SPACE REGULARITIES AND STRUCTURAL CONTROL IN THE GOLD-SILVER EPITHERMAL ORE-FORMING SYSTEMS (MULTI-LEVEL PROGNOSTIC MODELS, NORTHEAST RUSSIA)

M.M. Konstantinov, S.F. Strujkov (Central Research Institute of Geological Prospecting for Base and Precious Metals, TSNIGRI, 129B Varshavskoye shosse, Moscow, 113545, Russia)

ABSTRACT

A system of interrelated models is an efficient tool in exploration and evaluation of potential mineral deposits. This system consists of six levels: mining district, ore knot, mining field, mineral deposit, ore body, and ore shoot. The mining districts in Northeast Russia are generally volcanic-tectonic depressions controlled by regional faults that run orthogonal to the trend of the volcanic belt and exhibit a constant distance ("step") between them of about 250 km. Ore knots lie along the regional faults and have a step of 55-60 km. Main elements of the model are volcanic depressions and domes in combination with ore-controlling sections of regional, bow-shaped, magma-ore supplying faults. Mining fields occur at crossings and conjugations of these faults with a "step" of about 10 km. The mining district has a variety of mining fields: A - in the volcanic-intrusive dome; B - above the subvolcanic body; C - in exo-contacts of the granodiorite intrusion. The A-type model consists of a concealed granitoid massif, large subvolcanic body with a set of small subvolcanic and extrusive bodies, and volcanic vents and flows. The mineral deposit is restricted to the lower block on the slope of the dome that has a maximum width and variety of volcanic rock facies and propylitic alterations. The model of the B-type is controlled by an anticlinal fold in volcanic-sedimentary rocks above a gently-sloping subvolcanic body. The deposit is located near the anticlinal axis in quartz-chlorite-hydromica altered rocks. The C-type model consists of terrigenous (or volcanic) strata intruded by a granodiorite massive. The deposit is located in the tectonic block of rocks with sericite-chlorite-quartz alterations above the intrusion's roof.

As a rule, all of the above-mentioned deposit types comprise several complex groups of ore bodies ("bunches"). A "step" between the groups is about 800 m. The ore bodies are controlled by normal faults and fractures (or by bedding faults), forming veins, vein zones, and mineralized zones (or "mantos") with ore shoots. The ore shoots are located in structural traps and have a high proportion of vapor-dominated micro-inclusions with CO_2. The ore shoots (and ore bodies within the bunches) have a "step" of 150-300 m between them. The authors propose that in each case, the length of a "step" correlates with the depth of an assumed main or intermediate ore-magmatic (energy) chamber, responsible for the development of this particular level: 1) for mining district - in the upper mantle; 2) for ore knot - near the border of the crust at a depth of about 55-60 km; 3) for mining field - near the border between Mesozoic and Paleozoic basement of the volcanic belt at a depth of about 10 km; 4) for bunches of ore bodies - near the basement of the volcanic-tectonic depressions - at about 800 m depth. This empiric statistical rule may be used in the prediction of gold-silver epithermal deposits in volcanic belts.

INTRODUCTION

A system of interrelated models is an efficient tool in exploration and evaluation of the potential of mineral deposits. The concept of an "ore step" (a constant, regularly repeated distance between various model elements), is one of the most important features of the prediction. The problem of "ore steps" has been discussed often in the geological literature in examples of base and precious metal deposits (Kutina, 1971; Baryshev, 1990; Vikhter, 1990; and Strujkov et al., 1990). However, for different reasons, the ore "step" rule has not been widely used for prediction of gold deposits. One of the reasons was the absence of a systematic approach. In the past, investigators often paid attention to the regularities of some ore knots, deposits, or ore shoot distribution, in other words, to the individual elements of the geological models. Very little progress has been made in attempting to compare elements of different rank models, as well as, equal rank elements belonging to different systems (for example, an attempt to identify the "step" between mining fields located in different mining districts). Also, in real conditions, the ore "step" is usually broken by pre-ore and post-ore faults and may be irregular due to lithological inhomogeneity of the host rocks. Therefore, the ore "step" between ore bodies in various deposits commonly differs from the "ideal" one. In this connection, the use of the ore "step" in prediction models demands a statistical approach.

