ANNOTATION

to dissertation submitted for the Doctor of Philosophy degree (PhD), the specialty "6D070600 - Geology and Exploration of Mineral Deposits"

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"GOLD ORE PROCESSES AND GEOLOGICAL PROGNOSIS FOR KAZAKHSTAN DEPOSITS (BAKYRSHIK, BESTOBE, ARKHARLY) "

In the course of studies of three gold formations most important for Kazakhstan (gold-arsenic – Bakyrshik, gold-silver – Arkharly, gold-tellurium-bismuth – Bestobe), the current state of science in solving problems of theories of the gold ore deposits formation was analyzed, mineragenic productive levels were studied and the principles of generating predictive and prospecting models of the considered main industrial types of gold deposits were considered.

The genetic aspects of gold deposits formation and, mainly, the forms of gold migration, the features of its behavior and deposition in different thermodynamic conditions and different geological environments have always attracted heighten interest of both leading scientists and exploration geologists, since they are of great practical importance in intentional prospecting and evaluation of new ore fields and the authors of the study mentioned it in the work. Thus, for the formation of Bakyrshik deposit, several predictive and prospecting models of three genetic types have been proposed – syngenetic (exogenous hydrothermally-sedimentary), epigenetic (endogenous hydrothermal-metasomatic) and polygenic syngenetically-epigenetic, in different combinations, combining the first two types. Despite the contradictory views based on a large volume of factual material, they all complement each other, which indicate the extreme complexity of this problem. It is confirmed by the example of Bakyrshik analogues – giant deposits of gold of the black shale formation in Russia (Sukhoi Log and others), Uzbekistan (Muruntau), Kyrgyzstan (Kumtor), etc., a long discussion on which continues up to the present time.

In the last decade, the rapid development of new technologies for the hydrometallurgical leaching of gold with various solutions (bromide, iodide, ammonium-thiosulfate, thiosulfate, hypochlorite, etc.) was accompanied by multifaceted experimental, including autoclave, studies of the kinetics of dissolution of a noble metal with the determination of thermodynamic constants and physicochemical substantiation of the ongoing redox processes. The obtained experimental data serve as the basis for physicochemical and thermodynamic modeling of the behavior of gold and its complexes under various conditions.

One of the least understood in the problem of the thermodynamics of the formation of gold deposits are the issues of the deposition of gold in its native state on geochemical barriers, to solution of which we paid considerable attention in this work. The main results of the work are the determination of the evolutionary trend of polygenic physicochemical and thermodynamic processes in the formation of gold deposits with the successive transformation of metastable gold into its native

phase. The significance of the fineness of gold as an indicator of the physicochemical conditions of hydrothermal ore formation is considered in detail. The main types of gold-localizing geochemical barriers were analyzed. The research results can be used both, for the further development of the deposit formation theory, and for drawing up forecast maps of promising areas, conducting prospecting and exploration work.

Thanks to the groundbreaking development of equipment and technology for processing gold-bearing ores, especially with use of cyanide leaching methods, the range of deposits with a low gold content that are involved in industrial development has expanded. To date, it is considered profitable to develop deposits with a gold grade of 0.62 g/t. And there is more to come. All possible kinds of integration of various methods of ores cyanide leaching with factory technology allows to further reduce the average gold content in ores to 0.3-0.5 g/t. In addition, it should be taken into account that tests are underway to develop other cheaper reagents (thiourea, iodides, chlorides, etc.), which will further reduce the cost of gold production in the future. All these circumstances make it possible to recommend the industry of the Republic to raise the problem of the gold and silver deposits development in Kazakhstan (Arkharly) to an appropriate level. It is a common fact that the numerous objects of gold-silver mineralization listed in the state cadastre mostly of the ore occurrences category and only some of them belong to small and medium-scale deposits. However, the example of the development of similar objects in Russia (Dukat, Olympiadinskoe, Baley), Argentina (Pascua Lama), Mexico (Pachuca), Papua New Guinea (Porgera), Peru (Yanakocha), Romania (Rosia Montana) and a number of other countries shows that with a decrease in the cut-off grade of industrial ores to 0.5 g/t and less, many previously known small objects turned into large ones, and in some cases reached the volume of authentic deposits.

As a result of detailed microscopic and microprobe studies of ores in the oxidation zone of the Arkharly deposit, various silver halides and splicings of electrum with native silver, which are key to the restoration of hypergene mineral formation processes, have been identified for the first time.

