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# MANTLE MAGMA-THERMOFLUIDODYNAMIC AND INTRACRUSTAL GRANITOID-HYDROTHERMAL-METASOMATIC AURIFEROUS SYSTEMS

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*Contents of typical models of formation of abyssal and intra-core ore-forming systems are discussed. As it has been already marked, the interaction between core and mantle ore-forming systems occurred at formation of large and unique golden-ore deposits. The interaction of the abyssal mantle substance with formations of the Earth's crust has been carried out by penetration of high-temperature gas-fluids, magmatic melts and solid bodies, forming diapiric magma-thermofluidodynamic systems on borders of the inner core with the bottom mantle and within the limits of the upper mantle – the Earth's crust.*

## General provisions: plumtectonics, riftogenesis, diapirism

Golden-ore, complex gold-platinum and gold-platinoid-rare-metal ore associations of industrial purpose are shown in various geological conditions [1, 2]. Such unconventional complex ores of gold, platinum and rare metals are revealed in golden-ore, skarn-iron-ore copper-molybdenum-porphyritic, rare-metal-rare-soil-carbonatite, rare-metal-albite-greisen, gold-sulphite-black-shale, pyrite-polymetallic, ocean iron-manganous and sulphidic formations. Genetically they are attributed to sedimental-hydrothermal, metamorphogenic-metasomatic, magmatogenic-hydrothermal and polygenic formations.

Complex deposits and ore fields of the unconventional type were formed in riftogenic zones of folded belts, arch-blocky and terrenous clumpy structures, in zones of tectonic-magmatic activization. Either the intracrustal granitoid-ore-metasomatic, or the mantle magma-fluidodynamic, or the combined polygenic-polychromic ore-forming systems participated in their formation. The largest ore objects appeared on the sites of active display of plumtectonics, riftogenesis, paleodiaperism, and metasomatism. Formation of such deposits was provided by processes of abyssal paleodiaperism and connected with them hydrothermal- metasomatic phenomena in conditions of sedimentation of in the imposed compensatory synclines, in zones of dispositions, metamorphism, magmatism, and particularly abyssal metasomatism. All these phenomena of active penetration of energy and substance occurred on the background of continuously occurring mantle-core paleodiapires, appearing under the influence of abyssal high-temperature fluid streams in splits of the Earth's crust and the mantle. Such ore fields and deposits are fixed by remote, surface abyssal geophysical, including seismotomographic, geochemical methods in the form of anomalies along the borders of lower-core, upper-mantle non-uniformities of blocks of deconsolidated rocks. Aureoles of redistribution, mobilization, exchange and accumulation of metals under the influence of thermofluid systems of mantle and core origins are revealed. Complex deposits are located on borders of such fields and surrounded by negative and lowered values of their intensity and located above gravity steps of abyssal seismic, paleomagnetic zones reflecting traces of influence of former fluidostreams.

As electrophysical researches of rocks have shown the tectonic processes, occurring in various layers terrestrial, lead to occurrence of high-stressed electric and electromagnetic fields [3]. Tectonomagmatic processes generate the mechanic-electrical phenomena in rocks, and the discharge of this energy initiates and supports energetically secondary tectonic-magmatic processes in different layers of the Earth. In the Earth's crust on depths of 15...5 m rocks possess the lowest conductivity. It leads to occurrence of electric fields of the highest intensity. Localization of rich ores here is possible to explain by these reasons. The developed theory of vortical currents in a liquid core allows speaking about a plasma condition in a core, and in an external core a strong ionization of atoms takes place [3]. Besides, periodically repeating volumetric deformations and their elastic consequences, if to accept their soliton nature, could serve as an energy basis of abyssal tectonics, riftognesis, and paleodiaperism [4]. Pulse degasification of the core and the mantle of the Earth, in conditions of ultrahigh pressures and temperatures, provided occurrence of plumes as soliton formations or self-organizing systems according to I.R. Prigozhin. Blocks of negative and lowered gravitational and magnetic zones fixed by the abyssal geophysical (seismic or gravitational) probing, possibly, confirm structural traps for abyssal metal-bearing fluids as products of intramantle magma-fluidodynamic systems. Periodically appearing wave-power fields, energetically conditioned by thermal influence of these systems in the Earth's crust and the upper mantle, transformed then into volumetric mineralogic-geochemical fields due to the phenomena of redistribution of a substance and its «contraction» into favorable structures. On the way of advancement of fluids to the top layers of the mantle and the Earth's crust they interacted with lateral rocks, exchanged components and borrowed metals, and then deposited them in structures ore-localization on depths of 10...1 km.

The size of the appearing ore objects was provided with the sizes of initial structures-traps, and also with the soliton-pulse mode of abyssal degasification of the core and the mantle owing to the occurring pulse processes of the general development of the Earth. Exactly from positions of the pulse hypotheses of the Earth development it is possible to explain interpassing of the substance and the energy at tectonic processes, as well as cyclicity of geological events and periodicity of ore-forming processes [5, 6].

#### Mantle magma-thermogluidodynamic metal-bearing systems

Global processes of the consolidated substance transformation take place in abyssal layers of the Earth owing to intermantle diaperism and high-temperature metasomatism. Abyssal high-heated fluids penetrated from zones of the external core, i.e. the bottom mantle, provided aamphibolization-phlogopitization of ultrabasic, basic rocks of the upper mantle with formation of separate layers of the transformed-deconsolidated rocks. These rocks, transformed by the abyssal metasomatism, are formed at a level of buildup of the «secondary zone of amphibolites» within the limits of the upper mantle [7–11].

The model of diaperism, mantle and intracrustal metasomatism is accounted for an explanation of the nature of the endogenic precious-metal ore-formation. According to representations of many geologists, diapirs appear from the rise of a light, highly heated substance from the boundary area of the external core and the bottom mantle of the Earth. Part of them, while rising to the upper mantle, forms astenospheric lenses which serve as potential sources of magma. Heating and deconsolidation of the mantle in marginal parts of rising diapirs led to increase in volume of a substance and to formation of arched uplifts in folded areas. Marginal part of the forming arch structure represented rather shallow near-fracture-compensatory deflection. Such imposed synclines, arisen in boards and on a pinching out of ophiolitic volcanogenic, terrenous folded belts, is necessary to consider as compensatory structures appeared in the Earth's crust of diapirs [12, 13]. In such compensatory graben-synclines the ore-bearing black-shale formations were subsequently formed, Fig. 1.

