects of subsoil use from the practical use of the pattern of dependence of chemical elements of natural and anthropogenic nature accumulation.

Thus, the limit of the contents of chemical elements in the rock mass of mineral raw materials, accounted as stocks of new type, will be defined by technical and economic calculations of final cumulative expenses efficiency.

Table 4 shows that, using the pattern of distribution of metals in direct proportion, which is determined by the degree of prevalence (clark) of each of them in the Earth's crust, we can define a new trend of development of the mining and metallurgical industry.

Table 3. Suggested maximum and minimum total world reserves of chemical elements in ore deposits (according to the empirical formula of Academician L.N. Ovchinnikov)

Item	Chemical element	Clark C,%	Maximum total world reserves in ore deposits Q_{max} , million tons	Maximum total world reserves in ore deposits Q_{max} , million tons
1	2	3	4	5
1	Iron(Ft)	4,65	$455,7\cdot 10^{3}$+	$195,3\cdot 10^{3}$
2	Titanium(Ti)	0,45	$4,41\cdot 10^{3}$-	$18,9\cdot 10^{3}$
3	Manganese(Mn)	0,10	$9,8\cdot 10^{3}$+	$4,2\cdot 10^{3}$
4	Barium(Ba)	$6,5\cdot 10^{-2}$	$6,37\cdot 10^{3}$+	$2,73\cdot 10^{3}$
5	Sulfur(S)	$3,7\cdot 10^{-2}$	$3,626\cdot 10^{3}$+	$1,554\cdot 10^{3}$
6	Vanadium(V)	$9,1\cdot 10^{-3}$	$0,8918\cdot 10^{3}$+	$0,3822\cdot 10^{3}$
7	Chrome(Cr)	$8,3\cdot 10^{-3}$	$0,8134\cdot 10^{3}$-	$0,3486\cdot 10^{3}$
8	Zinc(Zn)	$8,3\cdot 10^{-3}$	$0,8134\cdot 10^{3}$+	$0,3486\cdot 10^{3}$
9	Nickel(Ni)	$5,8\cdot 10^{-3}$	$0,5684\cdot 10^{3}$+	$0,2436\cdot 10^{3}$
10	Copper(Cu)	$4,7\cdot 10^{-3}$	$0,4606\cdot 10^{3}$+	$0,1974\cdot 10^{3}$
11	Cobalt(Co)	$1,8\cdot 10^{-3}$	$0,1764\cdot 10^{3}$+	$0,0756\cdot 10^{3}$
12	Lead(Pb)	$1,6\cdot 10^{-3}$	$0,1568\cdot 10^{3}$=	$0,0672\cdot 10^{3}$
13	Tin(Sn)	$2,5\cdot 10^{-3}$	24,5+	10,5
14	Molybdenum(Mo)	$1,1\cdot 10^{-4}$	10,78+	4,62
15	Antimony(Sb)	$5,0\cdot 10^{-5}$	4,9+	2,1
16	Bismuth(Bi)	$9,0\cdot 10^{-6}$	0,882+	0,378
17	Mercury(Hg)	$8,3\cdot 10^{-6}$	0,8134=	0,3486
18	Silver(Ag)	$7,0\cdot 10^{-6}$	0,686+	0,294
19	Palladium(Pd)	$1,3\cdot 10^{-6}$	0,1274+	0,0546
20	Platinum(Pt)	$7,0\cdot 10^{-7}$	0,0686+	0,0294
21	Gold(Au)	$4,3\cdot 10^{-7}$	0,04214-	0,01806
22	Rhenium(Re)	$7,0\cdot 10^{-8}$	0,00686+	0,00294
23	Aluminum(Al)	8,05	$788,9\cdot 10^{3}$+	$338,1\cdot 10^{3}$
24	Potassium(K)	2,5	$245\cdot 10^{3}$+	$105\cdot 10^{3}$
25	Phosphorus(P)	$9,3\cdot 10^{-2}$	$9,114\cdot 10^{3}$+	$3,906\cdot 10^{3}$
26	Fluorine(F)	$6,6\cdot{}^{-2}10$	$6,468\cdot 10^{3}$+	$2,772\cdot 10^{3}$
27	Zircon(Zr)	$1,7\cdot 10^{-2}$	$1,666\cdot 10^{3}$+	$0,714\cdot 10^{3}$
28	Lithium(Li)	$3,2\cdot 10^{-3}$	$0,3136\cdot 10^{3}$+	$0,1344\cdot 10^{3}$
29	Niobium(Nb)	$2,0\cdot 10^{-3}$	$0,196\cdot 10^{3}$+	$0,084\cdot 10^{3}$
30	Thorium(Th)	$1,3\cdot 10^{-3}$	0,1274+	$0,0546\cdot 10^{3}$
31	Boron(B)	$1,2\cdot 10^{-3}$	0,1176+	$0,0504\cdot 10^{3}$
32	Beryllium(Be)	$3,8\cdot 10^{-4}$	37,24+	15,96
33	Cesium(Cs)	$3,8\cdot 10^{-4}$	37,24+	15,96
34	Tantalum(Ta)	$2,5\cdot 10^{-4}$	24,5+	10,5
35	Uranium(U)	$2,5\cdot 10^{-4}$	24,5+	10,5
36	Germanium(Ge)	$1,4\cdot 10^{-4}$	13,72+	5,88
37	Tungsten(W)	$1,3\cdot 10^{-4}$	12,74+	4,2
38	Hafnium(Hf)	$1,0\cdot 10^{-5}$	9,8+	1,05
39	Indium(In)	$2,5\cdot 10^{-5}$	2,45+	1,05

