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Research Article

INVESTIGATION OF THE Au/Ag RATIO FOR CHARACTERISTICS OF THE ZONING OF GOLD MINERATION IN ORE ZONE NO. 2 OF THE OKZHETPES ORE FIELD

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ABSTRACT
The article presents the results of a study of the variability of the Au/Ag ratio indicators to identify the vertical and lateral geochemical zonality of gold mineralization. The results of the assay analysis of ores and ore-bearing rocks in five sections were used, 5 samples taking into account samples of all rocks, and 15 samples based on samples of ore zones of the Ore Zone No. 2 ore occurrence. The main industrial gold mineralization is disseminated pyrite-arsenopyrite ores of moderate sulfide formation. A 3- and 4-link vertical zonality and two waves of lateral zonality were revealed.

Keywords: *Au/Ag Ratio, Ore Formation, Gold Deposits, Brachianticline, Oxidation Zone, Assay Analysis, Statistical Sampling, Vertical Geochemical Zoning, Lateral Geochemical Zoning*

INTRODUCTION
Changes in the Au/Ag ratio are considered to be an important geochemical indicator of gold deposits. In many cases, they are used in the classification of ore formations, as one of the signs of the formation belonging of an object or to distinguish certain mineral types within the formations. In some cases, the variability of this indicator is used to identify the zoning of gold mineralization. There are also known cases of using data on the gold-silver ratio to resolve issues of the genesis of deposits as an indicator of the geochemical conditions of ore deposition. When characterizing various deposits, researchers pay attention to two aspects of the Au/Ag ratio: 1) the ratio in ores and ore-bearing rocks separately or in the whole deposit; 2) the ratio in gold minerals (mainly in the series of Au-Ag minerals) or in gold concentrate minerals. In this regard, the works of R.G. Kravtsova, A.S. Makshakov and L.A. Pavlova., N.V. Petrovskaya, T.N. Polyakova, A.G. Pilitsyn and A.A. Kremenetsky., M.S. Sakharova, V.G. Demidov, Z.T. Umarbekova, Sh.V. Khachatryan and O.P. Guyumdzhyan., S. D. Sher and many other researchers of this issue, whose works served as the basis for further research by the authors. Ore occurrence "Ore zone No. 2" located in the northwestern part of the Okzhetpes ore field (western end of the Bukantau ridge) where disseminated pyrite-arsenopyrite ores of moderate sulfide formation are developed was chosen as the object of research. The purpose of the research was to identify the vertical and lateral geochemical zonality of gold mineralization at the ore occurrence. Brief geological description of the ore occurrence "Ore zone No. 2" Ore occurrence "Ore zone No. 2" is located in the northwestern part of the Okzhetpes ore field and is confined to the southwestern wing of the brachianticline of the same name. The axis of this structure is oriented in the northwest direction. The core of the brachianticline is composed of Middle-Upper Devonian (D2-3) limestones, and its wings are composed of Lower Carboniferous deposits (massive and middle-layered limestones) and undivided C_{2-3} deposits, represented by sandstones, gravelstones, conglomerates with interlayers of siliceous rocks and limestones (Tangirov, 2019). The limbs of the brachianticline are complicated by high-order folding and numerous tectonic faults of northeastern, northwestern, and sublatitudinal strike. The morphology of the mineralized zone is complicated by disturbances, in connection with which flexure-like inflections are observed along the strike from sublatitudinal to northwestern (azimuth 300-320°). The thickness is from 10 to 50 m, the dipping of the zones

is steep to the southwest, and in some places almost vertical. Up to a depth of 90-100m from the surface, an oxidation zone is developed. Ores and ore-bearing rocks are colored brown by iron hydroxides. The host rocks are represented by dolomites and limestones with sulfide mineralization (Fig. 1). Intrusive formations are represented by dikes of dioritic porphyrites and granodiorites. The main industrial gold ore mineralization is disseminated pyrite-arsenopyrite ores of moderate sulfide formation, characteristic of the neighboring Kokpatas ore field, as well as areas of Dzhelsay, Boztau, Karatag, Karatas, Telketau, Bakhtli and others (Tangirov A.I. 2019).

MATERIALS AND METHODS

To identify the vertical and lateral geochemical zonality of gold mineralization at the ore occurrence, a statistical analysis of data on 1960 core samples from 28 core boreholes and 1152 mud samples from 48 cone boreholes was performed. In this case, the results of assay analysis of ores and ore-bearing rocks in five sections were used. 5 samples were studied, taking into account samples for all rocks, and 15 samples for samples of ore zones (Fig. 2). The obtained results were also compared with the data of other researchers on various gold deposits of the world.