Alongside with the uplift of the forming diapir there is a partial fusion and migration to the crust by tectonic zones of arisen mantle magmas by means of fractional fusion [14.] Highly-heated volatile components at the same time separated from diapir and rising upwards heated rocks of the Earth's crust and by means of magmatic replacement involved them in magma-formation. Avearage-silicic associations of magmatites appeared. They are considered by products of mixture mantle basalt magmas with the Earth's crustal material or core melts. Typical derivatives of such processes are considered to be the rocks of the gabbro-plagiogranitic formation widely presented in ophiolitic, folded belts and in black-shale strata of the imposed compensatory synclines. Volcanic-plutonic metal-bearing associations were formed in the upper horizons of the Earth's crust. Melts of tholeiitic basalts, which were produced by the risen diapir, could appear on depths of 130...60 km. In the Earth's crust they created intermediate focuss on different depths 20...5 km [15]. Processes of differentiation of magmas and their saturation by abyssal fluids took place in intermediate chambers, Fig. 2.

Uplift of diapir accompanied by heating of a substance in a «mantle wedge» between the seismofocal zone on contact of diapir and the Earth's crust have led to reduction of the lithosphere capacity and rise of the astenosphere. Riftogenic fractures, which were destroying arched uplifts, appeared as a result of intensive stretching efforts in the zone of terrein, volcanogenic ophiolitic belts. In this period the magmatism has been developing mainly in the intrusive form.

The subsidence of the crust and formation of marginal sea basins, where deposition of terrigenous formations enriched by organics has been carried out, appeared simultaneously with occurrence of fractures of the riftogenic type, stretching and outpouring of tholeiitic magmas. Intrasynclinal uplifts have segregated in the most raised part of the mantle diapir. Here the non-differentiated effusive and intrusive subsulicic-ultrabasite magmatites have formed the ophiolitic associations. They were replaced by limestone-alkaline series with small volumes of average and silicic rocks forming small intrusions and dykes.

#### Conditions of formation of gold-bearing thermofluid systems

Intramantle processes of the abyssal substance transformation (amphibolization of peridotites, recrystallization of garnets peridotites) were accompanied by redistribution and subtraction of precious metals up to 50 % from their total quantity in initial rocks of the mantle. It provided occurrence of metal-bearing magma-thermofluidodynamic abyssal systems in the mantle [1, 2, 17].

Geochemical researches have shown that parities of contents of the majority of ore elements in formations of the Earth's mantle are close to chondritic. In the initial stone and iron meteorites the content of precious metals is considerably higher than in all types of rocks of the Earth's crust and the upper mantle. For example, contents of gold are ranging from 0,01 up to 4,51 g/t [16, 17], platinum and platinoids from 0,06 up to 7,5 g/t [18, 19]. As the composition of meteorites is compared to the composition of central zones of the Earth, many researchers believe about essential accumulation of gold and platinoids in the core of the Earth, for example, gold up to 4 and more g/t. Besides, high contents of heavy metals in the bottom parts of the mantle are probably connected with the phenomena of their accumulation in residual strongly fluidized melts owing to fractionation of metals among firm, liquid and fluid phases of crystallizing magmas and their addition by abyssal fluids in the intermediate focuss [20]. Geochemical researches have shown that in the initial stage of crystallization of thoeiilitic magmas the coefficients of gold distribution among these phases have made $K_P^{Au}$=1,3:1:3 and 2,5:1,:21 in the final stage. For granitoid magmas these geochemical parameters have made 2:1:5 in the initial stage of crystallization and 5,5:1:(53...114) in the final stage. Transmagmatic solutions also could transport gold since at crystallization of thoeiilitic melts in the intermediate chambers

