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ON SOURCES OF SUBSTANCE OF GOLD ORE DEPOSITS AND THEIR WATER FLOWS OF DISPERSION

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On the basis of comparison of differences of ore enclosing rock clarkes with granite clarkes it is established, that gold ore deposits and their water flows contain only those elements for which this difference is positive. High correlation of values of these differences with abnormal contents of elements in ores and water flows of dispersion shows, that source of these elements are enclosing rocks. Presence of granitization fields in structure of all investigated deposits shows, that extraction of elements from enclosing rocks occurs as a result of their granitization. It is supposed, that transfer of elements is carried out by pore solutions, and their deposition occurs as a result of nonequilibrium state between pore and gravitational waters.

Complex materials collected during hydrogeochemical researches in Near Amur region allowed to propose a number of the assumptions relative to sources of gold ore deposit substance and their water flows of dispersion in the Amur oblast.

Surprising similarity of mineral structure of each formation type of gold ore deposits in all the gold ore provinces in the world inevitably forces to assume, that there is any general, global process controlling this phenomenon.

The most general law for gold ore deposits is their close connection with granitoids. It has been established in Middle Ages (see for example [1]) and is discussed actively at regular intervals up to the present.

It is natural to assume, that it is necessary to search the above mentioned process just in the granites – gold ore deposits system.

More than 30-years researches of ore deposits of Near Amur region gave to the author the large material testifying wide development of metasomatic granitization in this region where the granitoids area occupies more than half of territory. Evidences of granitization are found practically near to all the gold ore deposits investigated by the author [2], and also established and in details investigated by other researchers [3–6]. It, and also many other facts have led the author to idea, that it is the metasomatic (anactetic) granitization is that global factor which controls sources and conditions of formation of gold ore deposits of the Amur oblast.

This problem was considered repeatedly. The role of granitization in formation of ore deposits and questions of mobilization of substance at granitization are in detail elucidated in works [7–14] and many others. A.G. Davydchenko [12. P. 134–135] even declares, that the metamorphogenous processes caused by granitization, are the basic source of metal components of core deposits of minerals. This idea, in his opinion, obtained in our country the greatest recognition (in comparison with juvenile and magmatogenous theories about sources of ore substance, B.Sh.). A.I. Belevtsev [15] writes: «Ultrametamorphism was powerful process of separation of small elements from initial rocks and their moving beyond limits of granitization areas».

The main agent of metasomatic granitization is, undoubtedly, water ([8, 15–20] etc.). In conditions of metasomatic granitization it is not simply water, but intergrain (pore) water which properties differ sharply from properties of gravitational water [15, 20–23]. Again we shall quote J.N. Belevtseva [15. P. 97]: «In rocks (metamorphic – B.Sh.) oregenous elements are in easily mobile form... and enrich intrapore molecular-film solutions that caused their mobility...». Here it is affirmed, that «moving of oregenous elements at metamorphism in many cases reaches 70...75 % from the initial contents of elements in rock». J.N. Belevtsev ([15. P. 94, the diagram]) related Cr, V, Mn, Pb, Cu, Ni, Co which are collected in rocks in scattered state on greenschist, amphibolite and granulite stages and decrease in 10...16 times in granites in process of metasomatic granitization, to easily movable ones in process of metamorphism.

The important role of the bound water has been pointed by V.I. Vernadsky [24, 25]. It is possible, that he meant exactly this water as the agent of the mechanism of regulation of processes in the crust of the Earth. For our research its ability to dissolve enormous quantities of the substances necessary to form structure of ore deposits and their water flows of dispersion is most important. So, pore waters, by the observations of P.A. Udodova and others [21], contain cupper (2,7 mg/l), zinc (up to 63 mg/l), nickel (up to 6,3 mg/l), titanium (up to 0,16 mg/l), manganese (up to 63 mg/l). Such quantities exceed in hundreds and thousand times even abnormal contents of these elements in water flows of dispersion of ore gold deposits.