RESULTS

Statistical analysis of the variability of the Au/Ag ratio along section I-I using data from 9 wells showed the following

On the horizon from +200 to +273, the highest Au/Ag ratio was 164 and the lowest was 0.021, with an average value of 7.50. Indicators above the average value are noted on the horizons: 266-273; 238-250; 222-232; 212-216. And on horizons 232-236; 214-224; 204-212 there are indicators below the average value. (Fig. 2) (Table No. 1).

On the horizon from +150 to +200, the highest value of the Au/Ag ratio was 4.0 and the lowest was 0.03, with an average value of 1.14. Indicators above the average value are marked on horizons: 192-197; 186-188; 174-182. And on horizons 184-188; 172-176; 168-170 are marked indicators below the average value. (Fig. 2) (Table No. 1).

For the Northern ore zone, the variability of indicators was estimated at two horizons.

On the horizon from +200 to +248, the highest value of the Au/Ag ratio was 54, and the lowest was 0.0001, with an average value of 7.0. Indicators above the average value are noted on the horizons: 244-246; 232-240; 222-226. And on horizons 246-248; 240-244; 226-232; 218-222; 200-202 there are indicators below the average value (Fig. 3) (Table No. 2).

On the horizon from +150 to +200, the highest value of the Au/Ag ratio was 32, and the lowest was 0.001, with an average value of 3.0. Indicators above the average value are marked on the horizon 196-198. And on horizons 192-194 and 164-166, indicators are below the average value (Fig. 3) (Table No. 2).

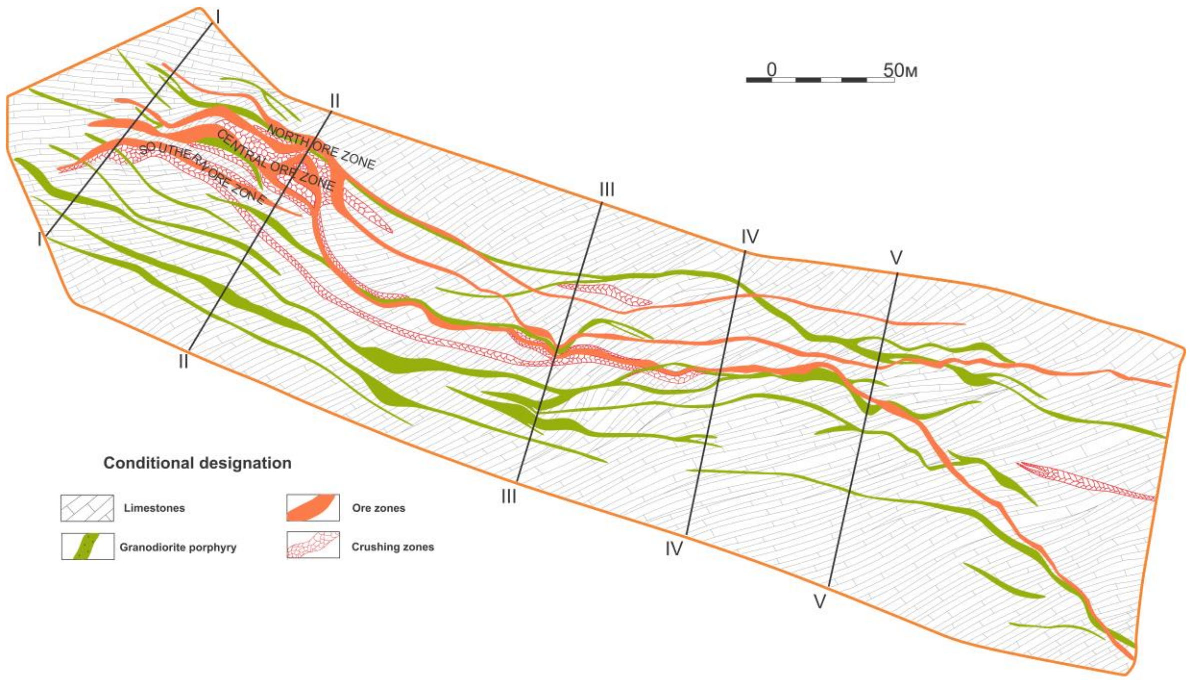
In the Central ore zone, the variability of indicators was also estimated at two horizons.