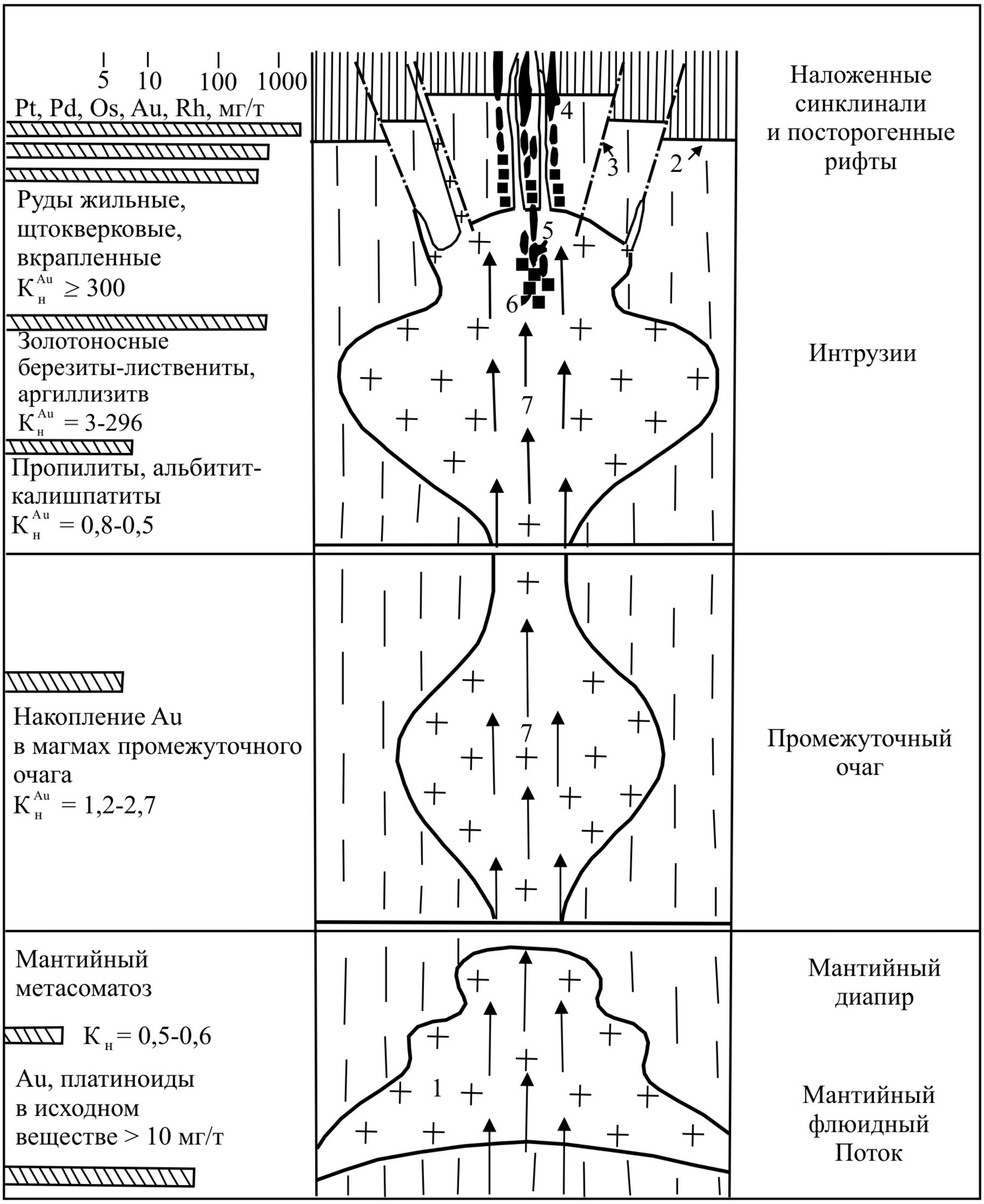


***Fig. 1.*** *The mantle-crust model of formation of gold-platinoid-rare-metal deposits in black-shale strata of orogenic-riftogenic structures of Proterozoic-Phanerozoic: 1) hyperbasite-basite-plagiogranitic intrusions; 2) compensatory synclines and postorogenic rifts; 3) marginal abyssal fractures; 4-6) ores: 4) veined, 5) stockworked, 6) impregnated; 7) fluid mantle stream; СВ – North-East; ЮЗ – South-West; км – km.*

*Explanation to Fig. 1:*

*Руды жильные, штокверковые, вкрапленные – Veined, stockwork, and impregnated ores*
*Золотоносные березиты-лиственинты, аргиллизиты – Gold-bearing beresites-listvenites, argillizites*
*Пропилиты, альбитит-калишпатиты – Propylites, albitite-kalifeldspars*
*Накопление Au в магмах промежуточного очага – accumulation of Au in magmas of the intermediate focus*
*Мантийный метасоматоз – Mantle metasomatosis*
*Au, платиноиды в исходном веществе (мг/т) – Au, platinoids in the initial substance (mg/t)*
*Наложенные синклинали и посторогенные рифты – Imposed synclines and postorogenic rifts*
*Интрузии – Intrusions; Промежуточный очаг – Intermediate focus;*
*Мантийный диапир – Mantle diapir; Мантийный флюидный поток – Mantle fluid stream*

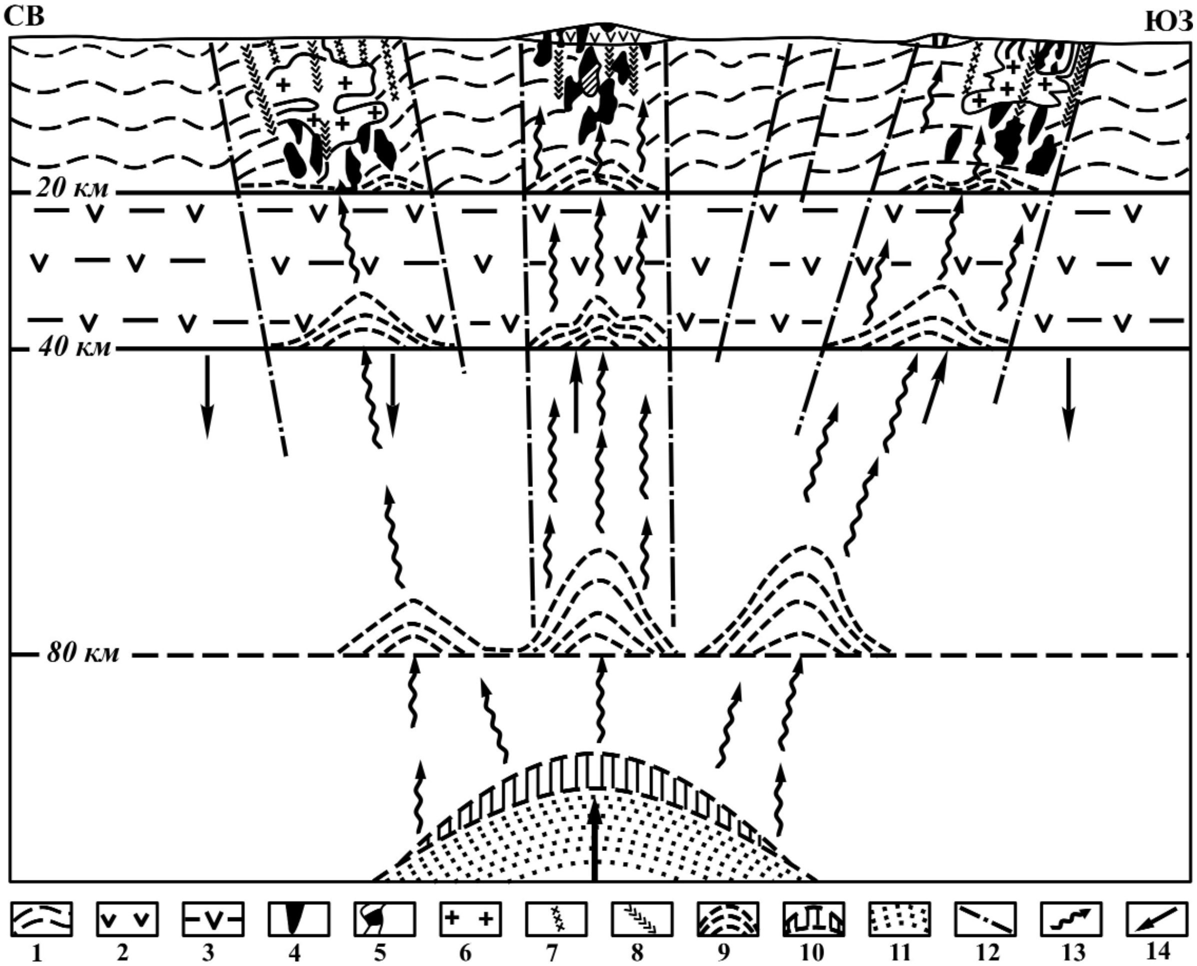


***Fig. 2.*** *The model of formation of complex gold-platinum-platinoid ores in black-shale horizons of the Charskiy ophiolitic belt, North-East of Kazakhstan: 1) sedimental crust; 2) outflown andesite-basalts; 3) complex of highly-metamorphozed rocks; 4) hyperbasite; 5) gabbroids; 6) granitoids; 7) dykes of diorite-lamprophyres, plagiogranite-porphyries; 8) dykes of diabases, polerites, porphyrites; 9) intracore diapirs of the formation zone of average, sour and basic melts; 10) abyssal melts of diapirs; 11) zones of partial melting of diapir formations; 12) abyssal fractures of I-III orders; 13) abyssal fluidostreams; 14) direction of movement of the magma-generating area of diapir*

the 2...2,5-fold accumulation of this element in products of their crystallization has been revealed.