The occurrences of the gold-tellurium-bismuth formation (Bestobe) are one of the classic examples of proper gold ore deposits, which, in terms of prevalence among various industrial-genetic types, rank high in Kazakhstan. This formation is one of the most studied types of gold mineralization. Often geochemical barriers during deposition are the contacts of environments with sharply different mineralogical composition (quartz with sulfides, chlorite-sericitic metasomatites, carbonaceous-clayey siltstones, etc.). Sensitive indicators of productive gold – bismuth and tellurides were revealed.

Basis and initial data for the development of the topic. The basis for the development of the topic of the dissertation is field work, data from laboratory and microscopic studies. The initial data are microscopic study of ore deposits, information about the geological structure of the studied deposits.

The work is based on the study and analysis of fund materials from previous years and a literature review, in-situ data, core and stone material, the results of laboratory studies during the author's research work from 2016 to 2020

Thin rock sections were made from the main samples. Out of total 155 polished thin sections and 100 thin sections, 30 polished thin sections and 25 thin sections described using microscope, in laboratories during training and internship in the Natural History Museum Laboratory Department of Earth Sciences, Department of Mineralogy, London, UK

Justification of the need for carrying out the research work.

Kazakhstan was one of the most important gold-bearing provinces of former Soviet Union. On the basis of various geological and economic types of gold deposits, the gold mining industry has been successfully developed recently in the Republic. Due to the exhaustion of the fund of easy-to-reach deposits and the ever-increasing needs of the national economy in scarce raw materials, a steady increase in the efficiency of prospecting and exploration work and the accelerated development of new ore objects are required. The solution to this complex state problem must involve in-depth and comprehensive scientific research aimed at studying the conditions for the formation of gold-ore and gold-bearing deposits and improving the principles of compiling deposit models and predicting gold mineralization.

Information about the planned scientific and technical level of development is determined by the completeness of geological studies of the conditions for the formation and location of the Bakyrshik, Bestobe, Arkharly deposits.

A literary and patent review of domestic and foreign scientific works was carried out in regards the problem of forecasting and modeling. Modern methods of study in laboratories fitted with equipment as per contemporary requirements of science and technology were selected. The scientific and technical level of the dissertation is determined by the novelty of obtained results, the prospects for using the results for forecasting and prospecting for gold deposits, by the completeness of the research. The major types of gold ore formations in Kazakhstan and gold ore processes have been studied in the dissertation. General principles for compiling forecast and prospecting models for gold deposits have been developed. Models for reference fields Bakyrshik, Bestobe, Arkharly were created.

Information about the metrological support of the dissertation. The veracity of obtained results is confirmed by the use of modern instruments metrologically testing for conducting geological research in modern certified laboratories of the "Innovative Geological and Mineralogical Laboratory" of Satbayev University, at the Ore Mineralogy Laboratory of the Natural History Museum (London) with aid of Zeiss EVO 15LS SEM scanning electron microscope, Cameca electron probe micro-analyzer, JCXA 733 electron probe micro-analyzer, INCA ENERGY energy-dispersive spectrometer, at the Institute of Geological sciences named after K.I.Satpaev.

Relevance of the topic. Genetic aspects of the formation of gold deposits, prevailing in Kazakhstan, such as Bakyrshik, Arkharly and Bestobe, especially, the forms of gold migration, the features of its behavior and deposition in different thermodynamic conditions and different geological environments have a great practical value in the purposeful search and evaluation of new ore fields.

The novelty of the topic. The research is determined by the fact that, based on the new obtained factual data in combination with existing views on the formation of gold deposits in carboniferous sequence, a three-stage model of the Bakyrshik deposit formation has been developed: sedimentary-diagenetic; tectonic-metamorphogenic; intrusive-thermal-metamorphogenic.

- for the first time, at the Arkharly deposit in the oxidation zone, silver halides were found in association with native silver and gold, which are of crucial significance in the restoration of hypergene mineral formation processes.

- the gold ore processes of the deposits under consideration were studied in detail, the factors of ore content were identified, predictive models based on geological data were developed.

All this will serve as the basis for conventional prospecting for deposits of this type.