The ore "step" is a universal regularity in different ranks of metallogenic taxons and the present study exemplifies this regularity in the gold-silver epithermal deposits of Northeast Russia. The following metallogenic taxons were used in the analysis: ore-bearing province - mining district - ore knot - mining field - and ore deposit. In this metallogenic system, each higher unit of this scheme usually includes several lower units with relatively barren space between them. The ore-bearing provinces are large regions of the Earths crust (tens of thousands of sq.km), corresponding to fold systems or volcanic-plutonic belts that comprise a series of metallogenic formations. Mining districts represent large (thousands of sq. km) ore-bearing areas, linked to megablock structures. Ore knots are ore-bearing areas (hundreds of sq. km), which are long-lived tectonic-magmatic systems. Mining fields (tens of sq. km) contain associated mineral deposits and occurrences, with a single structural control, mineral composition, and origin.

RESEARCH METHODS

This present paper is based on a broad statistical database for 7 mining districts, 22 ore knots and 180 mining fields and potential areas of Northeast Russia. The research method was developed during many years of study by the authors using a wide literature base of published data (Konstantinov et al, 1992). An objective of these studies was to create generalized images (models) of the different ranks of ore mineralization and to analyze the geometric regularities of their distribution.

RESULTS OF INVESTIGATION

Model of the Ore-Bearing Province

The ore-bearing province of gold-silver epithermal ore mineralization is represented by the Okhotsk-Chukchi volcanic-plutonic belt (OCVPB) and the adjoining so-called perivolcanic zone, which comprise a region of connected subvolcanic bodies and dikes (Bely, 1977 and Sidorov et al., 1989). Mining districts can be predicted in the ore-bearing province. Their distribution is controlled by submeridional (orthogonal to the volcanic belt) regional faults (Konstantinov et al., 1993). Such faults may be boundaries of autonomous tectonic blocks and often display horizontal offset. Along these faults, volcanites of calc-alkaline and anatectic rhyolitic formations penetrate far inland. Mining districts lie along the volcanic belt with a "step" (distance between them) of about 250 km. This regularity is illustrated in the scheme of mining district distribution (Fig. 1). The following known mining districts are located in 250 ($\pm$25) km distance increments from one another (west to east): Burgagylkansky, Karamkensky (Karamken and Agatovskoye deposits), Ducatsky (Arylah, Lunny, Mechta, Tydid, Ducat, Goltsovy, and Primorskoye deposits), and Evensky (Start, Dalneye, and Kubaka deposits).