#### Abyssal magmatism and metasomatism

The main concentrators of sulfur and majority of heavy metals in all types of mantle magmatic and metasomatic rocks were sulfides.

Amphiboles, micas, and carbonates are the main capacitors of volatile components – $H_2O$, CO, $CO_2$, P, Cl, F, CNS, that play an important role in fluid mass-transfer. At high concentration these elements could be concentrated in sulphidic phases, and at small contents of sulfur in initial melts the metals were distributed in silicate and in oxide minerals. Saturation of magmatic melts by sulphur was carried out owing to the phenomena of magma sulphurization [21]. Taking into account the contents of ore and volatile components in various mantle sources, N.S. Gorbachev [22] believes that secondary enriched metasomaticaly transformed peridotites or rocks of the non-depleted mantle are most perspective regarding ore-generating abilities.

In conditions of the transmagmatic mechanism of the differentiation of basaltoid magmas an increase of stream of fluids can be expected (Fig. 2). Features of metasomatically changed xenoliths of mantle rocks, obtained from kimberlites and alkaline basalts, specify presence and migration in the upper mantle of water fluids enriched by $CO_2$, CO, F, S, CNS, P, Fe, Ti, Au, Ag, Pt, Pd, Os, Ir, Ru and other heavy elements. These fluids have caused metasomatic transformations of primary rocks of the mantle with occurrence fluid-bearing minerals-amphiboles, micas, carbonates, oxides. Fluid mass-transfer and connected with it mantle metasomatosis have led to formation of metasomaticaly enriched volatile and ore elements of magmatites of the upper mantle similar in structure with primary high-temperature «non-exhausted» peridotites [22]. It is not excluded that metasomatically changed peridotites are in fact fragments of an extensive area of the upper mantle changed by ascending streams of abyssal mantle fluids.

In the upper mantle and the Earth's crust it is possible to allocate abyssal areas (> 60 km) where processes extractions of non-coherent elements by ascending streams of abyssal fluids prevail, and the area of unloading of fluids (15...5 km) where enrichment of melts and rock-forming minerals magmatites by non-coherent elements prevails. With fluid mass-transfer it is necessary to connect the formation of abnormally high concentration of gold and platinum metals in magmatic copper-nickel-sulphidic and in post-magmatic ore deposits.

Widely occurring mantle metasomatosis has, probably, provided redistribution of precious metals in rocks of not only the external, but also in the internal geospheres of the Earth. For example, geochemical researches of recrystallized at mantle metasomatosis garnets from abyssal peridotitic inclusions in kimberlites of Siberian platform double reduction of gold contents had been established in comparison with initial rocks: $K_H^{Au}$=0,5...0,6. By our early geochemical works it has been shown that among xenoliths of abyssal (garnet peridotites) in kimberlites, lamporites, and alkaline basalts has stood apart two types: unchanged xenoliths and their changed differences. In changed peridotites and recrystallized garnets a reduced content of gold up to 2...4 mg/t is fixed, and in unchanged differences of 10 mg/t of Au on average. Besides, hyperbasite, alnoites, kimberlites, lamporites, formed on significant depths of the upper mantle at active participation of mantle alkaline metasomatosis, are usually depletion by gold up to 0,5...3 mg/t instead of usual values 8...10 mg/t in initial magmatites. The non-uniform distribution of gold is established in various magmatites and metasomatites of abyssal origin, revealed in the Earth's crust: from 0,5 up to 47 mg/t. Thus, the main role in the fixing of chalcophile and precious metals in basite and hyperbasite of the upper mantle belongs to sulphur. At high values of pressure and temperature the sulfur has collected in these magmatites (and especially in the intermediate focus-chambers at addition in them of transmagmatic fluids) and owing to its properties could grasp and bury metals in forming rocks. Therefore rocks of basite-hyperbasite formations, if they are enriched by sulphidic sulphur, bear increased concentrations of Au and EPG up to $n\cdot10^{-6}...n\cdot10^{-5}$ mas. % instead of $n\cdot10^{-7}...n\cdot10^{-8}$ mas. % in ordinary tests from similar rocks not enriched sulphur.

The revealed increased concentrations of platinum metals up to 1...9 g/t and more Pt, Pd, Os, Ir, Rh in golden-ore zones, ore bodies and near-ore metasomatites of a number of the known large and superlarge deposits of Russia and abroad can serve as additional proofs of participation of the mantle substance at formation of large complex gold-platinoid ore objects [1, 23, 24]. Processes of abyssal granitization of the lower-crustal blocks of rocks (magmatic replacement under D.S. Korzhinskiy) in areas of their active decompaction under the influence of abyssal thermofluidostreams can serve also as additional proofs of the initial stage of «abyssal magma-thermofluidodynamic systems» as products of plumtectonics activity.

Periodically repeating deformations and their elastic consequences could serve as power basis of abyssal tectonics and metasomatism (under the terminology of E.D. Glukhmanchuk [4]) if to accept their soliton nature, and powerful electric charges arisen in the external core and the mantle, the Earth's crust, in connection with formation of electric and electromagnetic fields [3].

Pulse degasification of the core and the mantle in conditions of ultrahigh pressures and temperatures has provided occurrence of plumes as soliton formations or self-organizing systems under I.R. Prigozhin. Fixed by abyssal physical probing blocks of negative magnetic and gravimetric anomalous zones, possibly, confirm periodically arisen structural traps in the mantle and bottoms of the Earth's crust for metal-bearing abyssal heated fluids. It also formed the basis for formation of mantle magma-thermofluidodynamic ore-forming systems. The size of ore objects was provided with the sizes of initial structure-traps as well as with the soliton-pulse mode of repeated abyssal degasification.