Transferring our researches from this regularity to the plane of practical application, we have defined, anticipating full exhaustion of stocks of metals in traditional ore deposits, the following format of actions of mankind:

1) determining the volume and mass of the continental part of the Earth's crust;

2) calculation out of these figures of volume and mass of that part located from the surface to a depth of 5 km, which we have called the depth of anthropogenic-technical possibilities H_{ATB}. Up to reach this depth man can at the stage of development of science and technology in the next decade to work safely, using traditional and innovative technologies of mining;

3) assumption that the calculated, based on H_{ATB} = 5 km, the continental part of the Earth's crust can be used for mining by 30%, considering the actual limitations of natural and man-made nature;

4) calculation of the estimated quantity of chemical elements in this, considered as useful, part of the Earth's crust on the basis of clarks by A.P. Vinogradov and the minimum industrial content by L.N. Ovchinnikov;

5) calculation of the availability of the estimated number of chemical elements to mankind on the basis of their extraction, projected for 2050.

Table 4. Availability of the most important minerals demanded by mankind (as estimated by the authors)

Item	Chemical element	Assumed amount of chemical elements in the continental part of the Earth's crust at a depth of H_{ATB}=5 km, bln. tons[*]	Projected production for 2050 from the subsurface including all types of losses to the finished commercial product, million tons	Availability of the estimated amount of chemical elements in the continental part of the Earth's crust, years
1	2	3	4	5
1	Iron(Fe)	$5,75\cdot 10^{6}$	$10\cdot 10^{3}$	575000
2	Titanium(Ti)	$164,5\cdot 10^{3}$	20	$8,225\cdot 10^{6}$
3	Manganese(Mn)	$11,7\cdot 10^{3}$	40	292500
4	Barium(Ba)	$2,755\cdot 10^{3}$	-	-
5	Sulfur(S)	$1,145\cdot 10^{3}$	-	-
6	Vanadium(V)	$0,69\cdot 10^{3}$	-	-
7	Chrome(Cr)	57,6	70	823
8	Zinc(Zn)	578	40	14450
9	Nickel(Ni)	$1,996\cdot 10^{3}$	10	499600
10	Copper(Cu)	$0,639\cdot 10^{3}$	90	7100
11	Cobalt(Co)	$0,95\cdot 10^{3}$	0,5	$1,9\cdot 10^{6}$
12	Lead(Pb)	$0,05\cdot 10^{3}$	12	4167
13	Tin(Sn)	3,656	2	1828
14	Molybdenum(Mo)	13,99	0,6	23317
15	Antimony(Sb)	0,073	0,4	182,5
16	Bismuth(Bi)	0,474	-	-
17	Mercury(Hg)	0,008	-	-
18	Silver(Ag)	0,179	0,06	2983
19	Palladium(Pd)	0,0495	0,00045	110000
20	Platinum(Pt)	0,0144	0,0006	24000
21	Gold(Au)	0,0108	0,006	1800
22	Rhenium(Re)	0,00057	0,01	94
23	Aluminum(Al)	$2,35\cdot 10^{7}$	0,250	14,6
24	Potassium(K)	$1,46\cdot 10^{7}$	1	129000
25	Phosphorus(P)	$38,86\cdot 10^{3}$	0,3	37100
26	Fluorine(F)	$0,742\cdot 10^{3}$	0,02	-
27	Zircon(Zr)	$84,2\cdot 10^{3}$	-	1,82
28	Lithium(Li)	$0,182\cdot 10^{3}$	0,1	-
29	Niobium(Nb)	$0,167\cdot 10^{3}$	-	-
30	Thorium(Th)	$0,11\cdot 10^{3}$	-	-
31	Boron(B)	$0,053\cdot 10^{3}$	-	-
32	Beryllium(Be)	$0,1235\cdot 10^{3}$	-	-
33	Cesium(Cs)	8,23	-	-
34	Tantalum(Ta)	45,7	-	-
35	Uranium(U)	18,28	0,1	182800