On the horizon from +200 to +248, the highest value of the Au/Ag ratio was 28, and the lowest was 0.0003, with an average value of 3.64. Indicators above the average value are noted on the horizons: 240-244; 226-230. And on horizons 246-248; 234-240; 224-226; 202-206 there are indicators below the average value. (Fig. 3) (Table No. 2).

On the horizon from +170 to +200, the highest value of the Au/Ag ratio was 0.04 and the lowest was 0.0005, with an average value of 0.012. Throughout the horizon, there are even indicators at the level of the average value. Only on the horizon 197-200 there are indicators below the average value. (Fig. 3) (Table No. 2).

For the Southern ore zone, the variability of indicators was estimated at two horizons.

On the horizon from +200 to +248, the highest value of the Au/Ag ratio was 64, and the lowest was 0.001, with an average value of 8.23. Indicators above the average value are noted on the horizons: 244-248; 242-244. And on horizons 236-242; 226-232; 206-212; 200-204, there are indicators below the average value (Fig. 3).



Picture 1: Schematic geological map of the Ore Zone No. 2 ore occurrence

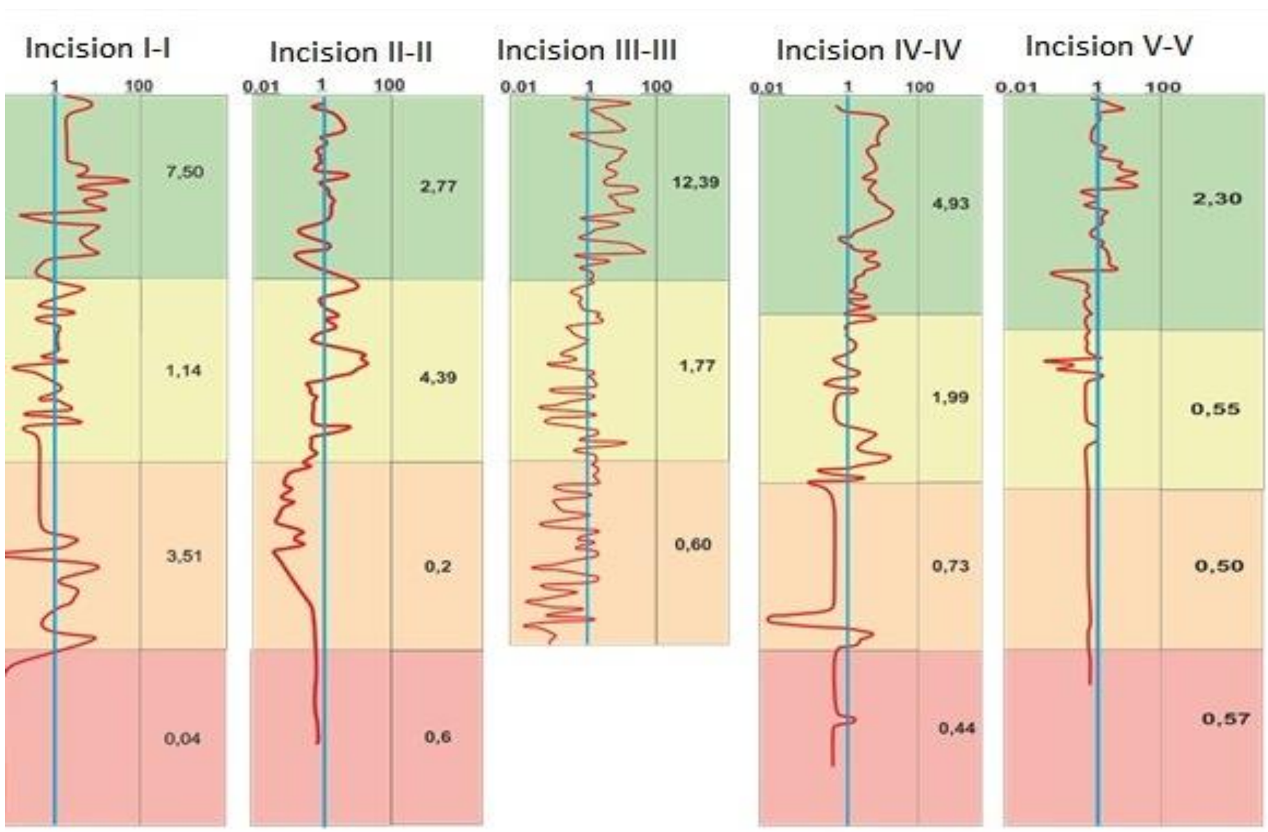


Figure 2: Changes in the Au/Ag ratio along the vertical in ore-bearing rocks along the sections of the ore occurrence "Ore zone No. 2

On the horizon from +190 to +200, the highest Au/Ag ratio was 0.1 and the lowest was 0.003, with an average value of 0.014. Indicators above the average value are marked on the horizon 196-198. And on horizons 198-200 and 194-196, indicators are below the average value (Fig. 3) (Table No. 2).