Some features of water flows of dispersion of ore gold deposits (for example, regular presence of sharply increased contents of titanium, vanadium, manganese, zircon and other elements which have not high soluble and unstable minerals in ores) are inexplicable from the point of view of formation of water flows of dispersion due to chemical destruction of ores.

Thus, the assumption has ripened, that both gold ore deposits, and their water streams of dispersion, at least, on territory of High Near Amur Region, in area of tectonomagmatic activization (divine) are the product of the process of metasomatic granitization.

As an example of relation of zones of granitization processes and gold ore deposits we shall show vicinities of the Ingaglinskaya intrusion in Verkhne-Selemginsky auric area on which periphery all the gold ore deposits of this area (figure) are located. There are fineer bodies of leucagranites of K–Na slope of late Cretacious age alkalinity in the field of this large massif of plagiogranites and granodiorites. The bodies of the same complex are found in the limits of ore fields of the Kharginskoye, Unglichikanskoye and Sagurskoye deposits.

Ingaglinskiye granites (γPZ_3) are presented by two large massifs – the Ingaglinsky one (400 sq. km) and the Lucachecksky one (100 sq. km), as well as by several fine bodies. The majority of researchers considers the Ingaglinsky complex as a batolite-like body, however G.I. Neronsky [23] has put forward the assumption of its plate-like form with thickness 5...6 km, immersed on northeast. The northwest part of the massif contains many small outputs of the same granitoids.

In places granitoids, especially in endocontacts, are transformed into quartz-albite-microcline differences. All rocks of the massif are everywhere cataclasited, amphibolized, chloritizated, and epidotized. Especially frequently cataclase with blastic changes is shown in fine bodies.

Granites are developed in central and northern parts of the massif, and granodiorites and quartz diorites – near contacts and around xenolites of enclosing rocks. Structure of rocks are quite often porphyraceous. Granites consist from oligoclase, quartz, microcline, biotite, hornblende and pyroxene (up to 15 %). There are andesine, coated with chess albite and monocline pyroxene in quartz diorites. Transitions between versions of