The relatedness of the work with other research projects. The author of the thesis participated in the development of the scientific technical program "Scientific support of problems of replenishment and development of mineral resources in Kazakhstan for 2006-2008" on the subject "Development of new theories of the deposits origin and generating of ore-forming systems models for priority minerals". It resulted in the study of theoretical issues of gold deposits formation in Kazakhstan, and on that basis - the development of their forecasting and prospecting models with the systematization of known and predicted geological and industrial types of gold deposits in Kazakhstan.

Under the Program "Scientific substantiation of mineral reserves replenishment for the industrial development of the Republic of Kazakhstan for 2012-2014, "Creation of a scientific basis for the assessment of gold-bearing structures and volumetric models of the main types of gold deposits", the state of affairs of science was analyzed in solving problems of the theory of gold deposits formation, the productive mineragenic levels were examined, and the principles of constructing predictive and prospecting models of the major industrial types of gold deposits have been developed.

The purpose of the work is to identify the regularities of the ore formation process and the determination of physicochemical and thermodynamic barriers of gold deposition in the most important deposits of Kazakhstan, with geological and metallogenic forecasting in search for deposits of such type.

The concept of the work was to study the most important types of gold deposits in Kazakhstan with the generation of their geological and genetic models, study the conditions of gold ore processes, obtaining data for predicting deposits of this type.

The objects of research are the most important geological and industrial types for Kazakhstan: 1) gold-sulfide in terrigenous carboniferous complexes (Bakyrshik); 2) gold-silver continental volcano-plutonic belts (Arkharly); 3) gold-sulfide-quartz (Bestobe)

The subject was to study ores of the three geological and industrial types of Kazakhstan, their microscopic study, using precision methods for studying the substance, as well as a detailed analysis of the available data on these objects.

Objective of the research:

1. Collection, generalization and analysis of data on geology and mineralogy and geochemistry at the present stage of study.
2. Detailed microscopic study of gold ore mineralization at the Bakyrshik, Arkharly, Bestobe deposits.
3. Identification of the trend of the gold ore process in each type of deposit under study.
4. Justification of geochemical and thermodynamic barriers at which gold was deposited in the given geological and industrial types.
5. Identification of the main geological forecasting models for the Bakyrshik, Arkharly, Bestobe deposits.

The research methodological base consists of the following main methods and analyzes:

Rock and mineral samples from the Bakyrshik, Arkharly, Bestobe deposits were analyzed at the Natural History Museum Laboratory Department of Earth Sciences (London) with aid of Zeiss EVO 15LS SEM scanning electron microscope and Cameca SX100 electron probe micro-analyzer.

Zeiss EVO 15LS SEM is a versatile analytical scanning electron microscope that can operate in variable pressure and high vacuum modes. Low vacuum mode was used for visualization and high-quality X-ray analysis of the samples. When analyzing samples, a pressure of 60-100 Pa was mainly used, although it can be increased to 200 Pa. Mineral identification is performed by the EDX detector with regular calibration to analyze the core elements in silicates, the prevailing rock-forming minerals, and can readily provide the information needed for mineral identifications. This scanning electron microscope has also been utilized to create thin section maps demonstrating the distribution of basic and trace elements (Si, K, Al, P, Ce, Nd, Eu, Gd, Y, etc.).

Samples (universal thin sections and plates) were analyzed using a Cameca SX-100 electron probe microscope with a dispersion wave, which is widely used in mineralogy and geochemistry at the Museum of Natural History (London). Operating conditions: accelerating voltage 20 kV, beam current 20 nA, and beam diameter 20 μm. Typical synthetic compounds and natural minerals were used as probe standards. PAP matrix corrected. Multiple peak overlap corrections were applied before matrix correction. Based on the results of electron probe analysis, the qualitative chemical composition of the minerals was determined.

In a number of cases, the study of the chemical composition of 50 samples was carried out in the IGS Mineralogy Department using a JCXA 733 electron-probe microanalyzer with an INCA ENERGY energy-dispersive spectrometer.

Highlights for defense:

1. In the metallogenic zones of Kazakhstan, using the example of selected reference deposits, the gold-ore specificity of each object is shown, the spatio-temporal combination of three main processes is determined: disseminated sedimentogenic ore genesis, epigenetic redistribution and postmagmatic hydrothermal mineral formation, which predetermined the dominant manifestation of certain typomorphic ore formations.

2. In the formation of the gold ore giant Bakyrshik, prevailing organic matter played an important role, which predetermined the large-scale concentration of gold on the geochemical reduction barrier.