#### Intracrustal granitoid-hydrothermal-metasomatic ore-forming systems

Such ore-forming intracrustal systems were formed due to development of fluid-enriched granitoid intrusions and accompanying hydrothermal-metasomatic processes. Magma-ore-metasomatic systems of such type originated and developed in the Earth's crust on depths of 15...1 km. The largest magma-hydrothermal-metasomatic ore-forming columns originated owing to their interaction with abyssal thermofluid streams at disintegration of the mantle magma-thermofluidodynamic system above mantle-crustal diapirs. Interaction of abyssal heated fluids with crustal fracture-porous cold waters has led to disintegration of mantle thermofluid systems. In the Earth's crust the magmatic processes were accompanied by the metasomatic phenomena of the areal type (contact and alkaline autometasomatosis): formation of magnesia-limy skarns, post-skarn metasomatites-greisens, albite-kalispar-biotite-serecitic, beresite-listvenitic, gumbeitic, eisitic, argillizitic, propylitic metasomatites with formation of large ore-metasomatic columns with the length of 1...3,8 km vertically.

Early alkaline metasomatites are located in the bottom parts of such ore-metasomatic columns (amphibolic, albite-kalispar-biotitic or propylitic); greisens, beresite-listvenites, gumbaites – in middle parts; eistites, argillizites, quartzites with various-mineral gold, gold-palladium-telluridic-antimonic ores in the upper parts.

Golden-ore and gold-platinoid ore fields and deposits are located in terreins, volcanogenic, ophiolitic belts, marginal parts of arched uplifts and median massifs with two-story volcanogenic-terrigenic or carbonate-shale cuts of the upper part of the Earth's crust with moderate capacity of 35...48 km. Regional laws of formation and location of such ore fields and deposits in folded belts were defined by riftogenic blocks of sedimental-volcanogenic, volcanogenic, ophiolitic complexes of rocks complicated by limiting these structural regional blocks abyssal longitudinal fractures of the I order, and by cross-section fractures of the II order, areas of their crossings with fracture zones of the II and the III order. All of them represent a difficultly-blocky construction of the bases of upper-crustal ore-bearing structures. Abyssal fractures are fixed by series of ruptures-chips, jointing zones, granitoids of the increased basicity, sometimes bodies of basite-hyperbasite, dykes of dolerite-diabasic, dioritic-lamprophyric, porphyritic compositions, areal and local metasomatites. They are developed in boards of paleotrogs, terrigenous-volcanogenic, ophiolitic, terrein belts, on pinching out of abyssal fractures among Proterozoic-Paleozoic blocks of rocks. A separate group of ore objects is composed of ore-bearing ancient green-stone belts of Canada, Australia and other continents. They are described in detail in domestic and foreign geological literature.

Ore fields are characterized by the complex-block internal structure and located in joints of the most complicated longitudinal and cross-section fold-explosive structures of the regional type in zones of active display of paleodiapirism. The largest зgolden-ore and complex gold-platinoid ore fields and deposits are localized in blocks with the repeated display of abyssal and intracrustal magmatism and metasomatism. Location of such ore fields and deposits in riftogenic blocks of the Earth's crust has been controlled by fractures, zones of fracture, crushing, mylonitization and metasomatic replacement on areas of development of the black-shale strata broken by intrusions of basite-hyperbasite-plagiogranitic, diorite-sienite-porphyritic, granite intrusion or dykes, rods of dolerite-diabasic, diorite-lamprophyric, plagiogranitic, granite-sienite-porphyritic rows [1, 2, 17, 23]. Hydrothermal-metasomatic processes, proceeded in the upper parts of the Earth's crust at disintegration of the abyssal magma-fluid system above mantle diapirs, provided decompaction of initial rocks owing to the phenomena of hydration-metasomatosis with increase in volumes of changed rocks by 12...22 %. Superfluous volumetric growth of separate large blocks of rocks of the Earth's crust has led to diaperism and rift-formation. All this promoted the beginning of new fractures, fractures of the II order, fracture zones and horst-graben structures of the compensatory type.

Marginal areas of the developed diapiric domes represented near-fracture compensatory deflections where the ore-bearing black-shale formations or volcanogenic-sedimentary blocks were formed. Intrageosynclinal uplifts and riftogenic compensatory hollows, deflections occurred in sides of blocks with the greatest rise of mantle diapir. A number of them occurred on pinching out of riftogens or in boards of green-stone, ophiolitic, volcanogenic belts on the areas of riftogenesis and is connected with buildup of basite, hyperbasite-basite-plagiogranitic intrusive series in fractures of abyssal deposition. For example, ore fields Saraly in Kuznetsk Alatau, Zun-Ospy in East Sayan, Western Kalba, Tyan-Shang (Saralinskoe, Muruntauskoe, Bakyrchikskoe, Akzhalskoe, Boko-Vasilyevskoe), in Priamurye (Bamskoe, Dukatskoe), Kumtora in Kirghizia, Muruntau. Quite often in such structural-formational, structural-facies zones the overlapping of allopelagic magma-ore-metasomatic formations with occurrence of ore-metasomatic zoning of regional and local types is observed [26, 27].

**Regional and local endogenic zoning of ore fields and deposits**

Regional metallogenic zoning shows itself as change of various formational types of ores and accompanying metasomatites relative to intrusive bodies on prodeleting zones of separate structural-formational zones, on areas of complication by arched, linearly-transveral, focus-ringed, linearly-longitudinal (in relation to axes of folded systems) structures. They are fixed by granitoid intrusions, dyke belts and various metasomatites. Gold, complex gold-platinoid-rare-metal ores are paragenetically connected with diverse orogenic-riftogenic granitoid intrusions with increased basicity – with the early subduction-collision gabbro-plagiogranitic and the late riftogenic gabbro-sienite-granitic, diorite-sienite-porphyric intrusions. All of them are attributed to the intrusive series of mantle and intracrustal types.