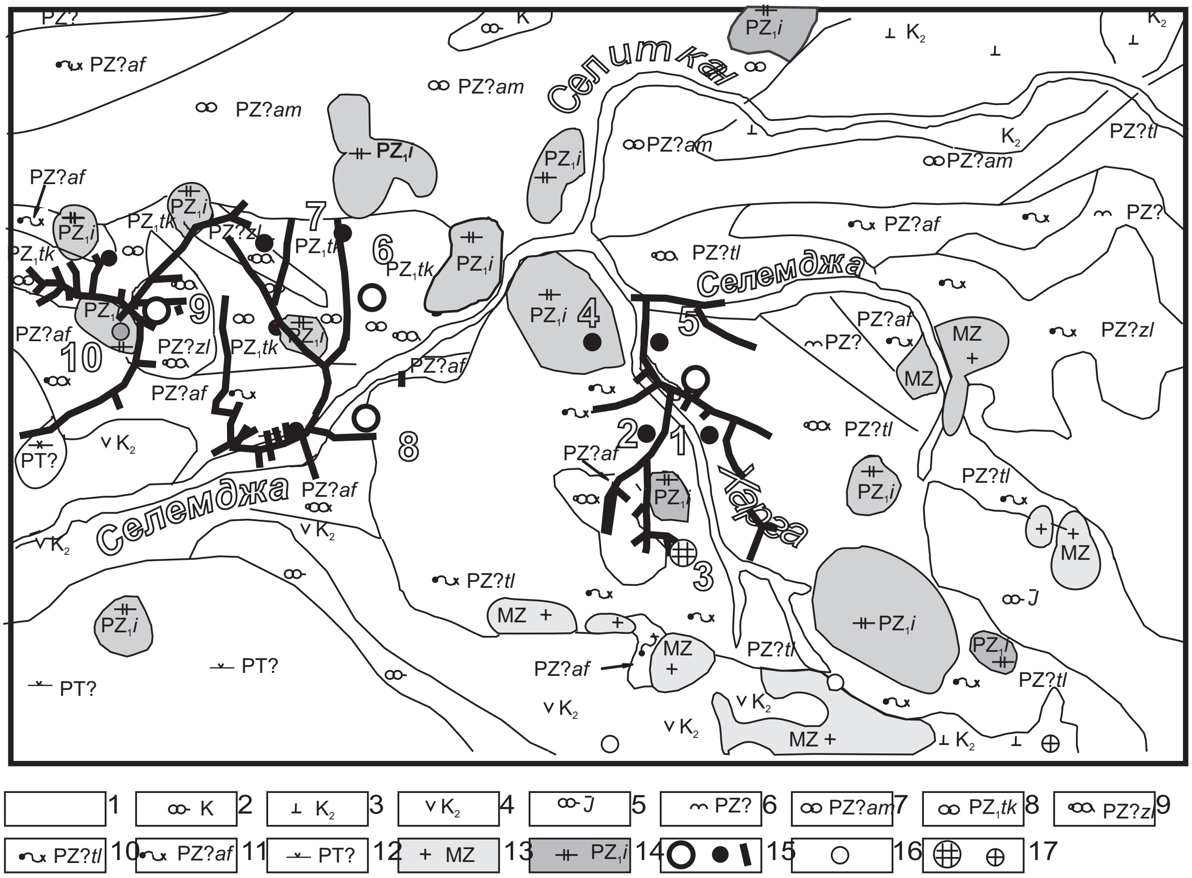

Figure. *Geological – metallogenical scheme of the Verkhne-Selemginsky area (it is made by materials of survey works). A geological basis – by geologic survey works. The V.A. Zlobin article [30] is used. 1) Modern depositions; 2) sedimentary depositions of cretaceous age; 3) effusives and tuffs of acidic composition of high cretaceous age; 4) effusives of basic composition structure of low cretaceous age; 5) sandstones and aleurolites of Jurassic age; 6) faunal characterized sand-slate thicknesses of low and middle Paleozoic; 7) the amnusskaya and ekimchanskaya suits of slightly sericitized sandstones, aleurolites of paleozoic age?; 8) the tokurskaya suit of fillitized clay slates (paleozoic?); 9) the zlatoustovskaya suit of fillitized clay slates and aleurolites, metasandstone with rare lenses of marbleized limestones, green actinolite – clinozoisite-chlorite-albite slates (metavolcanites); 10) the talyminskaya suit of metamorphosed sandstones of fillitized albite-quartz-chlorite-mica slates, containing lenses of marbleized limestones, microquatzites and bundles of amphibole slates (metavolcanites-paleozoic?); 11) the afanasyevskaya suit of mica-quartz-albite, graphite-sericites, quartz-graphite-sericites, quartz-sericites and amphibole slates (paleozoic?); 12) biotite, biotite-garnet, biotite-hornblende gneisses and crystal slates conditionally of low proterozoic age; 13) mesozoic granitoids: porphyraceous granodiorites and granite-porphyries 14) low Paleozoic granitoids (granodiorites, granodiorite-porphyries, granite-porphyries, plagiogranite-porphyries, quartz porphyries, and diorite porphyrites) the ingaglinsky complex; 15) deposits and displays of gold mineralization: a) deposits; б) ore manifestations; в) alluvial deposits; 16) manifestation of tin ore and tungstene mineralization; 17) manifestation of antimonic mineralization; figures – manifestations of gold and antimonic mineralization: Deposits: 1) Kharginskoye (Zlatoustovskoye); 2) Afanasyevskoye; 3) Leninskoye; 4) Ingagli-Yasnenskoye; 5) Unglichikan-Berezovskoye, 6) Tokurskoye, 7) Innokentyevskoye, 8) Sagurskoye, 9) Voroshilivskoye* rocks are gradual. Other massifs have the same zonation and structure.