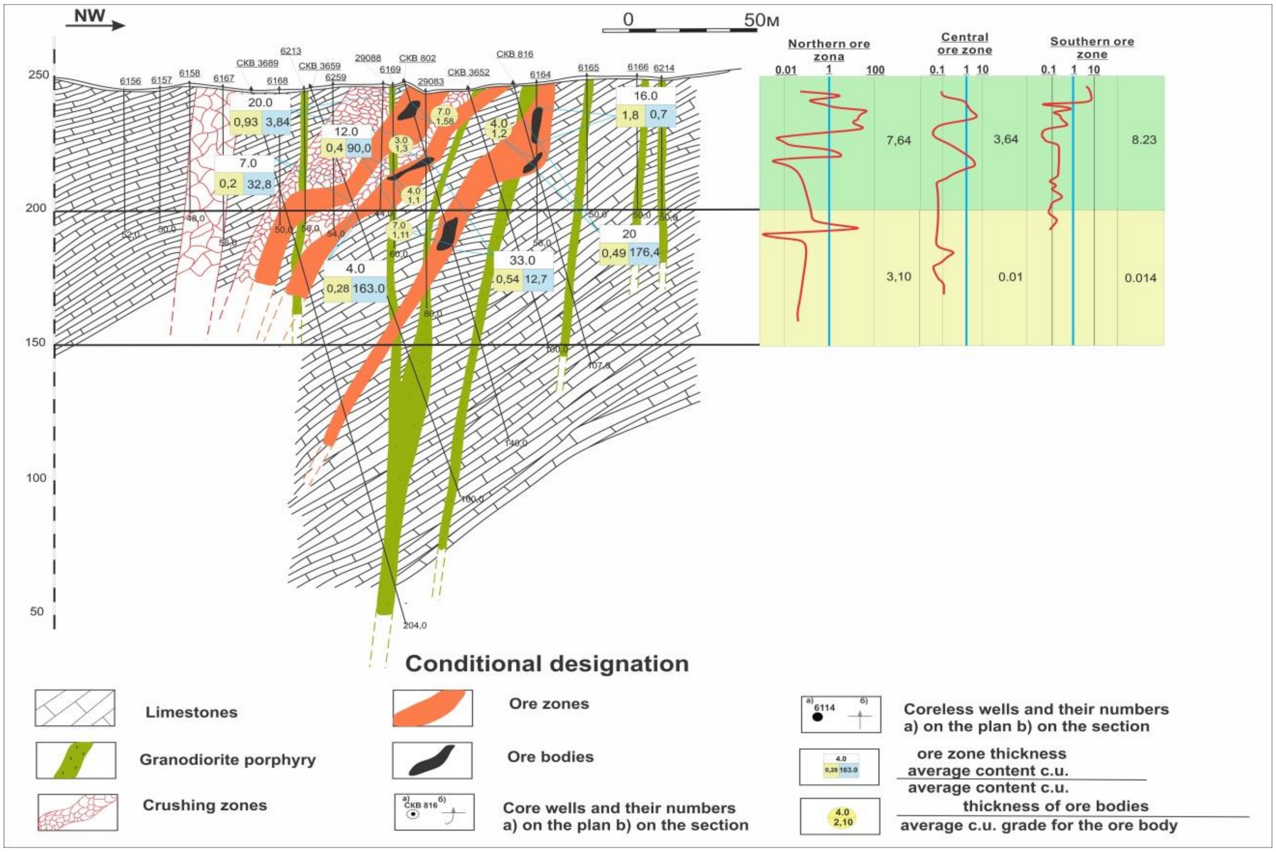


Figure 3: Schematic geological section I-I. Changes in the Au/Ag ratio for the "Northern", "Central" and "Southern" ore zones in the alignment section I-I.

Statistical analysis of the variability of the Au/Ag ratio along section II-II using data from 11 wells showed the following.

On the horizon from +200 to +260, the highest value of the Au/Ag ratio was 112, and the lowest was 0.011, with an average value of 13.96. Indicators above the average value are noted on the horizons: 250-246; 238-242; 208-214; 200-206. And on horizons 258-252; 224-234; 213-216 there are indicators below the average value (Fig. 2) (Table No. 1).