For example, in southern part of the North-Chinese platform, in the belt Tsynlyn the metallogenic zoning of ore belts has been revealed [28]. Here from northwest to southeast of the belt at immersing of the basis of Archean the zoning of mineralization corresponds to the folloing sequence: Au→Mo→W→Pb, Zn and connected with change of type of endogenic mineralization – gold-quartz veins → gold-bearing breccias and stockwork ores; molybdenum-porphyric → molybdenum-tungsten-skarn. Similar laws of location of complex endogenic mineralization are established within the limits of metallogenic belts Nanling in Southern China. In southeast part of the Siberian platform three folded systems, various in time of their formation are established: the most ancient is Aladanskaya, Proterozoic of Stanovoi range and Baikal. From northwest to southeast at immersing of the platform basis the zoning of mineralization changes under the scheme: W, Mo→Sn, Pb, Zn [28]. In Transbaikalian folded region intensive processes of riftogenesis and tectonic-magmatic activization have occurred. An example of structures with combined complex of mineralization is the known gold-tungsten belt allocated by S.S. Smirnov.

Zoning in distribution of mineral types of complex mineralization is revealed for gold-generating granitoids of Siberian pericratonic metallogenic belt: in granitoid massifs ores of the greisen rare-metal formation are deposited, veined gold-rare-metal sulphidic in contacts of intrusives, and sulphoantimonitic golden-ore deposits over a distance from granitoids are deposited further. The fluid mode of such intrusions corresponded to their high restoration at close activity of HF and HCl in mineral-forming systems (magmatites-fluids). It also has caused formation of complex gold-platinoid-rare-metal ores in general metallogenic belts.

Geosynclinal, orogenic and postorogenic magmatites with accompanying metasomatites occurred within the limits of folded belts, folded and riftogenic mobile zones. Near-surface volcanoplutonic belts with accompanying propylites-metasomatic quartzites, sericitic, argillizitic metasomatites with vein-impregnated gold-sulphidic mineralization of industrial value have occurred in the initial stage of development of mobile folded zones. They are connected with efussion-intrusion basaltoid magmatism. Then appeared midabyssal-hypabyssal granitoid intrusions with increased basicity (granitoids of «motley composition» under the terminology of Yu.A. Kuznetsova) with metasomatites of gold-skarn, gold-skarn-magnetitic, gold-rare-metal-albitite-greisen, gold-quartz-beresitic, gold-quartz-sulphidic formation. At the stage of riftogenesis and tectonic-magmatic activization of structures the hypabyssal – shallow gabbro-diorite-granodioritic, gabbro-sienit-granitic, andesitic magmatites were formed with accompanying propylites, eisites, argillizites with gold-copper-skarn, gold-copper-porphyric, gold-silver-propylitic, gold-telluridic-propylit-argillizitic, gold-antimonitic, gold-chalcedony-argentitic near-surface ores. Usually gold and complex gold-platinoid-rare-metal mineralization of such type occurrs in connection with buildup of the I and the II phases of granitoid intrusions, dykes of motley composition, molybdenum-tungstic and tin ores with rare elements (Bi, Te, Se, Tl, Sb, Nb, Ga, Sr, Sc) are connected with the III and the IV phases of intrusion of the garnet-porphyritic type. Regional intrusion-ore-metasomatic and geochemical zoning occurs within the limits of large metallogenic zones. Zoning is caused by abyssal buildup of intrusions (2...7 km), metasomatites and ores (0,5...5 km) and by value of the erosive cut of separate structural blocks of these zones. For example, in Urals Mountains metallogenic zones with combined gold-platinoid-bearing skarns in the bottom of ore-metasomatic columns and gold-platinum-bearing copper-porphyric ores at the top of these columns (Gumeshevskoe and Tarutinskoe complex skarn-copper-porphyric deposits (with Au, Pt, Pd).

Productive granitoid intrusions were controlled by riftogenic abyssal fractures. They bear traces of magmatic replacement and alkaline-acidic autometasomatosis, and unproductive intrusives are deprived of such changes. For productive intrusions the following are peculiar: increased basicity, sodium-potassic specialization of rocks, sharply expressed alkaline-acidic autometasomatosis; development of magnesia-limy skarns, post-skarn metasomatites and rocks of two petrochemical rows-diorites and plagiogranites; prevalence of chlorine over fluorine in the fluid phase of intrusions (Cl:F 2...50) [29]. Rocks of productive granitoid intrusions and accompanying contact metasomatites (magnesia-limy skarns, post-skarn metasomatites) are enriched with Au ($\overline{X}$=3...7 mg/t, $V$>80 %, $K_H$≥2...3 for granitoids and $\overline{X}$=10...350 mg/t, $V$?100 %, $K_H$≥5...250 for skarns, post-skarn metasomatites). For unproductive intrusions – $\overline{X}_{Au}$=2...3 mg/t, $V_{Au}$<70 %, $K_H^{Au}$ ≥0,8...1,7) and for accompanying metasomatites метасоматитов ($\overline{X}_{Au}$=5...8 mg/t, $V_{Au}$< 80%, $K_H^{Au}$<1...4).

The general tendency to gold accumulation up to $K_H^{Au}$=1,1...2,5 from formations of the early phase to late differentiators of the second or the third phase is noticed for productive intrusions. The revealed tendency of gold accumulation in rocks and minerals of late differentiators of potentially productive granitoid intrusions testifies to its accumulation in residual melts ($K_H^{Au}$=1,1...2,7) and especially in fluids of the subsolidus area ($K_H^{Au}$=53...300). A distinct repeated accumulation of Au is established at buildup of late phases (III–VI) of symmetric-zonal-dyke bodies of gabbro-dolerites in Saralinskiy golden-ore field. Here in early gabbro-dolerites the contents of metal are revealed 1,8...2,9 mg/t, and in similar dyke rocks of III-VI phases of introduction – 3,4...14 mg/t Au: $K_H^{Au}$=1,1...7,5. This tendency has also come to light at comparison of unchanged fine-grained dykes of the gabbro-dolerite group (2,7 mg/t Au) with late marginal parts (phases III–VI) of dyke bodies of diabasic porphyrite (7,7 mg/t Au) where alkaline autometasomatosis has not revealed itself at all: $K_H$=1,3...2,8. The revealed tendencies testify to accumulation of gold in late portions of magmatic melt at its differentiation in the intermediate focus-chambers (in residual melts) [30].

Coefficients of gold distribution among liquid, firm and fluid phases of crystallized melts have made 1,3:1:3 in the initial and 2,5:1:21 in the final stage of crystallization for toleiitic magmas both 2:1:5 and 5,5:1:53...14 for granitoid magmas [20, 25].