As it is seen from the given description, ingaglinskye granites are far from classical intrusive rocks. They have all evidences of metasomatic formations – shadow structures (spotty structure – Neronsky [23]), basal front, sharply detached leucosome and melanosome in gogglies, porphyry and stripe migmatites, amphibole-hornblende restites. Changes is enclosing rocks – folded (pleated) migmatites albite-sericite leucosome and epidot-biotite-amphibolite melanosome in rocks of the afanasyevskaya and sagurskaya suits – testify to presence of granitisation – and these phenomena are advanced not on all suit mass, but on the sites gravitating towards ingaglinskiye granitoids and dome structures. In the last (as L.V. Ejrish [26] believes), all the gold deposits of the region are located.

There is also one more proof of the extremely gradual, it is possible to tell continuous process of formation of granitoids in the history of development of the Verhne-Sklemdzhinsky area. By G.I. Neronsky [23], ingaglinskiye granitoids are characterized by the following definitions of absolute age by biotites in 230...235; 179,5; 155 million years. Nevertheless definitions of absolute age of granitoids of the area on biotites make the following row: 296; 230; 190...210; 197; 179,5; 160; 155; 147; 146; 139; 139; 136; 135; 118; 102; 96. The row is continuous, and it is not possible to catch in it statistically separate groups.

Thus, there are enough bases to assert, that process of metasomatic granitization has been developed enough widely. That formation of gold ore deposits occured due to mobilization and redistribution of ore mineralization elements in enclosing rocks, completely unambiguously writes L.V. Ejrish [26]. G.I. Neronsky [23] also approaches to this: « contents of porous water in Verhne-Selemdzhinsky area is 5,78...0,11 %. This quantity is quite enough that amounts of elements being necessary for accumulation in industrial quantities were dissolved and transferred...».

As it is seen from fig. 1, all the gold ore deposits and the alluvial deposits formed from them are located in the field of distribution of granitoids, gravitating in the greater degree towards granitoids of the ingaglinsky complex and rocks containing migmatite of the Afanasyevskaya, Zlatoustovskaya and Sagurskaya suits. V.F. Zubkov [27] considers as possible to unit two last. These rocks were also the basic suppliers of substance for formation of gold ore deposits and their water flows of dispersion.

V.A. Zlobin [29] picks up on sharp depletion of young granitoids by heavy metals.

All this testifies to the big role of metasomatic granitization in formation of gold ore deposits of the Verhne-Sklemdzhinsky auric area and their water flows of dispersion.

In process of granitization, at processing various initial rocks (sedimentary, metamorphic, intrusive, ultrabasic, basic, middle) in granites, enormous masses of the substances inherent to these rocks and not inherent to granites are mobilized in a mobile state. The mobilized substances enter in intergrain waters, are accumulated in them and transferred to discharge area being in contact with air or gravitational waters. Here during discharge the substance being most nonequilibrium with gravitational waters (arsenic, antimony, zinc, copper, bismuth, nickel, cobalt, silver, gold, and bivalent sulfur) fall out in sediment as sulfides and sulphosalts (gold – in a native kind). They form, in particular, gold ore deposits. Less nonequilibrium elements-titaniun, manganese, iron, vanadium, chrome, zircon – enter in water flows of dispersion and are kept in them. The part of zinc, lead, silver, gold, antimony, arsenic being equilibrium with gravitational waters also is kept in the specific equilibrium – nonequilibrium state in water flows of dispersion, falling out in different parts of a flow as sulfides, sulfates, carbonates and native elements.

One of proofs of importance of the substances extracted from various rocks at granitization, is rather sharp distinction in mineral structure of gold ore deposits in dependence on the rocks where they are deposited. It is the extremely important, that metasomatic granitization is relatively low temperature process. By the *P-T* diagram of conditions of formation of different type granites [16. P. 12], the possibility of formation of metasomatic granites at atmospheric pressure and temperature is not denied by any way.