On the horizon from +150 to +200, the highest value of the Au/Ag ratio was 112 and the lowest was 0.2, with an average value of 36.05. Indicators above the average value are noted on the horizons: 196-200; 186-192. And on horizons 194-196, indicators below the average value are noted (Fig. 2) (Table No. 1).

On the horizon from +100 to +150, the highest value of the Au/Ag ratio was 0.2, and the lowest was 0.01, with an average value of 0.114. On the horizon 130-136, there are indicators below the average value (Fig. 2) (Table No. 1).

For the same section, the Au/Ag ratios studied in separate samples compiled for the Northern and Central ore zones showed the following.

For the Northern ore zone, the variability of indicators was estimated at two horizons.

On the horizon from +200 to +238, the highest value of the Au/Ag ratio was 26.8, and the lowest was 0.03, with an average value of 3.92. Indicators above the average value are marked on the horizons: 234-228. And on horizons 234-238; 208-214; there are indicators below the average value (Fig. 4) (Table No. 2).

On the horizon from +164 to +200, the highest value of the Au/Ag ratio was 0.6, and the lowest was 0.04, with an average value of 0.24. On the horizon 164-168, there are indicators below the average value (Fig. 4) (Table No. 2).

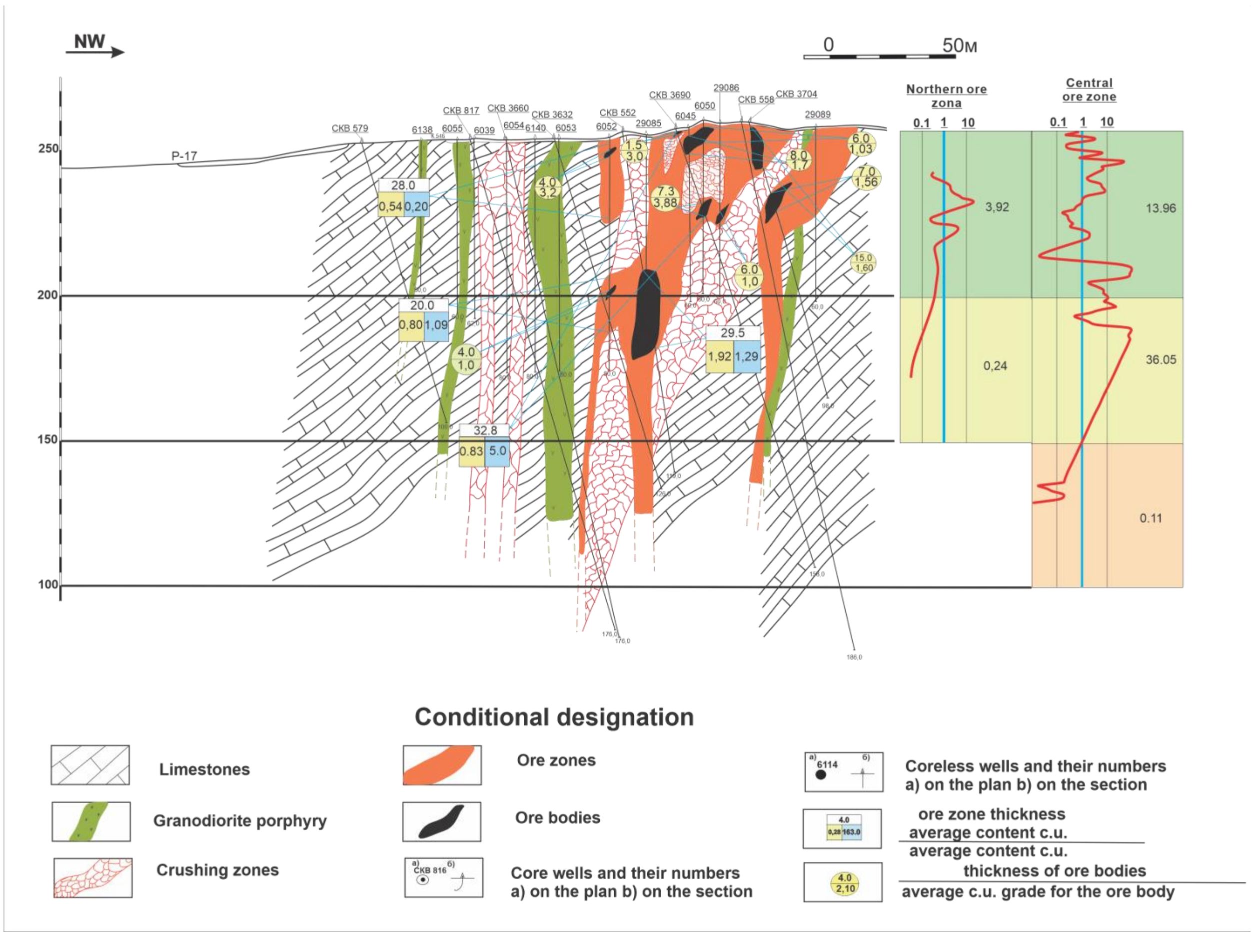