36	Germanium(Ge)	95,5	-	-
37	Tungsten(W)	1,713	0,5	3426
38	Hafnium(Hf)	1,95	-	-
39	Indium(In)	3,656	-	-

[*] 30% of the amount according to the minimum industrial content, adopted by Academician L.N. Ovchinnikov

Results of calculation show that practically all most demanded chemical elements to mankind at definition of their quantity by a pattern of prevalence (clark) of each of them in terrestrial crust will be enough for many years ahead.

Besides, one more positive condition of sufficiency of time before full exhaustion of reserves is the fact that confirmed on statistics of geological prospecting works stocks of chemical elements on the majority of metals frequently considerably exceed the total stocks calculated according to the minimal industrial content on clarks. This fact is reflected in Table 2.

Thus, we have confirmed that:

1) reserves of minerals demanded by mankind in traditional ore deposits are running out and in 25-100 years there will come a moment when they will not exist;

2) the regularity of the accumulation of chemical elements in accordance with their prevalence in the Earth's crust (clarks) and their recalculation in accordance with the minimum industrial content adopted by Academician L.N. Ovchinnikov, shows the availability and possibility of providing mankind with them for the historical perspective;

3) the revealed pattern of dependence of total reserves of metals and their minimum industrial contents in ore deposits on clarks, described by the log-normal law (logarithmic function with inverse proportionality), can be used further for calculation of reserves in the Earth's crust depending on the minimum industrial contents;

4) all the geochemical laws stated by us in the aggregate determine the situation of civilization development in accordance with its needs in all demanded chemical elements for an indefinite historical period without economic shocks and catastrophic crisis situations;

4) the human society is obliged to perceive the developing inevitable situation of depletion of stocks in bowels as a signal to timely decision of all technological and organizational issues of satisfaction of requirements in a course of use of essence of the created solution;

5) It should be particularly noted that in recent years, Kazakh geologists have revealed and proved another practical proof of the increase in reserves of both traditional and proposed by us deposits of a new type, taking into account the micro-and nano-levels of chemical elements in traditional deposits, which had not previously been determined and not considered [11]. This work needs to be continued in order to specify the missed opportunities in the calculation of reserves (naturally, within the clarks and minimum industrial content);

6) the essence of the stated solution is an organic component of the complex of future sciences called "geo-engineering" developed and offered as a basis of technocratic civilization by the founder and the Chairman of the Davos Economic Forum Klaus Schwab.