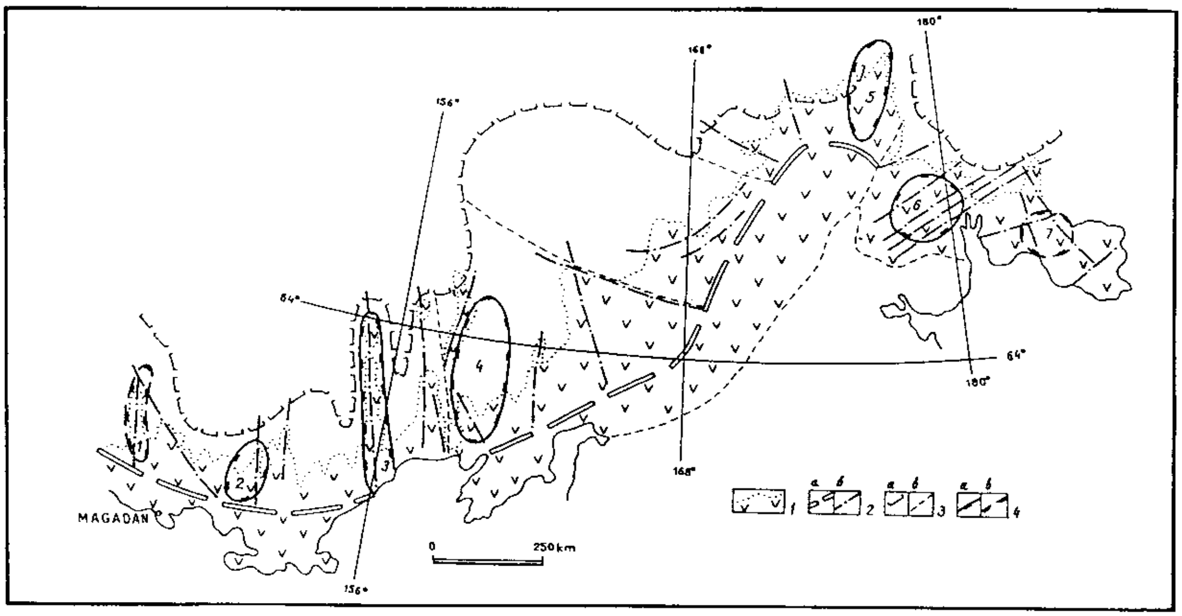


Fig.1. Scheme of the main mining districts location in the Okhotsk-Chuckchi volcanic-plutonic belt (OCVPB)
1 - volcanic rock; 2a - Major fault of the OCVPB (border of the inner and outer zones), 2b - other faults; 3a - border of the perivolcanic zone of the OCVPB, 3b-border of the subzones of the OCVPB; 4 - contour of: 4a - mining district, 4b - potential mining district. Arabic numerals mark following mining districts: 1 - Burgagylkansky, 2 - Karamkensky, 3 - Ducatsky, 4 - Evensky, 5 - Maysky, 6 - Verhne-Amguemsky, 7 - Erguveemsky

In poorly studied regions, where all of the ore objects are not yet known, the distance between the neighboring ore objects may not be equal to the ore "step", but approximately several times more (divisible by the length of one ore "step"). For example, it may be proposed that there could be an occurrence of two missed potential mining districts in the very poorly studied part of the OCVPB to the east of the Evensky mining district. At a distance of three "steps" from the Evensky mining district, lies the Maysky mining district, including the Mayskoye and Sopka Rudnaya deposits and some other prospective areas.

Adding 225 km to the east from the Maysky mining district, we match up with the Verkhne-Amguemsky mining district (Valunistoye deposit). At the next "step" from the Verkhne-Amguemsky mining district, lies the Erguveemsky potential mining district. It is remarkable that a number of smaller deposits between these mining districts (Nyavlenga and Julietta) are regularly spaced at distances equal to 1/2 or 1/4 of the "step".

The lower boundary of the asthenosphere occurs at a depth of 250-300 km (Gutenberg, 1959 and Magnitsky and Jarkov, 1970). The "step" between the mining districts presumably correlates with the depth of the ore-magmatic chamber in the upper mantle at the lower asthenospheric boundary, and the chamber is responsible for origin of the mining district.

Model of the Mining District

The mining districts, considered here, represent large, commonly elongated volcanic-tectonic depressions. A cyclic repetition of effusive/intrusive assemblages of felsic and intermediate rocks, changed by deposition of molasses, is widespread in the mining districts. Ore knots can be predicted and should occur in mining districts.

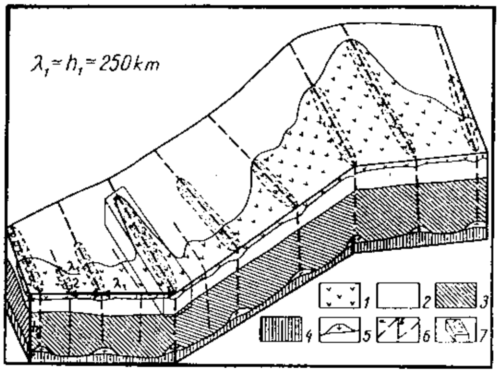


Fig.2. Model of the Russian part of the Pacific volcanic-plutonic belt (block-diagram)
1 - volcanic-plutonic belt; 2 - crystal (metamorphic) basement + PZ & MZ marine terrigenous formations; 3 - astenosphere; 4 - upper mantle; 5 - mantle chamber; 6 - regional faults, orthogonal to the volcanic belt: a) major, b) minor; 7 - mining district and borders of the next model.