How to check assumptions about formation of gold ore deposits and their water flows of dispersion due to processes of granitization? If elements of gold ore deposits and their water flows of dispersion are result of granitization, than the elements making a positive difference between clarkes of rocks undergone to granitization, and granites clarkes (further *P*) should concentrate in them. To confirm this the author subtracted from clarkes of content of ultrabasic, basic and sedimentary rocks clarkes of contents in granite. Results of calculation are given in Table 1.

Only the elements, and necessary comparisons with elements of water flows of dispersion (clarkes are recalculated in g/t) are shown. From Table 1 it is seen the large difference between differences of contents of elements in various intrusive and sedimentary rocks and contents in granites. First of all amaze enormous scales of possible transfer of elements. So, the difference of gold makes in ultrabasic rocks $5\cdot10^{-2}$ g/t.

It is enough to process in granite as low as 20 million tons of ultrabasic rocks to obtain a large gold deposit.

The maximal differences of contents in rocks being granitized and contents in granites is (g/t): Ag – 6,50; As – 5,1; Cu – 80; Sb – 0,74; Zn – 60. These values of differences of elements among themselves and with difference of gold correspond approximately to their relations in gold ore bodies.

For comparison of the specified values for each deposit the tables are made. In the first one logarithms of differences (*P*) are compared with average arithmetic of logarithms of contents of elements in a water flow of dispersion ($C_{в}$), and in the second one – with the normalized logarithm of the maximal contents ($C_{в\max}$):

$$C_{в\max}=C_{в}+3S,$$

Where: $C_{в\max}$ is the normalized maximal contents of elements in a water flow of dispersion; $C_{в}$ is average arithmetic of logarithms of contents of elements in water flow of dispersion; S is dispersion of logarithms of contents.

Table 1. *Positive differences (P) of average contents in the various effusive and sedimentary rocks with average contents in granites (clarkes by A.P. Vinogradov, [30])*

Variety of rocks							
Ultrabasic		Basic		Middle		Sedimentary	
Elem.	Value of difference	Elem.	Value of difference	Elem.	Value of difference	Elem.	Value of difference
		Ag	0,05	Ag	0,02	Ag	6,5
Au	0,05	As	5				
				As	0,9	As	5,1
Co	195	Co	40	Co	5	Co	15
Cr	1750	Cr	1750	Cr	250		
		Cu	80	Cu	1,5	Cu	37
Mn	900	Mn	1400	Mn	600	Mn	70
		Mo	4			Mo	1
Ni	1099	Ni	152	Ni	47	Ni	87
						Pb	0
		Sb	740			Sb	1,74
						Sn	7
		Sr	1,4	Sr	500	Sr	150
		Ti	6,7	Ti	5700	Ti	2200
		V	160	V	6	V	9
						W	0,05
		Zn	70	Zn	660	Zn	20
				Zr	600		

Note: clarkes are recalculated in g/t

$C_{в}$, as shown above, reflects contents of a local hydrogeochemical background in deposit area, and $C_{в\max}$ – abnormal contents in water flow of dispersion.

Not differences and contents in water flows of dispersion, but their logarithms are correlated according to established lognormal distribution of heavy metals contents in rocks and natural waters [2]. System of comparison of clarke differences with the maximal normalized contents in waters will be shown on the example of the deposit Kirovskoye.

From comparison of the tables it is visible, that correlation of P with values of average contents is much less, than its correlation with maximal, i. e. superfluous contents, as follows from the assumption stated above.

Elements of water flow are well correlated with rock (ultrabasic, basic, intrusive and sedimentary) elements, being superfluous in relation to granites. All elements (Au, Ag, As, Co, Cr, Cu, Mn, Mo, Ni, V, Zn, Ti, Sb, Sn, Cr, Zr) coincide practically. From them Au, Ag, As, Co, Cu, Mo, Ni, Sb are found in ores as own minerals – sulfides and sulphosalts (Au – in a native kind). Water flow in the huge majority of cases contains those elements which are superfluous in enclosing rocks in relation to granites. Relation of elements coinciding with superfluous ones in relation to granites in water flow and incoincident is 14:2, i. e. 87,5 %.