Figure 4: Schematic geological section II - II. Changes in the Au/Ag ratio in the "Northern" and "Central" ore zones in the alignment section II - II.

In the Central ore zone, the variability of indicators was also estimated at two horizons.

On the horizon from +200 to +260, the highest value of the Au/Ag ratio was 112, and the lowest was 0.011, with an average value of 13.96. Indicators above the average value are noted on the horizons: 242-250; 236-242; 200-212. And on horizons 252-258; 224-230; 212-216 there are indicators below the average value (Fig. 4) (Table No. 2).

On the horizon from +186 to +200, the highest Au/Ag ratio was 112 and the lowest was 0.2, with an average value of 36.06. Indicators above the average value are noted on the horizons: 196-200; 186-192. And on horizons 192-196, indicators are below the average.

On the horizon from +100 to +150, the highest value of the Au/Ag ratio was 0.2, and the lowest was 0.01, with an average value of 0.114. On the horizon 130-136, there are indicators below the average value (Fig. 4) (Table No. 2).

Table 1: Average values of Au/Ag ratio at various depths of ore occurrence "Ore Zone No. 2"

Depth level (Absolute marks)	Incision I-I	Incision II-II	Incision III-III	Incision IV-IV	Incision V-V
above +200	7,5	2,77	12,4	4,93	3.0
from +150 to +200	1,14	4,4	1,77	2.0	0,55
from +100 to +150	3,51	0,2	0,6	0,73	0,5
from +50 to +100	0,04	0,6		0,44	0,57

