

ABSTRACT

of the thesis for the Philosophiae Doctor (PhD) degree with a specialization in
«Geology and exploration of mineral deposits» 6D070600

Anastasia P. Miroshnikova

GEOLOGICAL CONDITIONS OF FORMATION AND CRITERIA FOR FORECASTING OF GOLD-SULPHIDE-QUARTZ DEPOSITS OF STOCKWORK TYPE (BY THE EXAMPLE OF VASILKOVSKOE DEPOSIT, NORTHERN KAZAKHSTAN)

The main object of the research is the Vasilkovskoe deposit, which is located at the intersection of the Dongulagashskiy and Vasilkovskiy-Berezovskiy fault. It is characterized by a frame-block tectonic structure and contrasting hydrothermal changes in rocks. The deposit is located at the Altybayskiy intrusive massif composed of gabbro, gabbro-diorites, diorites, quartz diorites, plagiogranites and granodiorites. Stockwork mineralization is represented by veinlet, vein-impregnated and impregnated ores. The main ore mineral is arsenopyrite.

Relevance. Gold is one of the priority types of minerals. The value of gold is great as it is a currency reserve of the state, necessary for the stable development of the economy and economic security in times of crisis and decline in production. The territory of Kazakhstan is rich in mineral resources. One of the priorities is to strengthen the mineral resource base of gold. Kazakhstan has an important task to increase gold production to the level designated by the President of the country - 70 tons per year. The task can be solved by involving into operation the most prospective types of gold deposits. One of these types is gold-sulphide-quartz stockwork deposits.

The prospect of these deposits consists in the fact that many of them belong to large and super-large ones (Fort Knox in Alaska, Djerui in Kyrgyzstan, Djilao in Tajikistan, etc.). The Vasilkovskoe deposit is the largest gold deposit in Kazakhstan. It is currently being developed by Altyntay Kokshetau. However, until now, many questions have not been finally resolved concerning the formation process of ore bodies, the age of the rocks enclosing gold mineralization, the distribution depth of ore bodies etc.

Some of these problems have been resolved in this thesis.

The object of the research is the Vasilkovskoe gold-sulfide-quartz deposit.

The aim of the thesis is to determine the criteria for forecasting and searching for stockwork gold-sulphide-quartz deposits (by the example of the Vasilkovskoe deposit).

Objectives of the research:

1. To investigate the rocks of the Altybayskiy intrusive massif using modern research methods (optical microscopy, spectral assay, etc.), to determine criteria for the similarity and / or differences between the rocks of the gabbroid and granodiorite complexes;

2. To determine the absolute age of the granodiorite and gabbroic complexes enclosing the Vasilkovskoe deposit using modern isotope-geochronological methods.

3. To study in detail the mineral composition of ores of the Vasilkovskoe deposit, to determine the main stages of mineral formation and to specify the sequence of ore assemblages formation using modern instrumental research methods (scanning electron microscopy, micro X-ray spectral assay) at a new level;

4. To determine the forms of extraction and the minerals-carriers of gold, to determine its mineralogical and geochemical features (composition, fineness);

5. To specify the criteria for forecasting and searching for the gold-sulphide-quartz deposits of the stockwork type (by the example of the Vasilkovskoe deposit) based on the research performed by the author and the assay of data of previous researchers.

The solution of these objectives resulting from the research allowed doctoral candidate to defend the following **provisions**:

The first defended provision. Gold ore mineralization at the Vasilkovskoe deposit is related to the gabbroid and granodiorite intrusions formed in a tectonically intense geodynamic conditions. It contributed to intensive metasomatic transformation of rocks in the contact zone and the manifestation of endogenous ore formation processes. The various patterns of REE behavior, contrast grades of trace elements (Rb, Th, Ce, Zr) and other petrochemical indicators denote a staged intake of ore-bearing fluid from various igneous sources at a variable melting process.

The second defended provision. The local U-Pb (SHRIMP) method for determination of the age of enclosing igneous rocks showed that gabbroid and granodiorite complexes were intruded within a narrow time interval (470–465 million years ago), which corresponds to the Median-Ordovician Period.