This dependence in mathematical connection with the logarithmic dependence mentioned above will take the form of an exponential degree dependence with inverse proportionality, which shows that the greater their number exponentially. Thus, for each chemical element demanded by mankind on the basis of data on clark and on total reserves in the Earth's crust we are able to calculate its quantity depending on the quality (content) we have established. In the concrete case we are talking about minimum industrial content which will change towards decrease in connection, firstly, with improvement of technologies of exploration, extraction and processing and with decrease of prime cost; secondly, depending on demand in the market and required quantity of each element in a definite period of time.

On the basis of the calculated quantity we have defined provision with quantity of chemical elements depending on production, oriented on 2050 forecasts, convincingly showing on absolute solvability of problem of full exhaustion of stocks of traditional deposits by attraction to production of accumulations of chemical elements of new type.

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Минералды ресурстарды тәжірибелік тұрғыдан кеңейтіп жасаудағы химиялық элементтер кларктарының рөлі мен мәні

М.Ж. Битимбаев[1], К.Б. Рысбеков[1], Д.К. Ахметканов[1*], М.С. Кунаев[2], В.Г. Лозински[3], К.К. Елемесов[1]

[1]Satbayev University, Алматы, Қазақстан
[2]«MK – Metals Holding» ЖШС, Алматы, Қазақстан
[3]«Днепр политехникасы» ұлттық техникалық университеті, Украина

**Корреспонденция үшін автор: d.akhmetkanov@satbayev.university*

Аңдатпа. Адамзат әрқашан металл минералдарына мұқтаж болады. Меншікті шығынның төмендеуіне қарамастан, оларды қайталама көп рет пайдалану көлемін ұлғайтуға, сондай-ақ беріктік сапасы мен тозуға төзімділігін арттыруға, металл қорытпаларына синтетикалық материалдарды қосуға, сондай-ақ болашақта атом деңгейінде табиғи тау жыныстары мен олардың құрамдас минералдарынан қажетті химиялық элементтерді жасанды құрастыруға көшуге және Мұхит суынан металдар алуға жер қыртысының массивінен кен өндіру сұранысқа ие өнімді жеткізудің негізгі көзі болады. Осы шешілмеген постулаттарға сүйене отырып, біз қолданыстағы геохимиялық заңдылықтарға, пайдалы қазбалар ретінде пайдалануға жарамды минералды заттардың жинақталуына жан-жақты талдау жасадық. Газ бұлтының газ шаңына конденсациясы бар Күн жүйесінің планеталарының пайда болуы, бұл өз кезегінде адиабаталық сығылу нәтижесінде жердегі типтегі планеталарға және матеориттері бар астероидтық белдеуге айналды, химиялық элементтердің күнде, метеориттерде және жер қыртысында бірдей таралуына себеп болды. Біз адамзаттың жер қыртысының континенттік бөлігін игерудің максималды тереңдігі, минималды өнеркәсіптік құрамы (уақыт өте келе азаюға қарай өзгеретін), объективті шектеулерді ескере отырып, өнеркәсіптік пайдалану үшін мүмкін болатын жер қыртысының бір бөлігіндегі кларкқа сәйкес пайдалы қазбалар мөлшерін ескере отырып, анықтадық сұранысқа ие химиялық элементтердің қорлары. Есептеулер олардың алдағы жылдарға жеткіліктілігін көрсетеді, бірақ бұл табиғатта жұмыс істейтін объективті геохимиялық заңдылықтармен құрылған, бірақ қазіргі уақытта ескерілмеген жаңа типтегі кен орындарындағы қорлар болады. Пайдалы қазбалардың құрамын микро және нано-деңгейдегі Талдамалық жалпылауға ерекше назар аудару керек, ол қазіргі уақытта анықталмайды, минималды өнеркәсіптік деңгейде Кларк құрамынан әлдеқайда жоғары шектерде есепке алынбаған қорлар болып табылады. Жер қыртысында кларктарды және басқа да геохимиялық заңдылықтарды пайдалану геологиялық барлау жұмыстарын жүргізу кезінде жаңа аналитикалық мүмкіндіктер, мақалада қысқаша сипатталған және осы мақаланың дамуына неғұрлым егжей-тегжейлі және дәлелді баяндаудың мәні болып табылатын жаңа типтегі кен орындарынан пайдалы қазбаларды өндіру және өңдеу кезінде жаңа технологиялық шешімдер жасауды талап етеді.