Ore knots usually represent smaller isometric volcanic-tectonic depressions, consistent with the ore-magmatic chamber structure. In the model, these depressions have a semicircular shape, bordered by a linear fault from one side and by a bow-shaped fault from the other side. The central part of the depressions is made up of molasses sediments and the periphery consists of felsic volcanics. The centers of the volcanic eruptions and subvolcanic bodies occur in the periphery of the depressions and trace the bow-shaped faults. The ore knots lie along the same regional faults, which control the mining district, with a "step" of about 55-60 km. A good illustration of this geometry is a sketch map of the Ducatsky mining district (Fig. 3), where the "step" corresponds to a distance between the Goltsovsky, Ducatsky and Arylahsky ore knots. In the northern part of the Ducatsky mining district, the post-ore fault "broke" the "step" and offset the next potential ore knot (Nyagainsky) after the Arylahsky ore knot. For example, the distance between the Karamkensky and Agatovsky ore knots (100 km) in the Karamkensky mining district and between Kubakinsky and Evensky ore knots (130 km) in the Kubakinsky mining district, are roughly divisible by the same "step".

Based on seismic and gravimetric data (Belyaev, 1970), the depth of the crust is about 40-50 km in the studied region. The "step" between the ore knots (Fig. 4) may, therefore, correspond to the depth of the intermediate ore-magmatic chamber occurring near the Mohorovich boundary.

Model of the Ore Knot

Main elements of this model (Fig. 5) are local volcanic-tectonic domes and depressions, combined with ore-controlling intervals of the regional faults and bow-shaped magma and ore-supplying faults (Strujkov et al, 1990). Mining fields can be predicted in ore knots. Mining fields occur at intersections and conjugations of these faults with a "step" of about 10 km (Fig. 5). Vacant or "empty" fault intersections are especially prospective for new discoveries. This proposition proved true in the author's work experience in the Arylahsky ore knot. In this area, a new gold-silver occurrence was first predicted, and then confirmed by trenching and drilling (Zeleny prospect).

Most of the mining fields in similar position, should be considered for exploration. However, not all of the mining fields comprise economic deposits. The "step" may be exemplified by the Mechtinskoye, Tydidskoye, Krasinskoye and Ducatskoye mining fields in the Ducatsky ore knot, and also by the Lunnoye and Arylahskoye mining fields in Arylahsky ore knot (Fig. 3).

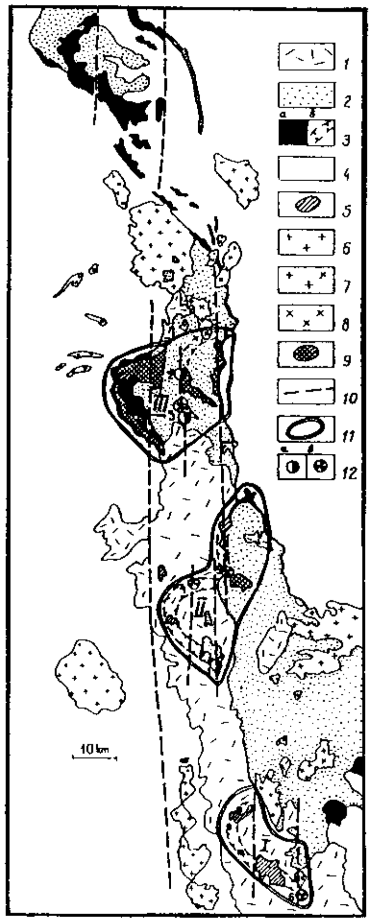
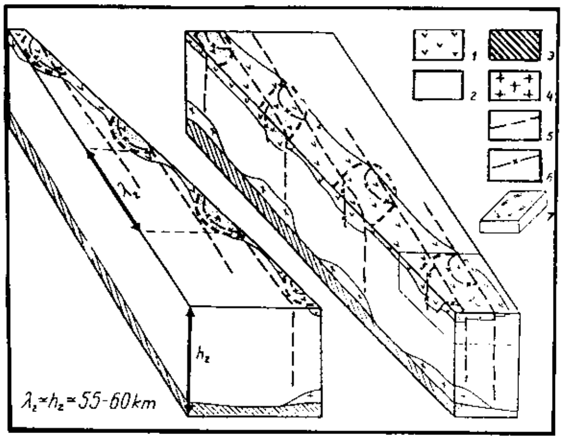