3. For the first time in the oxidation zone of the Arkharly deposit, silver halides (chlorides, bromides, iodides) were discovered, the sources of which are native silver and gold, and the formation of the latter in the hypergenesis zone is associated with gold-rich sulfate-chloride waters, which, as they are filtered into deeper horizons become less oxidized and under the influence of various reducing agents are corraded with the formation of native gold.

4. The main forecast data for gold mineralization of the considered geological and industrial types were revealed, the most important of which are: a) ore-controlling factors; b) a complex set of geological objects (structures, rocks, minerals, etc.); c) development of models of reference objects based on a set of features inherent in particular formationally similar manifestations of gold mineralization.

The practical relevance of the work. The result of the dissertation work is the new obtained geological data, on the basis of which medium- and large-scale forecasting is proposed in the search for the most important geological and industrial types for Kazakhstan: gold-sulfide in terrigenous carboniferous complexes (Bakyrshik); gold-silver continental volcano-plutonic belts (Arkharly); gold-sulfide-quartz (Bestobe).

Publications and approbation of the work. Based on the results of the scientific research, 15 articles and reports were published, including 3 papers in an international scientific journal included in the Scopus database and having a non-zero impact factor and 4 articles in scientific journals recommended by the Ministry of Education and Science of the Republic of Kazakhstan, 1 article in "Geology and Protection of Mineral Resources of Kazakhstan" RSCI journal. The results obtained have been widely tested at international and republican scientific conferences

The structure and volume of the thesis. The dissertation work consists of an Introduction, five Chapters, a Conclusion, a List of references and Appendices. The volume of the thesis is 150 pages of typewritten text, 10 Tables, 64 Figures, the List of references includes 74 titles.

The Introduction provides a general description of the dissertation work. The objective is defined, tasks are set to achieve the objective, the relevance of the

topic is formulated, the scientific provisions submitted for defense and the practical significance of the dissertation are stated

The Chapter I presents a brief geological position of the deposits (Bakyrshik, Arkharly, Bestobe), namely, their regional position, tectonics, information about sedimentary, volcanic and intrusive rocks involved in the geological structure of objects.

In Chapter II, the main types of gold ore formations in Kazakhstan are presented, their characteristics are given, and the mineralogy of ores of the studied objects is also given.

Gold-arsenic carboniferous formation. Gold-bearing carboniferous deposits in Kazakhstan have a wide age range (Early Proterozoic - Upper Paleozoic) and belong to various formational types of sediments formed in a wide variety of geotectonic conditions.

The gold-arsenic carboniferous formation (gold-carboniferous-sulfide) is an independent industrial-genetic type of mineralization, which corresponds to ore occurrences and deposits of the Kalba region of East Kazakhstan, formed under the conditions of the orogenic development of the Zaisan fold system.

A distinctive feature of the ore-bearing strata is the conjugation in terms of the time of their formation with volcanic processes in the structural-formational zones bordering in the southwest (Zharma) and northeast (Rudnoaltaiskaya), the presence of a significant amount of volcanomictous material and dispersed carboniferous material in the terrigenous rocks, successive change of marine sedimentation conditions to continental, one of the important elements of deposits of gold-arsenic carboniferous formation is the presence of organic carboniferous material in the composition of ore-bearing sediments and ores.

Gold-silver formation. The formation of shallow gold and gold-silver deposits (Baley type according to N.V. Petrovskaya) is confined to the volcano-plutonic belts that compose the upper structural layer of the folded regions of Kazakhstan.

The main features of the deposits of the gold-silver formation are:

1. Close structural-paragenetic connection of shallow gold mineralization with magmatism of orogenic volcano-plutonic belts of Kazakhstan, with which it forms a single magmatogenic-ore system.

2. The confinement of deposits to zones of deep preexistent faults dissecting complex systems of paleovolcanic structures, fragments of concentric and radial faults of ring volcano-tectonic structures, specific ore-bearing explosive structures, often combined with the centers of volcanic structures.

3. One of the specific criteria for evaluating Au-Ag deposits is a pronounced zoning (vertical and lateral) in the formation of metasomatites, the distribution of mineral associations, changes in the structural and textural features of ores, etc. It is important in assessing objects as a comprehensive criterion for determining

various parameters of mineralization, including the degree of deposits erosion, possible vertical range, scale and intensity of mineralization.

4. Widespread occurrence of fields of epidote-actinolite-chlorite propylites or low-temperature secondary quartzites, which serve as one of the signs of delineation of gold-adularia-quartz mineralization development.