Transmagmatic fluids could also introduce gold into intermediate magmatic chambers as at crystallization of thoeiilitic and granitoid melts in these intermediate chambers a 2...2,5 and 2...5,5-fold accumulation of metal in products of their crystallization is revealed and its essential accumulation ($K_H^{Au}$=1,7...114) in minerals of magnesial skarns, formed in the magmatic stage of intrusion buildup, is established.

Magmatic processes in the Earth's crust were accompanied by the metasomatic phenomena with formation of large and fine ore-metasomatic columns 1,2...3,8 km in length on a vertical. Long existed thermofluidostream provided a wide front of redistribution, exchange, addition, subtraction of ore components from lateral rocks on the way of fluid advancement. In the bottom parts of such columns potassic-sodic autometasomatites are, and further along the cut – skarns, greisens, beresites-listvenites, gumbaites, propylites, eisites, argillizites and ores of various structure. The noted metasomatic zoning, most likely, testifies to the oxidizing influence of fracture-porous waters of lateral rocks of upper part of thermohydrocolumn on abyssal fluids of regenerative condition. For the largest ore-metasomatic zones-columns, formed in apical parts of granitoid intrusions and dyke beams, the attributes of participation of abyssal fluidostreams are peculiar. They are revealed in magmatites and autometasomatites in the form of extensive on the depth the zonal constructed metasomatic column with traces of the phenomena of gradual oxidation of abyssal fluids towards the top of this column. It is emphasized by change of mineral paragenesis and geochemical associations of elements with depth.

Matasomatites and ores in the general ore-metasomatic column are located naturally: in the bottom of the column lie alkaline metasomatites of quartz-albitic, calispar-albitic, albite-biotite-muskovitic compositions with impregnated ores Au-W-Mo-Os-Pt; in the middle part – greisens, beresites-listvenites, gumbaites, sometimes propylites with stockwork ores Au-Bi-Te-As-Pt-Pd; in the top – carbonaceous listvenites or eisites-argillizites with veined, veined-stockwork mineralization Au, Au-Ag-Pd-Sb-Hg (see Fig. 13, 18, 19). These parts of the hydrothermal column are emphasized by geochemical fields-aureoles of exhaustion of Au, Ag, Pt, Pd in the bottom, and in the average-top parts – accumulation of ore elements. Upper-ore Sb, Ba, Hg, Tl; near-ore Cu, Pb, Zn, As, Ag, Au, Pt, Pd, Bi, Te, Se; under-ore Ti, Ni, V, Co, Mn, Cr, Os, Ir, Mo, Be, W groups of elements are allocated in the aureoles.

Formation of golden-ore and complex gold-platinoid-rare-metal deposits in the Earth's crust has been carried out by two ways: 1) at buildup of granitoid intrusions of the motley composition, diorite-lamprophyric rods, dykes when local post-magmatic ore-forming hydrothermal streams appeared; they created low-volume ore-metasomatic columns and golden-ore, gold-rare-metal ore objects with poor and average stocks of precious metals; 2) Large and superlarge combined ore-metasomatic columns where large ore deposits were created have formed at participation of abyssal magmas and mantle highly-heated fluids. Overlapping of intracrustal and abyssal-mantle ore-forming magma-thermo-fluidodynamic systems has also provided formation of large and superlarge ore deposits. Such deposits were formed owing to repeated long processes of «contraction» of the ore substance into the uniform geochemical aureoles-fields and later transformed into large ore deposits.

The sequence of geologic-geochemical events at formation of such complex of precious-metal deposits is the following ($K_H^{Au}$):

- mantle metasomatism of abyssal substance and deposition of metal-bearing thermofluid systems – 0,5;
- buildup of hyperbasite-basite intrusions in the Earth's crust – 1,2...2,7;
- autometasomatic serpentisation of hyperbasite-basite – 0,9...1,0;
- injection of gabbro-plagiogranitic intrusions – 1,7...5,6;
- metasomatic olivinization of serpentites – 0,7...0,8;
- K-Na autometasomatosis of granitoids – 0,8...0,6, a $K_H^{EPG}$=0,5...0,6;
- propylitization of volcanites, dykes of gabbro-dolerites – 0,9...0,8, a $K_H^{EPG}$=0,8;
- beresitization-listvenitization, greisenization or argillization of magmatites, carbonaceous shales – 3...300, a $K_H^{EPG}$ =36...410;
- silicification or sulphidization of magmatic, metasomatic, carbonaceous terrigenous rocks – 300...2000, a $K_H^{EPG}$>1050.

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## REFERENCES

1. Korobeynikov A.F. Unnconventional complex gold-platinoid deposits of folded belts. – Novosibirsk: Scientific Research Center of Institute of Geology and Gas and Mineralogy of the Siberian Branch of the Russian Academy of Sciences, 1999. – 237 p.
2. Korobeynikov A.F. Complex deposits of precious and rare metals. – Tomsk: Publishing house of TPU, 2006. – 327 p.
3. Vorobyev A.A. Balance and transformation of energy types in bowels. – Tomsk: Publishing house of Tomsk State University, 1980. – 212 p.
4. Glukhmanchuk E.D. Deformations of elastic consequence in the upper layers of the Earth's crust as an indicator of movement of magmas and fluids // Geologiya i geophisika. – 1992. – № 6. – P. 32–36.
5. Usov M.A. Geotectonic theory of self-development of a matter of the Earth // Bulleting of Academy of Sciences of the USSR. Series geol. – 1940. – № 1.
6. Martyanov N.E. Thoughts on pulsations of the Earth. – Krasnoyarsk: Krasnoyarsk Scientific and Research Institute of Geology and Minerals, 2003. – 272 p.
7. Ryabchikov I.D., Beottcher A.L. Composition of water fluids equilibrium with phlogopitobearing mantle paragenesis at high pressures and temperatures // Bulleting of the Academy of Sciences of the USSR. Series geol. – 1980. – № 3. – P. 56–61.
8. Lazko E.E., Serenko V.V. Peridotites with zonal garnets from kimberlites of Yakutia: evidence of high-temperature abyssal metasomatosis and intramantle metasomatism? // Bulleting of the Academy of Sciences of the USSR. Series geol. – 1983. – № 12. – P. 41–53.
9. Letnikov F.A. Superabyssal fluid systems of the Earth and the problem of ore-genesis // Geologiya rudnykh tel. – 2001. – V. 43. – № 4. – P. 291–307.
10. Anderson D.L. The derthe of mantle reservoirs. Magmatic processes Physiochemical in principles // The Geochemical Society, Special Publication 1 // Ed. by B.O. Mustn. – 1987. – P. 3–12.
11. Boettcher F.L., O`Neil J.R., Windom K.E. et al. Metasomatism of the upper mantle and the genesis of kimberlites and alkalilasalts // Proc. 2-nd Intern. Kimberlite Conf. – 1979. – V. 1. – P. 173–182.
12. Korobeynikov A.F. Mantle-crustal model of formation of endogenic deposits of gold // Geology, searches and investigation of mineral deposits. – Irkutsk: Publishing of IPI, 1990. – P. 29–40.
13. Korobeynikov A.F. Geologic-geochemical model of gold-bearing ore-magmatic systems // Geologic-genetic models of ore-magmatic systems. – Irkutsk: Publishing of IPI, 1991. – P. 3–15.
14. Ringwood A.E. Composition and geogenesis. – Moscow: Nauka, 1981. – 111 p.
15. Frolova T.I., Perchuk L.A., Burikova I.A. Magmatism and transformation of the Earth's crust of active margins. – Moscow: Nedra, 1989. – 261 p.
16. Scherbakov Yu.G. Geochemistry of golden-ore deposits in Kuznetsk Alatau and Mountainous Altai. – Novosibirsk: Nauka, 1974. – 278 p.
17. Korobeynikov A.F. Gold in endogenic processes of the Earth's crust and mantle // Reports of the Academy of Sciences of the USSR. – 1988. – V. 299. – № 5. – P. 1233–1237.
18. Rakhimov H.R. Geochemical features of elements of the platinum group and gold in various phases of meteoritic substance (with use of radioactivation methods of analysis). – Dis. Cand. sciences. – Tashkent, 1989. – 167 p.