Fig.3. Geological sketch map of the Ducatsky mining district →
1 - Upper Cretaceous felsic and intermediate volcanites; 2 - Lower Cretaceous terrigenous carboniferous rock; 3a - Early Cretaceous felsic volcanites, 3b - contour of the assumed peripherical bow-shaped magma-ore supplying fault; 4 - terrigenous rock of Verkhoyansk complex (Trias-Jura); 5 - Late Cretaceous felsic subvolcanic body; 6 - Late Cretaceous granite; 7 - Late Cretaceous granodiorite; 8 - Early-Late Cretaceous granodiorite; 9 - Early-Late Cretaceous diorite; 10 - Early Cretaceous felsic subvolcanic body; 11 - ore-controlling fault; 12 - boundary of the ore knot; 13 - mining fields: a - gold-silver, b - silver-lead-zinc & tin-silver. Latin numerals mark the following ore knots: I-Arylakhsky, II-Ducatsky, III-Goltsovsky; arabic numerals mark the following mining fields: 1 - Ducat, 2 - Arylakh, 3 - Lunny, 4 - Mechta & Maly Can, 5 - Tydid, 6 - Goltsovy.



← Fig.4. Model of the mining district (block-diagram)
1- volcanogenic & sedimentary fulfillment of the depression; 2 - crystal (metamorphic) basement + PZ & MZ marine terrigenous formations; 3 - astenosphere; 4 - chamber at the border of earth crust and upper mantle; 5 - sections of the regional fault; 6 - bow-shaped faults; 7 - ore knot and borders of the next model.

Geological data suggest that the border between the Verkhoyansky complex (P-J) and older metamorphic rocks, occurs at a depth of 10 km. Geologic, seismic, and gravimetric data indicate a complex granitoid, sill-like pluton, and possibly an ore-magmatic chamber (Shashkin, 1984) at this depth. Therefore, the "step" of 10 km between the mining fields may correspond to the depth of the intermediate chamber responsible for their formation at the boundary between the Verkhoyansky complex (P-J) and older metamorphic rocks.

Models of the Mining Fields

Our studies show that the mining fields model can be classified into three major types: A - in volcanic-intrusive domes; B - above a felsic subvolcanic body; and C - in the exo-contacts of a granodioritic intrusion (Konstantinov et al., 1993). The A-type model (Ducat, Tydid, Mechta deposits) consists of a buried granitoid massif, large subvolcanic body framed by small subvolcanic and vent bodies, and lava flows. In this model, the deposit occurs in the descended block at the slope of the volcanic-intrusive dome and is characterized by the maximum width and diverse lithology of the host volcanics, and by low-temperature propylitic alterations.