5. Many large objects of Au-Ag mineralization are characterized by the manifestation of ore-bearing explosive and eruptive breccias, which, along with their industrial value, indicate the location of the most permeable areas of ore-bearing structures.

6. Finally, a significant role in identifying the geological features of Au-Ag deposits is played by the study of the patterns of placement within them and the parameters of bonanza ore pillars, containing significant gold reserves and differing, at least several-fold, in its high contents.

Gold-tellurium-bismuth formation. On the territory of Kazakhstan, manifestations of gold-tellurium-bismuth (quartz) subformations are known in the Caledonian folded zones of the Chingiz-Tarbagatai, Maikain and Chu-Ili regions, in the Hercynides of the Urals, Southwestern Altai and Zhongar-Balkhash structure.

Manifestations of gold-tellurium-bismuth quartz subformation with features inherent in plutonogenic-hydrothermal mineralization are localized within post-fold (near-fault) structures, which are very diverse in their kinematic nature and pattern.

For the gold-tellurium-bismuth quartz subformation of Kazakhstan, it should be noted, that the completeness of the manifestation of the latest productive associations of minerals plays an important role in determining the industrial significance of its objects. Hence, the specification of geochemical exploration criteria, which consists in the presence of complex haloes (Cu, Pb, Zn, Mo, As, etc.) along with gold of bismuth, silver, antimony and tellurium.

The Chapter also contains the description of ore mineralogy of the studied objects.

Mineralogy of ores of the Bakyrshik deposit. The predominant ore minerals are pyrite and arsenopyrite; antimonite is noted in the near-surface horizons; marcasite, chalcopyrite, pyrrhotite, and galena are much rare. There are four paragenetic associations of different ages – pyrite-I – melnicovite – marcasite, gold-I – pyrite-II – arsenopyrite, gold-II – sphalerite – galena – chalcopyrite and gold-III – antimonite – marcasite – enargite (V.A. Narseev, M.M. Starova).

The mineral composition of the ores is rather uniform, although the number of ore minerals exceeds 35. Iron disulfides and arsenopyrite predominate. Antimonites are sometimes found. The rest of the minerals are rare. Gold is mainly associated with pyrite and arsenopyrite and forms very thin precipitations, detected only at high magnifications (1500x – 1600x).

Mineralogy of the Arkharly deposit ores. The ores of the deposit are characterized by a number of features inherent in all near-surface deposits. They are dominated by banded, collomorphic and crustyform textures of mineral aggregates; lamelliferous and frame-septate textures of quartz are quite common. The main vein minerals are fine-grained metacolloidal quartz and chalcedony. Quick veins contain adularia, silver sulfides, and low-grade gold.

The main ore minerals are pyrite, sphalerite, galena, chalcopyrite, gold and hematite. The minor and rare in a number of veins include acanthite, bornite, pyrrhotite, freibergite, polybasite, arsenopyrite, pyrargite, melnicovite-pyrite, marcasite, more undefined silver telluride and complex silver and bismuth sulfide (single finds), cinnabar, goethite, chalcocine.

Mineralogy of ores of the Bestobe deposit. The main ore minerals are native Au, arsenopyrite, pyrite, antimonites; minor and rare – sphalerite, galena, chalcopyrite, pyrrhotite, marcasite, rutile, magnetite, apatite, sphene, leucoxene. ilmenite, lellingite, gersdorffite, safflorite, tennantite, tetrahedrite, berthierite, burgunite, molybdenite, scheelite, bismuthine, tetradymite, altaite, claprotolite, wittikhenite, aikinite, native As, Sb and Ag, electrum, cinnabar; nonmetallic - quartz, calcite (main), sericite, chlorite, albite, magnesite, dolomite, siderite, barite, epidote. The amount of sulfides in quartz veins is 2-3%.

The Chapter III presents the processes of gold formation, types of geochemical barriers of precipitators and gold concentrators.

The characteristic features of gold are the tendency to complexation and ease of recovery, which in many respects predetermines the migration ability of the noble metal in natural conditions.

The reasons for the chemical inertness of gold lie in the high values of its redox potentials (E), due to the very low stability of its aqua-ions.