As to the lithofilic elements which are not forming own minerals their close correlation link with differences (P) is proof by the fact that they are residual in waters of flow of dispersion, i.e. not dropped out during interaction of porous solutions with gravitational ones. Even in such high concentration (actual maximal contents, mkg /l are: Mn – 1141; Ti – 327,6; V – 20,7; Cr – 2,9; Zr – 1,3) they are in an equilibrium state with gravitational waters. For comparison we shall give the average contents in waters for the hypergenesis zone [22. P. 21-22]: (Mn – 49,4; Ti – 10,7; V – 1,55; Cr – 8,6; Zr – 193,2).

Thus, correlation of differences P of contents in enclosing rocks and granites (further- differences) with the maximal normalized contents of elements in waters has shown, that correlation link of elements among themselves on the deposit Kirovskoye are in the full consent

Table 2. *Correlation between logarithms of clarke differences of element contents of various rocks with granites (P) and average logarithms of contents of water flow of dispersion ($C_{в}$), the deposit Kirovskoye*

Water flow of dispersion		Ultrabasic rocks		Water flow of dispersion		Basic rocks		Water flow of dispersion		Middle rocks		Water flow of dispersion		Sedimentary rocks	
Elem.	lg C_{Max}	Elem.	lg$P$	Elem.	lg C_{Max}	Elem.	lg$P$	Elem.	lg C_{Max}	Elem.	lg$P$	Elem.	lg C_{Max}	Elem.	lg$P$
Coinciding elements															
Au	-1,20	Au	-3,30	Ag	-1,06	Ag	-1,30	Co	-1,36	Bi	0,07	As	0,43	As	0,70
Co	-1,36	Co	2,29	As	0,43	As	-0,30	Cr	-0,11	Co	0,19	Co	-1,36	Co	1,17
Cr	-0,11	Cr	3,24	Co	-1,36	Co	1,60	Cu	0,18	Cr	0,26	Cu	0,18	Cu	1,56
Mn	1,25	Mn	2,95	Cr	-0,11	Cr	3,24	Mn	1,25	Mn	0,28	Mn	1,25	Mn	1,84
Mo	-1,20	Mo	0,00	Cu	0,18	Cu	1,90	V	-0,32	V	0,57	Ni	-0,90	Ni	1,94
Ni	-0,90	Ni	3,29	Mn	1,25	Mn	3,14	Zn	-0,04	Zn	0,29	Sb	-0,30	Sb	0,24
				Mo	-1,20	Mo	-0,39	Zr	0,40	Zr	0,11	Sn	-1,08	Sn	0,84
				Ni	-0,90	Ni	2,18					Ti	1,14	Ti	3,75
				Ti	1,14	V	2,20					V	-0,32	V	1,95
				V	-0,32	Zn	1,84								
				Zn	-0,04	Ti	3,82								
Coefficients of correlation															
0,470				0,441				0,181				0,486			

with the proposed hypothesis about formation of gold ore deposits and their water flows of dispersion due to granitization.

Material on the other objects has been processed in the same way. Results are shown in tab. 3.

Table 3. *Coefficients of correlation between logarithms of differences of clarkes of contents of various rocks with clarkes of granites (P) and logarithms of the maximal normalized contents of elements in water flows of dispersion (lg C_{max})*

FT	Deposits	Rocks				% Coincidence of elements
		Ultrabasic	Basic	Middle	Sedimentary	
	Kirovskoye	0,589	0,730	0,411	0,566	87,5
B	Ingaglinskoye	0,630	0,574	0,913	0,406	93,3
	Site Severny	0,791	0,588	-0,228	0,342	80,0
	Sagurskoye	0,589	0,730	0,780	0,566	86,7
G	Kharginskoye	0,531	0,617	0,253	-0,304	100,0
	Unglichikanskoye	0,897	0,419	0,473	0,542	100,0
Ч	Tarnakhskoye	0,627	0,588	0,688	0,533	80,0
	Site Kheckla	0,616	0,719	0,674	0,701	80,0
	Gold mountain	0,782	0,797	0,929	0,736	73,0
	Site Goratsiewsky	0,358	0,470	0,958	0,663	73,0
P	Burindinskoye	0,498	0,763	0,488	0,679	100