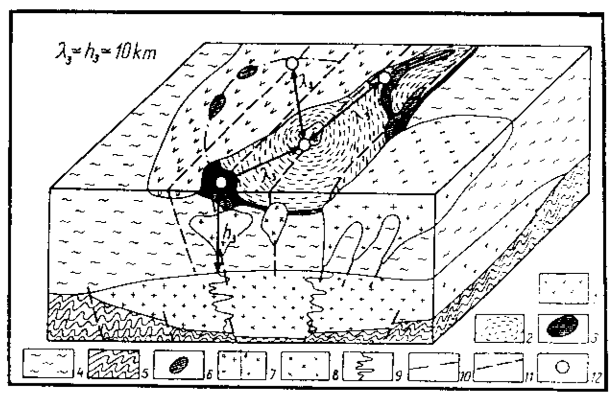


Fig.5. Model of the ore knot (block-diagram)
1 - Upper Cretaceous rhyolite & Upper-Lower Cretaceous andesite formations; 2 - Lower Cretaceous molasses formation; 3 - Lower Cretaceous rhyolite formation; 4 - Triassic-Jurassic marine terrigenous formation; 5 - PZ basement; 6 - Late Cretaceous felsic subvolcanic bodies; 7a - granodiorite, 7b - granite; 8 - diorite; 9 - zone of the transition from mafic to felsic magma in the chamber (after V.M.Shashkin, 1984); 10 - bow-shaped magma-ore supplying faults; 11 - ore-controlling sections of the regional faults; 12 - mining fields and borders of the next model.

The B-type model (Arylah deposit) is controlled by an anticlinal fold in the volcanic-sedimentary rocks overlying a gently-sloping felsic subvolcanic body. The deposit occurs at the axis of the fold and is characterized by quartz-chlorite-hydromica metasomatic alterations. The C-type model (Lunny deposit) is a sequence of the terrigenous or volcanic rocks cut by a granodiorite massif. The deposit occurs in a tectonic block with sericite-chlorite-quartz hydrothermal alterations near the top part of the granodiorite massif.

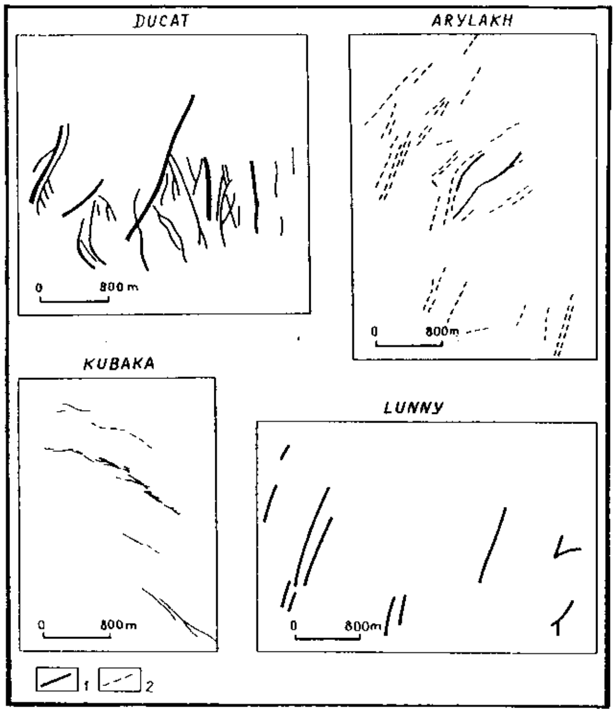


Fig.6. Bunches of orebodies distribution at gold-silver mining fields (plan)
1 - orebody with high gold and (or) silver grade; 2 - sub-economic orebody.

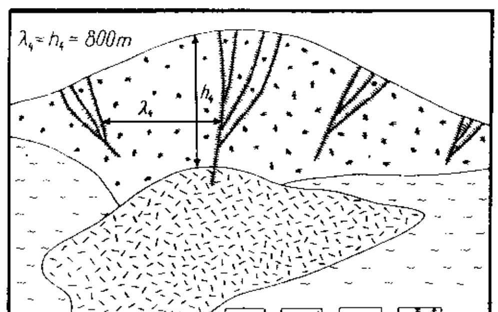
Ore deposits can be predicted in the mining fields. However, the term "ore deposit" is often considered only in the economic sense and its geological implication may be ambiguous. For example, in the Kubakinskoye mining field, a separate Severnaya ore zone (a bunch of ore bodies) is considered as an individual deposit, and in the Ducatskoye mining field, all of the ore bodies are considered like a deposit. Then, aiming at the comparison of the same rank units, we define a deposit as a "bunch of ore bodies" and the target of the prediction in the mining field. With this approach, it is easy to see that there is a "step" averaging 800 m between "bunches of ore bodies" in most of the mining fields (Fig. 6). The picture is so constant for the largest bunches of ore bodies, that it seems possible to explore the mining fields of the same type by a standard grid of trenches. However, smaller bunches often occur at a distance of 1/2 of a "step".