The redox potential of complex compounds of gold is much lower than that of an aqua-ion; therefore, with the participation of such addends as halogenide-ions in reactions, it is possible for gold to oxidize with weaker oxidants than in their absence. It is the complexation processes that reduce the redox potential that determine the good solubility of gold in chloride, bromide and iodide waters, in thiourea solutions containing elemental chlorine, oxygen, manganese dioxide, chloride or iron (III) sulfate as an oxidant. In addition, complexation enhances the stability of gold compounds. Aurum forms stable complexes with sulfur-containing ligands, cyanides and ammonia in reducing media. Consequently, the solubility and form of gold in a hydrothermal solution, as an element of variable valence, is directly dependent on the redox potential of the system, as well as on the composition of the active addends present, acidity-alkalinity, temperature and ionic strength of the system.

Thermodynamic, experimental, and mineralogical-geochemical studies of the last two decades, as well as our data, substantiate a significant role of iodide, thiosulfate, bromide, ammonia, and organo-gold complex compounds, along with conventional chloride, hydrosulfide, sulfide and hydroxocomplex forms in the migration of gold.

Our research on the topic under consideration is based on the results of an experimental study of the thermodynamic constants obtained in this case and, mainly, on the electrochemical analysis of the redox processes of the formation, migration and destruction of gold and silver complexes in hydrothermal solutions of different acidity-alkalinity and redox potential. Calculation of the free energy and oxidation potential of various complexes of noble metals allows us to delimit the fields of their stability on the Eh – pH diagrams and to determine the course of the evolution of the hydrothermal system during the formation of gold deposits. Such studies allow us to consider the direction of the redox reactions of various compounds, the stability and reactivity of which is predetermined by Eh – pH of the hydrothermal system. This approach, based on the application of methods of physical chemistry, is substantiated by fundamental research of the thermodynamics of mineral formation processes by the leading figures of Soviet and foreign geological science D.S. Korzhinsky, A.G. Betekhtin, V. Latimer, and then M. Purbe, G.M. Garrels, F.A. Letnikova, T.M. Sjeward, H.L. Barnes and others.

The main types of geochemical barriers: weakly reducing barriers of gold halide complexes, highly reducing barriers of sulfide and hydrosulfide gold complexes, alkaline and acidic barriers, thermodynamic barriers.

The Chapter IV sets out the general principles of developing a predictive prospecting model for gold deposits and provides models of the formation of the studied deposits.

As part of the development of the general principles of the predictive-prospecting model of gold deposits, we have tabulated regional, local search criteria for signs that are presented in the work.

The development of geodynamic models for the formation of various geological and industrial types of gold deposits showed that complex polygenic physicochemical and thermodynamic processes are manifested here naturally, in a certain sequence, in which there is a pronounced evolutionary directed transformation of metastable migration-capable sedimentogenic forms of gold into its native phase.

The ore process runs as per following pattern: sedimentation --- early diagenesis --- late diagenesis --- epizone --- dynamometamorphism --- mesozone (+ catazone) --- intrusive (effusive) magmatism.

Ore formation is accompanied by a certain structuring of the siliceous matrix (opal, chalcedony, quartzine, quartz, stishovite) and the transformation of the carboniferous matter of the ore-bearing strata.

The formation model of the Bakyrshik deposit – Mineralization gone has through three main stages: 1) sedimentary-diagenetic, 2) tectonic-metamorphogenic and 3) intrusive-thermal-metamorphogenic.

The model of the formation of gold mineralization at the Arkharly deposit – 1) the structural-paragenetic relationship of shallow gold mineralization with the magmatism of the volcano-plutonic belt, 2) confinement to zones of deep

preexistent faults, 3) the distribution of fields of epidote-actinolite-chlorite propylites or low-temperature secondary quartzites, a sign of contouring areas of gold-adularia-quartz mineralization, 4) vein metasomatites

Model of the Bestobe deposit formation – The carried out complex of isotope-geochemical, thermobarometric and mineralogical studies substantiates the three-stage formation of the deposit from the formation of a specific lithochemical formation significantly enriched in metastable forms of gold to the formation of intersecting vein type deposits with a significant development of gold in ores in native phase form

Brief conclusions based on the results of dissertation research

Examoned gold ore objects – Bakyrshik, Arkharly, Bestobe, which are part of the 3 main geological and industrial types of primary gold deposits in Kazakhstan: 1) gold-sulfide, developed in carboniferous strata of various ages (Bakyrshik, Bolshevik, Vasilievskoe, etc.); 2) gold-adularia-quartz (gold-silver – Arkharly, Taskora, Ushshoky); 3) gold-sulfide-quartz (Akbakay, Aksu, Bestobe, Zholymbet, Stepnyak, etc.). Among them, the leading in the world and in Kazakhstan is the gold-sulfide-quartz deposit (Bestobe). However, the focus in the work was on promising types – gold-sulfide, developed in carboniferous strata (Bakyrshik; for example, the predominant part of reserves, more than 50%, of native gold in Russia is concentrated in deposits of carboniferous-terrigenous complexes) and gold-silver (Arkharly) – shallow.