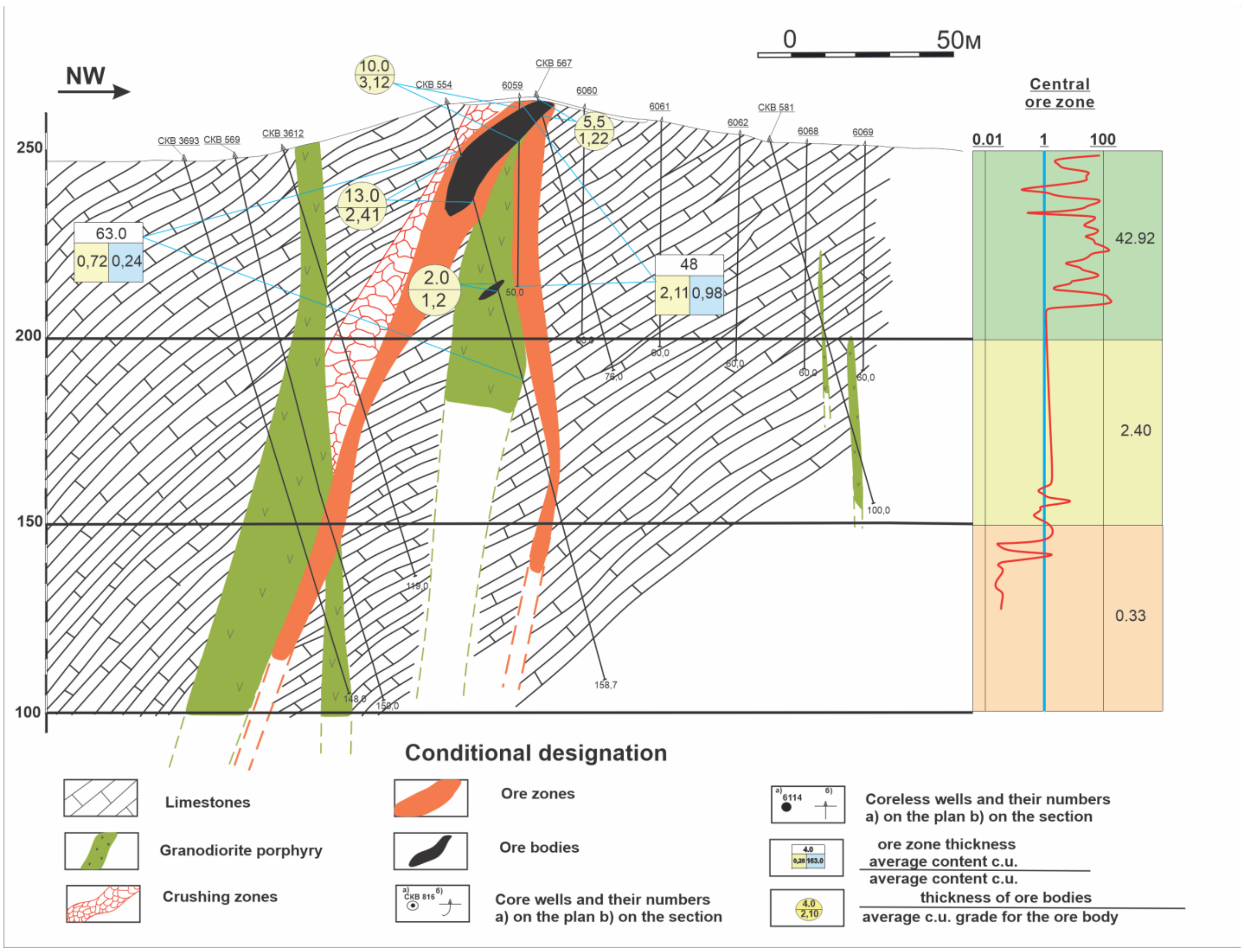


Fig.5. Schematic geological section III - III. Changes in the Au/Ag ratio by "Central" ore zone in section III - III

Statistical analysis of the variability of the Au/Ag ratio along section III - III using data from 9 wells showed the following.

On the horizon from +200 to +263, the highest value of the Au/Ag ratio was 104, and the lowest was 0.01, with an average value of 42.92. Indicators above the average value are noted on the horizons: 252-260; 228-248; 214-224. And on horizons 260-263; 208-214; 200-208 there are indicators below the average value (Fig. 5) (Table No. 1).

On the horizon from +150 to +200, the highest value of the Au/Ag ratio was 32 and the lowest was 0.01, with an average value of 1.77. Indicators above the average value are noted on the horizons: 194-200; 174-178; 150-156. And on horizons 180-194; 158-174 there are indicators below the average value (Fig. 5) (Table No. 1).
On the horizon from +100 to +150, the highest value of the Au/Ag ratio was 2, and the lowest was 0.0078, with an average value of 0.60. Indicators above the average value are noted on the horizons: 148-150; 124-132; 116-120. And on horizons 134-146; 120-124; 100-116 there are indicators below the average value (Fig. 5) (Table No. 1).
For the same section, the Au/Ag ratios studied for individual samples compiled for the Central ore zones showed the following.
In the Central ore zone, the variability of indicators was also estimated at two horizons.
On the horizon from +200 to +263, the highest value of the Au/Ag ratio was 190, and the lowest was 0.04, with an average value of 42.92. Indicators above the average value are marked on the horizons: 216-263. And on horizons 238-240, indicators below the average value are noted (Fig. 5) (Table No. 2).
On the horizon from +150 to +164, the highest value of the Au/Ag ratio was 16.02 and the lowest was 0.07, with an average value of 2.40. Indicators above the average value are noted on the horizons: 158-164; 150-152. And on horizons 152-158, there are indicators below the average value (Fig. 5) (Table No. 2).
On the horizon from +131 to +150, the highest value of the Au/Ag ratio was 2, and the lowest was 0.02, with an average value of 0.33. Indicators above the average value are marked on the horizons: 146-148. And on horizons 128-146, indicators below the average value are noted (Fig. 5) (Table No. 2).
Similar results were obtained for sections IV-IV and V-V (Table 2)
Figure 2 and tables 1 and 2 also show the lateral zonality of mineralization distribution. At different depth horizons, the highest values are observed in sections I-I and III-III or II-II and IV-IV, respectively.