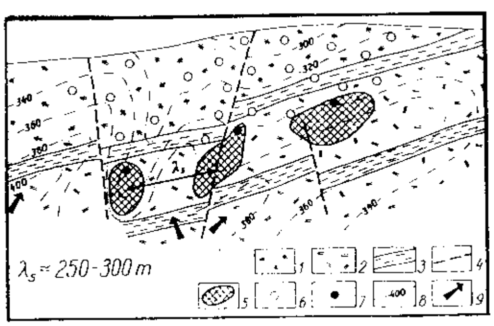
Observing the model of the Ducatskoye mining field (Fig. 7), it is obvious that the "step" of 800 m corresponds to the depth of the subvolcanic body, which is possibly an intermediate magmatic chamber occurring near the foot of the local volcanic-tectonic depression.

Model of the Ore body

Most of the studied ore bodies are controlled by normal faults and fissures (or in intra-formational fissures) and represent single veins, vein zones, and mineralized zones (or "mantos" type lodes). Ore shoots can be predicted within the ore body. Ore shoots contain main reserves of gold and silver, with the grades being one hundred or thousand times higher there than in common ores. The ore shoots usually occur in structural traps, which may be bends and branches of the ore-hosting fault, or intersections of crosscutting faults and dikes or siltstone caps.

Fig.7. Model of the mining field (cross-section) →
1 - rhyolite ignimbrite (extrusive facies); 2 - rhyolite (subvolcanic facies); 3 - marine terrigenous sedimentary rock; 4 - bunch of the orebodies.





← Fig.8. Model of the orebody (longitudinal section)
1 - rhyolite ignimbrite; 2 - rhyolite felsite; 3 - beds of argillite; 4 - fracture; 5 - ore shoot; 6 - essentially gaseous microinclusions in the vein minerals; 7 - microinclisions, which are homogenized either in gase, or in liquid phase at the same temperature on heating; 8 - paleo-isotherms; 9 - direction of the ore-bearing solution moving.

Fluid inclusions, homogenized both in the liquid and the gaseous phases at the same temperature, are present in vein quartz from the ore shoots. In addition, vapor-enriched inclusions are wide-spread above the ore shoots.

This is an indication that the fluid boiled at lower levels. The ore shoots and ore bodies in the bunches are characterized by a "step" of 150-300 m (Fig. 8). Deviations from the average statistical data are most typical at this level of the model. These deviations are accounted for by the alterations from pre-ore and post-ore tectonics.

DISCUSSION

The universality of the ore "step" is observed not only in the described levels (ore-bearing province - mining district - ore knot - mining field - ore deposit - ore body - ore shoot), but also at the planetary scale (distribution of the gold-bearing provinces around the Pacific ring), and also at the textural level (for example, in rhythmically banded textures).

Several hypotheses exist that are based upon the concept of the ore "step" and the question of its origin. Many investigators underline the tectonic nature of the ore "step", which is proved by numerous experiments on squeezing blocks of different materials (Pack, 1939 and Konstantinov, 1974). The fissures, formed by squeezing, are characterized by a regular distribution and can be used for ore "step" modeling.

Other authors stress a magmatic origin for the ore "step". Baryshev (1983) explains the "step" between polymetallic ore knots by the constant "step" of the corresponding basaltoid chambers, whose distribution is determined by viscous medium behavior in the power field of the Earth. The "step" is connected with the dominating length of the wave, which provides the most rapid growth of the dome at its crest. The roots of intermediate magmatic chambers grow from such domes in the surface of the primary magmatic chamber, and then these roots rise vertically. This hypothesis, accounting for the "wave nature" of the ore "step", is quite a good explanation for the existence of smaller deposits at a distance of 1/2 "step" from the known mining districts and ore knots.

Ueda (1980) assumes that the "step" between the deposits could be explained by the "hot spot" theory, according to which the continental plate moves with a constant speed and passes above the active ore-magmatic chamber, which "operates" over an equal time interval, like a sewing machine.