The third defended provision. Gold of two generations is present at the deposit: free, associated with quartz-carbonate veinlets and associated with sulphides. The main carrier of gold is arsenopyrite, while gold is not included in the crystal lattice of arsenopyrite, being a mechanical impurity, as evidenced by its high fineness and the results of electron microscopy. The close association of gold with bismuth minerals was observed.

The fourth defended provision. The formation patterns and sequence of ore formation at the Vasilkovskoe deposit were determined, the criteria for forecasting and searching for sulfide-quartz stockwork deposits were specified (collision geodynamic conditions, high tectonic activity; ore-control character of fault tectonics, intensive metasomatism processes and their zonal distribution; Au-As-Bi-Te mineralization manifestation; significant vertical magnitude of gold mineralization).

Scientific novelty:

- the sources of ore-bearing fluid were specified based on the interpretation of the patterns of rare and trace elements distribution;

- the age of igneous complexes was conclusively determined on the basis of the enclosing igneous complexes' age determination (15 sample) by the U-Pb method (SHRIMP);
- the form of gold presence in the ores of the deposit was determined
- new minerals not previously described in the literature (maldonite, ingodite, headleyite) were determined;
- the stages of mineralization formation were determined, and the sequence of ore assemblages' formation was detailed
- the geological conditions of formation were specified and the criteria for forecasting of the stockwork gold-sulfide-quartz deposits were proposed by the example of the Vasilkovskoe deposit.

Practical significance

The obtained results on the age of intrusion of intrusive complexes and data on their sources can be effectively used in design and performance of further geological exploration works in the territory of Northern Kazakhstan and adjacent areas.

New data on the mineral composition of ore deposits can be used to increase the percentage of gold recovery and adjust the already used flowsheets for beneficiation of gold and arsenic ores (see Act of manufacturing application).

The specified criteria for forecasting and searching can be used to determine new sulfide-quartz stockwork deposits and study known similar deposits.

The main results of the research:

A large volume of research and analytical work has been performed aimed at studying the material composition of rocks and ores of the Vasilkovskoe deposit. For the first time, complex geochronological research of the U-Pb, Ar-Ar, and Re-Os methods were performed. Analytical works were performed in research laboratories of Kazakhstan, Russia and Ireland.

Petrographic characteristics of rocks, structural and textural characteristics and the features of mineral intergrowth and replacement were studied in thin sections (86 pieces) with the use of Olympus BX-51 optical microscopes (the Affiliate of RSE 'NE CPMRM RK' 'VNIItsvetmet', Ust-Kamenogorsk), Polam-MCP300 (FSBI A.P. Karpinsky Russian Geological Research Institute 'VSEGEI', St. Petersburg).

To study the petrochemical features of the granodiorite and gabbroid complexes, a full silicate assay was performed for 27 samples. Assays were performed in the ALS Minerals laboratory in Lugri (Ireland). Concentrations of the elements were determined by ICP-AES, ICP-MS.

Mineralogical assay of ores and ore minerals was performed for 140 samples (85 polished thin sections, 55 briquettes). Researches were performed using the optical microscope Olympus BX-51 in the Affiliate of RSE 'NE CPMRM RK' 'VNIItsvetmet'. The quantitative composition of the minerals, the nature of gold distribution and its fineness were determined using the Tescan Mira 3 LMU JSM-6510LV scanning electron microscope equipped with an INCAEnergy 350 energy dispersive spectrometer in the Analytical Center of the V.S. Sobolev Institute of Geology and Mineralogy of SB RAS (Novosibirsk), as well as using the JSM-

6390LV scanning raster electron microscope manufactured by JEOL Ltd. with the accessory for the energy dispersive assay INCA Energy manufactured by OXFORD Instruments of the laboratory of engineering profile IRGETAS (Ust-Kamenogorsk).

The concentrations of noble metals (Au and Ag) in arsenopyrites of various generations were determined by the atomic absorption method using the Perkin-Elmer spectrometer in the Analytical Center of the V.S. Sobolev Institute of Geology and Mineralogy of SB RAS (Novosibirsk).