FT – formation type: B – beresite, G – apogreenschisht, Bl – apoblacks, D – diafluorite, P – quartz-propilite, JA – jasperoid

Data of Table 3 confirm completely the assumption about close binding of element contents in water flows of dispersion of gold ore deposits with elements, being superfluous in enclosing rocks in comparison with granites, i. e. that elements of a water flow of dispersion are extracted from enclosing rocks.

Comparison of contents of the elements forming positive differences *P* of contents between ultra basic, basic, middle, sedimentary rocks, on the one hand, and granites on the other hand, as well as consideration in this connection of mineral composition of ores and conditions of bedding of deposits and water flows of dispersion has shown the following.

The considered deposits of High Near Amur region (author explored practically all gold ore deposits and gold manifestation of the region) are deposited in geological formations in which the metasomatic granitization is clearly shown. This process, obviously, is basic «generator» of gold ore deposits in conditions of the given area of tectonic-magmatic activization.

Values of a difference (*P*) excellently (as a rule, at a level of coefficient of correlation 0,6 and higher) correlate with ore components of deposits of all formations and their water flows of dispersion. It is especially interesting, that such elements as manganese, vanadium, chrome, zirconium and titanium have not increased concentration in ores, but in water flows of dispersion of deposits have the same high contrast, as and ore elements.

It allows to plan the following scheme of formation of gold ore deposits and their water flows of dispersion.

In and after process of mobilization the elements having increased contents in rocks, undergone metasomatic granitization, and the lowered contents in granites, formed from them (elements of positive difference *P*), are in pore solutions in quasieqilibrium state. The part of them stays in pore solution, and the part is deposited as minerals being equilibrium with them and easily passing in these solutions. As soon as pore solutions obtain output in gravitational waters (fissures on which gravitational circulation is occurring), falling out of minerals being nonequilibrium with gravitational waters – quartz, sulfides and sulphosalts of lead, silver, zinc, copper, antimonies, arsenic, sometimes bismuth, tin, cadmium etc. – begins on walls of these fissures. In pore waters due to falling out of these minerals one can see decrease of contents. The gradient of concentration promoting inflow of new portions of substance and dissolution early equilibrium minerals near pore surfaces. Process continues up to achievement of quasiequilibrium state in the threefold system: ores – porous solutions – gravitational waters. However the part of ore elements in some compounds are widely known in search hydrogeochemistry, remains near to the deposit being equilibrium with subsoil waters in enough large contents. These compounds give water flows of dispersion.

Manganese, vanadium, chrome, titanium behave by other way. Their compounds, as a rule, are equilibrium with earth (gravitational) waters in significant contents. Passing in subsoil waters from pore solutions, they form water flows of dispersion and further in diluted form migrate in lowered areas, being in part sedimented at adverse conditions. In particular, all waters of the first water-bearing horizon in Amur-Zeyskaya depression have high content of ferrum (up to 10 g/l) and always contain manganese (hundreds mkg/l) and titanium (tens mkg/l) [31].

Meaning globality of process of Earth granitization, it is necessary to assume, that formation of the majority of gold ore deposits of the globe occurs on the same laws which are established for deposits of the Amur oblast.

Presence of granitoid bodies as it was already noted, always was a search attribute for gold deposits. Our constructions show, that granitoid bodies being the most favorable for searches of gold should have attributes of metasomati granitization. Mobilization of elements in pore solutions and their penetration into enclosing rocks is spreaded as minimum on tens kilometers from the centre of granitization. Silicon, iron and bivalent sulfur goes especially far. Their loss can result to formation of ore deposits.

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