Soloviev (1978) supposed that geological structures of the central type of various ranks may be linked to intermediate energy chambers, occurring at the tectonospheric horizontal levels (Mohorovich boundary, asthenosphere boundary, etc.). Larger structures are related to deeper intermediate chambers, responsible for their origin.

Similar regularities were noted in this study in creating the various rank models of epithermal gold-silver deposits in Northeast Russia. We propose that the "step" between the model elements in each case corresponds to the depth of the intermediate ore-magmatic (energy) chamber, responsible for the ore mineralization of this level: 1) for the mining districts, at a depth of about 250 km near the asthenospheric boundary in the upper mantle; 2) for the ore knots, near the boundary of the crust at a depth of about 55-60 km; 3) for the mining fields, near the boundary between the Mesozoic and Paleozoic basement of the volcanic belt at a depth of about 10 km; 4) for ore deposits (bunches of ore bodies), near the basement of the volcanic-tectonic depressions at a depth of about 800 m.

We assume that the structural mechanism of ore "step" formation could be of a convergent character. For the lower levels (ore shoots), the tectonic factor is most important, and for the higher levels (mining fields, ore knots, mining districts) the magmatic factor is most significant. These factors may coincide in influence at some levels.

It is obvious, however, that this universal phenomenon revealed at the various levels and in different geological environments, should exist due to more common reasons. In all cases, the ore "step" is connected with the long-lived energy flow. The regularity at the high level is connected on the one hand, with the regular distribution (structuralization) of the energy within the flow, and on the other hand, is linked to the interaction of this energy with geological objects of different ranks. This interaction is based on the principle of maximum efficiency; a geological object changes towards the maximum absorption of the acting energy. For example, in the energy interaction, a regular (with some "step") system of stress and extension fissures is formed that optimally releases the outer pressure or, melting or crystallization takes place with maximum absorption of energy. The reasons and factors for the regular distribution of ore-bearing geological systems of various rank, deserve follow up studies.

CONCLUSIONS

1. Mining districts commonly represent large, often elongate volcanic-tectonic depressions, which are controlled by regional faults, which trend orthogonal to the volcanic-plutonic belt, with a "step" between them of about 250 km.

2. Ore knots are usually smaller isometric volcanic-tectonic depressions. Ore knots lie along the same regional faults as mining districts with a "step" of 55-60 km. Main elements of their model are volcanic depressions and domes in combination with the ore-controlling sections of the regional and bow-shaped magma-ore supplying faults.

3. Mining fields occur at the crossings and conjugations of the regional faults with a "step" of about 10 km. The mining district has a variety of the mining fields: A - in the volcanic-intrusive dome; B - above a subvolcanic body; C - in the exo-contacts of a granodiorite intrusion.

4. Ore deposits, as a rule, include several complex groups of ore bodies ("bunches"). The "step" between the groups is about 800 m.

5. Ore bodies are controlled by normal faults and fractures (or by bedding faults). They occur as veins, vein zones, and mineralized zones (or mantos) with ore shoots. Ore shoots are located in structural traps and have a large amount of vapor-dominated micro-inclusions with CO_2. The ore shoots (and ore bodies within the bunches) have a "step" of 150-300 m between them.

6. The authors propose, that a "step" in each case corresponds to the depth of an assumed main or intermediate ore-magmatic (energy) chamber, responsible for the development of this level: 1) for the mining districts, at a depth of about 250 km near the asthenospheric boundary in the upper mantle; 2) for the ore knots, near the crustal boundary at a depth of about 55-60 km; 3) for the mining fields, near the border between Mesozoic and Paleozoic basement of the volcanic belt at a depth of about 10 km; 4) for ore deposits (bunches of ore bodies), near the basement of the volcanic-tectonic depressions at a depth of about 800 m.

7. The suggested follow up to this study should include, the accumulation of statistical data for other regions, the explanation of the ore "steps" through energy concepts, and the transition to more aimful prediction based not only on the empirical regularities, but also on theoretical constructions.

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