Table 2: Average values of Au/Ag ratio for ore zones of ore occurrence "Ore zone No. 2"

Depth level (abs. marks)	**Incision I-I**			**Incision II - II**		**Incision III - III**	**Incision IV - IV**	**Incision V-V**
	Northern ore zone	**Central ore zone**	**Southern ore zone**	**Northern ore zone**	**Central ore zone**	**Central ore zone**	**Central ore zone**	**Central ore zone**
above +200	7,64	3,64	8,23	3,92	13,96	42,92	35,68	16,34
from +150 to +200	3,1	0,013	0,014	0,244	36,05	2,4		0,28
from +100 to +150					0,11	0,33		0,04
from +50 to +100								0,08

RESULTS

The obtained results show that at the Ore Zone No. 2 ore occurrence, a vertical and lateral zonality of the distribution of gold and silver is observed. In general, according to the results of statistical analysis for all five sections, two main vertical zones are clearly distinguished, these are the zone of oxidation and the zone of primary ores. In addition to the two main zones of vertical zonality, 2 to 4 waves of changes in the Au/Ag ratio are observed in different sections, which, in our opinion, are associated with specific mineralogical and petrographic characteristics of ore-bearing rocks.

DISCUSSION

In the Witwatersrand deposit, R. B. Hargraves (1963) pointed out the significant role of the redistribution of matter after its deposition, according to the study of the ratio of silver to gold in conglomerates. As a result of the statistical processing of the silver content in "schlich" gold mined from conglomerates, he notes an inverse relationship between the silver content in gold pieces and their size, which sharply contradicts a similar relationship in placers. In addition, there is a decrease in the content of silver in gold with depth in all layers of conglomerates, as well as the dependence of the Ag:Au ratio on the structural position of the layers. In younger layers of conglomerates, compared to the underlying ones, the silver content of gold increases, which also contradicts the assumptions about its mechanical redeposition from layer to layer (Sher C.D., 1974).

Reh (Reh, 1964) (Sher C.D., 1974) also came to the conclusion about the primary sedimentary genesis and subsequent redeposition of gold in the Witwatersrand based on the study of the gold–silver ratio in ores. According to M.S. Sakharova and V.G. Demidov, at the Darasun deposit located within the gold-molybdenum belt of Transbaikalia, where gold mineralization of the hydrothermal type is represented by a series of quartz-sulfide veins, it was noted that the Ag/Au values in the altered rocks are higher than in ore bodies. Thus, in altered rocks, the average value of Ag/Au is 4.0 i.e. 2.6 times higher than the average value for ore veins. For individual areas and depths in altered rocks, Ag/Au is 1.5-6 times higher than the average value of this indicator for ore veins (Fatyanov, 2010, Khomich, 2010, Boriskina, 2010).

It is also noted that in the vertical section of ore veins, the Ag/Au ratio changes with depth, reaching a minimum at medium depths of ore veins—in the zone of maximum ore productivity and again increasing at greater depths (Sakharova and Demidov, 1972).

According to G.A. Yurgenson, at the Baleisko-Taseevsky shallow gold-silver deposit, the ratio of gold to silver within the ore columns ranges from 1:2 to 3:1, averaging 1.5:2.1. Outside the enriched areas, ratios of 1:2 - 1:4 prevail (Yurgenson, 2015).

In a general summary of the volcanogenic gold-silver deposits of the Amur region, A.E. Perestoronin and V.A. Stepanov note that the average Au/Ag ratio at the Pokrovskoye deposit ranges from 1:0.8 to 1:3. In the Molodezhnoye ore body, it reaches 1:10 with fluctuations in individual samples from 1:0.3 to 1:108. At the Burinda deposit, the Au/Ag ratio ranges from 1:3 to 1:9, averaging 1:5 (Perestoronin, 2016).

According to Khachatryan and Guyumdzhyan, at the Phrut ore occurrence of a poor sulfide quartz-gold ore formation, opposite trends in the distribution of gold and silver are clearly visible in their quantitative ratios. In ores of quartz and quartz-pyrite associations (i.e., in ores of the lower horizons), low values of Ag/Au (0.8-8.1) are established, which increase sharply in polymetallic ores (100), in the upper horizons of the deposit. This trend is due to the Ag/Au ratio in the main ore-forming minerals, which is 1.5–9.3 for pyrite and sharply increases in sphalerite (418) and galena (3500). Thus, there is a tendency for Au to accumulate in relatively higher-temperature ores and minerals, and for Ag in low-temperature ones (Khachatryan, 2017; and Guyumdzhyan, 2017).

CONCLUSIONS

According to the materials of individual sections, with a certain degree of conventionality, two waves of lateral zonality can be distinguished. The maximum Au/Ag ratios are observed at depths up to 50 m (along section II-II up to 100 m) from the surface. This may be due to the influence of hypergenesis processes in the oxidation zone, where the migration ability of silver is much greater than that of gold. Thus, 3- and 4-link vertical zoning and two waves of lateral zoning were revealed at the Ore Zone No. 2 ore occurrence.

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