The isotopic composition of sulfide sulfur was determined for 16 samples in the Analytical Center of IGM SB RAS (Novosibirsk) using the Finnigan D mass spectrometer; SO₂ gas obtained from sulfides during the oxidation in the solid state was used for the assay.

Geochronological researches of igneous rocks enclosing granodiorite and gabbro complexes were performed in the FSBI A.P. Karpinsky Russian Geological Research Institute 'VSEGEI', St. Petersburg –15 samples in total. Age was determined by the local U-Pb method (SHRIMP) for zircon, as the most stable and informative mineral. Cathodoluminescent assay was performed for all zircons (more than 300 crystals) using the CamScan MX2500 scanning electron microscope with the CLI / QUA2 system.

To determine the age of ore mineralization, ⁴⁰Ar / ³⁹Ar assay was performed for biotite, sericite, and K-spar from the ore assemblage (5 samples in total). The assay was performed in the Analytical Center of IGM SB RAS (Novosibirsk) using the Micromass Noble gas 5400 mass spectrometer by the stepwise heating method in a quartz reactor.

Factual material and personal contribution of the author

The thesis work is based on the materials of the field works (3 field seasons, more than 200 samples) and research of the doctoral candidate for the period of 2012-2018. The author independently performed the study of the material composition of rocks and ores, as well as the interpretation of the obtained data on geochemistry, geochronology and isotopy.

The work was performed under the grant financing of the Science Committee of the MES RK on the topic 'Metallogenic Assay of Alkaline Magmatism and Gold Mineralization by the Example of the Bakyrchik, Vasilkovskoe and Sekisovka Deposits' (2015-2017).

In addition to thesis defender's materials, there have been used the published and stock materials of previous researchers such as V.M. Abisheva, M.S. Rafailovich, V.B. Chekvaidze, I.Z. Isakovich and other domestic and foreign authors, a list of which, as well as links, are given in the reference list.

Appraisal of the thesis. The results of the research and the main provisions of the thesis were reported at the 12th Annual Foreign Conference '12th SGA Biennial Meeting: Mineral Research' (Sweden, Uppsala, August 12-15, 2013), at the International Student Conference '37th Annual Meeting Mineral Deposits Studies Group' (Oxford, UK, January 6-7, 2014), International Scientific and Practical Conference 'Innovative Technologies and Projects in the Mining and Metallurgical Complex, Their Scientific and Personnel Support', (Almaty, March

18-19, 2014), at the International Symposium 'Giant Gold Deposits of Central Asia. Strengthening the Gold Potential of Kazakhstan' (Almaty, 2014), at the 13th Conference '13th Biennial SGA Meeting on Sustainable Resources' (Nancy, France, August 24-27, 2015), IX International Conference 'Effective Use of Resources and Environmental Protection - Key Issues for the Development of the Mining and Metallurgical Complex' and the XII International Scientific Conference 'Advanced Technologies, Equipment and Analytical Systems for Materials Science and Nanominerals' (Ust-Kamenogorsk, May 20-23, 2015), at the International Scientific and Practical Conference 'Abishev' readings - 2016 'Innovations in the Complex Processing of Mineral Raw Materials' (Almaty, January 21-22, 2016), at the 6th Russian Youth Scientific and Practical School with international participation 'New in the Knowledge of the Ore Formation Processes', (Moscow, Russia, November 28 - December 2, 2016), at the 38th International Annual Winter Conference 'Mineral Deposits Studies Group' (Ireland, January 4-7, 2016) at the SEG Annual Conference 'Ore Deposits of Asia: China and Beyond Proceedings of International Conference' (Beijing, China, September 17-20, 2017) and at the Satpayev' Readings 'Innovative Solutions of Conventional Problems: Engineering and Technology' (Almaty, April 12, 2018).

Publications. 28 works were published on the topic of the thesis, 7 of them in journals recommended by the Education and Science Control Committee of the MES RK (Bulletin of EKSTU, University Proceedings, Mining Journal of Kazakhstan, Geology and Subsoil Protection); 4 papers in journals included in the Scopus database and the Web of Science Core Collection; one monograph in co-authorship and 16 papers in materials of international scientific conferences of foreign and neighboring countries.