The work resolves the most important problems of ore genesis, which are associated with all types of deposits:

1. The direct dependence of gold fineness on Eh-pH conditions of evolving hydrothermal systems has been substantiated. Thus, the widest variation in the fineness of Au is noted for the Au-Ag deposits, which are characterized by multistage and variability of ore-forming processes. In gold-carbon-sulfide deposits, it varies within 1000-850, decreasing in later associations.

2. On the examples of typical deposits of Kazakhstan and the world, various types of geochemical barriers - Au concentrators were identified and categorized. The destruction of gold complexes, its precipitation and concentration occur in areas of abrupt change in the redox potential, acidity-alkalinity of the ore-forming system, its temperature and pressure, which are geochemical barriers to the hydrothermal fluids fluctuations.

3. A general geological model of the gold ore deposits formation has been developed based on the concept of the evolutionary direction of the ore process as per the pattern: sedimentation --- early diagenesis --- late diagenesis --- epizone --- dynamometamorphism --- mesozone (+catazone --- intrusive (effusive) magmatism, due to which a gradual transformation of initially migratory forms of gold (ionic and colloidal) into native occurs.

At its final stage, under the influence of intrusive (effusive) magmatism and tectonic-metamorphic processes, a sharp increase in the ores of the native phase occurs with a decrease in migratory forms of gold, down to the formation of compact gold-quartz ore bodies with a limited amount of sulfides.

I. Gold-sulfide type, developed in carboniferous strata (Bakyrshik deposit) - a unique and promising type in the West Kalba gold belt.

1. Through studying the carboniferous components of ores and ore-bearing rocks, we have established the presence of sapropelic organic matter (OM) and bitumen in them; we also established the degree of postsedimentary transformations at the stage of early metagenesis and dynamometamorphism by the nature of exothermic effects. Since the beginning of sedimentogenesis, OM has concentrated gold in the form of clusters and nanoclusters, and it is a source of gold for the formation of gold-bearing sulfides at the subsequent stages of lithogenesis and dynamometamorphism. The content of gold in OM ranges from 3.7–5.9 g/t (according to atomic absorption analysis) to 10 g/t (according to the author's data). Significant gold reserves in the form of clusters and nanoclusters that are not recoverable during the ore cleaning process were not taken into account when calculating reserves. Development of new methods for extracting gold from carbonaceous rocks is required: that will significantly increase the reserves of the deposit.

2. The main indicators of the Bakyrshik type deposits include: a) rhythmically-layered gold-bearing carboniferous-clayey and carbon-siltstone-pelitic microfacies of the black shale beds with increased contents of syngenetic gold (10-150 mg/t), organic matter (1-10%) and globular-framboidal pyrite; b) intense manifestation of mesozonal-suture folding, accompanied by viscous faults and zones of cleavage flow of rocks, multi-staging of deformation processes and the formation of hybrid structures of plicative dislocations intersection; c) widespread development of chlorite-albite, shungite-sericite and sericite-phlogopite-carbonate metasomatites in zones of cleavage flow and viscous faults.

II. Gold-adularia-quartz (gold-silver) type (Arkharly deposit) – essentially quartziferous ore with finely dispersed gold.

1. The epithermal gold-silver deposits of the Arkharlinsky ore field, in terms of the geological structure, ore deposition conditions and the mineral composition of ores, are similar to the world's famous large and medium-sized deposits of the same geological-industrial type, such as Cripple Creek, Angostura, Yanokocha, Kochbulak, etc. In contrast to these deposits, the exploration extent of Arkharly is lower, which must be replenished in the process of its development.