Негізгі сөздер: *кларк, Күн жүйесі, планеталар мен метеориттер, геохимиялық заңдылықтар, минералды ресурстар, қорлардың толық сарқылуы, шикізат базасының көбеюі, жаңа типтегі кен орындары.*

Роль и значение кларков химических элементов в практическом расширенном воспроизводстве минеральных ресурсов

М.Ж. Битимбаев[1], К.Б. Рысбеков[1], Д.К. Ахметканов[1*], М.С. Кунаев[2], В.Г. Лозински[3], К.К. Елемесов[1]

[1]Satbayev University, Алматы, Казахстан
[2]ТОО «MK – Metals Holding», Алматы, Казахстан
[3]Национальный технический университет «Днепровская политехника», Украина

**Автор для корреспонденции: d.akhmetkanov@satbayev.university*

Аннотация. Человечество всегда будет нуждаться в металлических полезных ископаемых. Несмотря на снижение удельного расхода, на увеличение как объемов вторичного многократного их использования, так и повышение прочностных качеств и износостойкости, на добавление к металлическим сплавам синтетических материалов, а также в будущем на переход к искусственной сборке на атомном уровне нужных химических элементов из природных горных пород и составляющих их минералов и получение металлов из океанической воды, шельфовых россыпей и донных отложений, добыча руды из массива земной коры будет основным источником поставки востребованной продукции. Исходя из этих непреложенных постулатов, нами произведен всесторонний анализ существующих геохимических закономерностей, накопления минерального вещества, пригодного для использования в качестве полезного ископаемого. Происхождение планет Солнечной системы с конденсацией газового облака в газопылевое, которое, в свою очередь, в результате адиабатического сжатия превратилось в планеты земного типа и астероидный пояс с матеоритами, послужило причиной одинаковой распространенности химических элементов на Солнце, в метеоритах и земной коре. Нами с учетом антропогенно - технических возможностей человечества по максимальной глубине освоения континентальной части земной коры, минимального промышленного содержания (которое со временем будет меняться в сторону уменьшения), количества полезных ископаемых в соответствии с кларком в той части континентальной земной коры, которая возможна для промышленного использования с учетом объективных ограничений, определены запасы востребованных химических элементов. Расчеты показывают их достаточность на долгие годы вперед, но это будет запасы в месторождениях нового типа, создаваемых действующими в природе объективными геохимическими закономерностями, но не учитываемых в настоящее время. Особое внимание должно быть обращено на аналитическое обобщение содержаний полезных ископаемых на микро- и наноуровне, которое в настоящее время не определяются, являясь неучтенными запасами в пределах гораздо выше кларкового содержания на уровне минимально промышленного. Использование кларков и других геохимических закономерностей в земной коре потребует создания новых аналитических возможностей при проведении геологоразведочных работ, новых технологических решений при добыче и переработке полезных ископаемых из месторождений нового типа, которые кратко описаны в статье и являются предметом более детального и доказательного изложения в развитие данной статьи.

Ключевые слова: *кларк, Солнечная система, планеты и метеориты, геохимические закономерности, минеральные ресурсы, полное истощение запасов, воспроизводство сырьевой базы, месторождения нового типа*.