19. Oleynikov B.V., Kopylova A.G., Korobeynikov A.F., Kolpakova N.A. Osmium in native iron of continental basite // Otechestvennaya geologiya. – 1998. – № 6. – P. 58–63.
20. Korobeynikov A.F. Fractionation of gold in magmatic melt at its crystallization // Reports of the Academy of Sciences of the USSR. – 1981. – V. 259. – № 5. – P. 1200–1204.
21. Almukhamedov A.I., Medvedev A.Ya. Geochemistry of sulphur in processes of magma evolution. – Moscow: Nauka, 1982. – 148 p.
22. Gorbachev N.S. Fluid-magmatic interaction in sulphide-silicate systems. – Moscow: Nauka, 1989. – 127 p.
23. Korobeynikov A.F. Platinum metals in golden-ore deposits of folded structures of Siberia and Northeast Kazakhstan // Geokhimiya. – 1998. – № 10. – P. 1009–1020.
24. Korobeynikov A.F. Complex gold-platinoid-rare-metal deposits – reserve of the XXI century // Bulleting of the Tomsk Polytechnic University. – 2001. – V. 304. – № 1. – P. 169–182.
25. Korobeynikov A.F. Conditions of gold concentration in Paleozoic orogens. – Novosibirsk: Institute of Geology and Gas of the Siberian Branch of the Academy of Sciences of the USSR, 1987. – 177 p.
26. Korobeynikov A.F. Features of behavior of gold at areal and local metasomatosis of granitoid intrusions of the Sayano-Altaiskaya folded area // Geokhimiya. – 1977. – № 2. – P. 288–297.
27. Korobeynikov A.F. Ore-metasomatic zoning on gold deposits // Geology of ore deposits. – 1983. – № 1. – P. 96–99.
28. Khe In. Regional, intermediate and local zoning of Au, Mo, W, Sn-mineralization on the example of areas of Russia and China // Izvestiya vuzov. Geologiya i razvedka. – 1998. – № 1. – P. 154–155.
29. Korobeynikov A.F. Criteria of connection of gold mineralization with magmatism and metasomatism in the Sayano-Altaiskaya folded area // Criteria of forecast evaluation of endogenic mineralization of the Altai-Sayanskaya area. – Novosibirsk: Nauka, 1982. – P. 89–93.
30. Korobeynikov A.F., Tchernyaeva E.I. Behavior of gold at formation of zonal dyke bodies of gabbro-diabases // Reports of the Academy of Sciences of the USSR. – 1987. – V. 292. – № 3. – P. 680–684.

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# COSMOSTRUCTURAL MODEL OF THE KALGUTINSKIY RARE-METAL DEPOSIT AREA (MOUNTAINOUS ALTAI)

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*Cosmostructures of the Kalgutinskiy rare-metal deposit area (Mountainous Altai) have been studied on the materials of multispectral space survey Landsat ETM+ and radar-tracking survey SRTM. The area is localized inside of the large ring structure of a complex construction, characterized by the long multistage (multipulse) development. Immersing of the root (focus) part of the structure from the north – northwest to the east – southeast is established. Position of the ring structure is controlled by the crossing knot of fracture zones of northwest, northeast and northeast – sublatitudinal directions. The Kalgutinskiy granite massif and the deposit itself are located in the internal belt of the structure in the ring 15,2 km in diameter. The perspective of ore-bearing ability of the southeast part of the area is highly evaluated in connection with development of small ring structures of the second type.*

## Introduction

Research of conditions of deposit formation, revealing of sources of matter and energy and reasons of ore deposition are the most important problems of mineragеny. Their solution is the base of forecast-prospecting models and underlies genetic constructions. A connection with large structures of the earth's crust which find their reflection in materials of regional geological, geophysical and space researches is established for many large and huge deposits of gold, uranium, polymetals, diamonds and other minerals [1, 2].

Last few years a new data on features of geological structure, petrology of magmatic formations and material composition of ores of the Kalgutinskiy deposit has been obtained allowing asserting about a significant energetic and material influence of the mantle source on the Kalgutinskiy fluid-magmatic system. Application of multispectral space surveys, possessing significant visibility, high information content at corresponding spatial resolution, allow obtaining new data about regional geological structures and abyssal composition of the deposit area. A number of new structures that have not been allocated before during ground geological and geophysical researches appear.

## Research technique

Materials of multispectral space survey using the system Landsat ETM+ (table 1) are used in the work. Al-titude of the orbit is 705 km, inclination 98,2°. Channels 1–3 give information in a visible range of the spectrum, channel 4 is in the infrared, 5–7 – in near and far thermal area, channel 8 (PAN channel) – gives