2. The results of the studies obtained show that: a) the deposit was formed during a multistage hydrothermal process. The change in time in mineral associations indicates a gradual cooling of solutions, as well as a decrease in the sulfur potential and an increase in the oxygen potential during their formation; b) solutions that deposited gold were enriched with zinc, lead, silver and copper, in contrast to earlier and later portions of solutions, which contained only iron and copper in small amounts; c) in quartz associations, the silver to gold ratio naturally increased with the cooling of hydrothermal solutions and with the increase in oxygen potential.

3. For the first time, silver halides (chlorides, bromides, iodides) were found in the oxidation zone of the Arkharly deposit, the presence of which reliably signals of its formation in a dry and hot climate. The formation of native gold in

the hypergenesis zone is associated with gold-enriched sulfate-chloride waters, which, as they filter into the deeper horizons of the oxidation zone, become less oxidizing and under the influence of various reducing agents are destroyed with the formation of native gold. Based on the data obtained on silver halides in the oxidation zone of the Arkharly deposit and based on the results of other researchers in the study of the oxidation zones of gold-sulfide deposits, it can be unambiguously stated that the source of silver in halide minerals is native silver and gold, as well as silver-containing sulfides.

A detailed study of the features of the formation of hypergene gold and silver in the oxidation zone is of not only theoretical but also applied significance. It is necessary to decrypt the gold and silver behavior in carrier solutions and to determine their physicochemical parameters, and is also of practical importance in applications for the development of new technologies of gold and silver extraction.

III. Gold-sulfide-quartz type (Bestobe deposit) **–** widely represented in Kazakhstan. Three types of productive associations are well-developed in the composition of their ores: beresite, quartz-veined, and bonanzite. The first is characterized by the predominant development in the composition of sulfides-associated gold ores, the second - by the predominant native segregations of gold of various dimensions (from nuggets to nanogold), the third is very rich ores with coarse gold. Even such a brief summary shows that they differ significantly in their technological properties. However, in practice, they are processed according to one or two technological schemes and sometimes a mass of gold remains in the tailings.

Assessment of the completeness of set tasks solution

All the tasks set for the dissertation are solved:

- the collection, generalization and analysis of material on geology and mineralogy and geochemistry at the present stage of study was carried out
- at Bakyrshik, Arkharly, Bestobe deposits detailed microscopic studies of gold ore mineralization were carried out
- laboratory tests of samples were carried out to identify the direction of the gold ore process in each type of deposit under study
- geochemical and thermodynamic barriers under which gold deposition in the considered geological and industrial types took place were substantiated
- geological forecasting models for the Bakyrshik, Arkharly, Bestobe deposits were generated.

Recommendations and baseline data for specific use of results

The carried out research can be applied to similar types of deposits.

Based on the results of the work, we have established the direction of the gold ore process, we substantiated geochemical and thermodynamic barriers, at which the deposition of gold occurs. Within the framework of the prepared geological forecasts, the characteristic features and search criteria for the types of deposits under consideration were given.

The main provisions and results of research are recommended to be used by geological prospecting organizations in forecasting and prospecting for gold

deposits of this type, as well as in the educational process of lecture courses in the disciplines "Geology of Mineral Deposits" of the Satbayev University.

The implementation of scientific research was carried out within the framework of the projects "Scientific support of problems of replenishment and development of mineral resources in Kazakhstan for 2006-2008" on the subject "Development of new theories of the deposits origin and generating of ore-forming systems models for priority minerals". The main intention was to study the theoretical issues of the formation of gold deposits in Kazakhstan and, on this basis, the development of their forecasting and prospecting models with the systematization of known and predicted geological and industrial types of gold deposits in Kazakhstan.

In the course of the research, the current state of science in solving the problems of the gold deposits formation theory was analyzed, the productive mineragenic levels were studied, and the principles for constructing predictive and prospecting models of the main industrial types of gold deposits were developed. Under the Program "Scientific substantiation of the replenishment of mineral reserves for the industrial development of the Republic of Kazakhstan for 2012-2014," "Creation of a scientific basis for assessing gold-bearing structures and volumetric models of the main types of gold deposits", in the form of scientific articles and reports in international scientific conferences and symposia

Assessment of the scientific level of the work performed as compared to the front rank achievements in this field

Based on the literature data analysis, the results of field and laboratory experiments, conclusion can be made that the dissertation work meets all the requirements of the state-of-the-art of science and technology. The use of modern research methods substantiates the reliability of the results obtained and the scientific value. Scientific provisions and results of the dissertation work are confirmed by publications and widely tested in the materials of international scientific and practical conferences.

List of published works on the dissertation topic

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