Petrophysical Model of Chelopech Gold-Copper Ore Deposit

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Abstract: Petrophysical model of Chelopech gold-copper ore deposit is based on the assumption that every feature and conditions of the formation processes are saved in the physical properties of every material. More than 200 specimens of volcanic, volcano-sedimentary, sedimentary rocks, hydrothermal altered rocks and ores are investigated. They come from 2 mining horizons, 2 structural (up to 2000 m) vertical boreholes and surface. The samples are very irregularly distributed. For every sample more then 20-petrophysical characteristics were defined. Just for two, density and effective porosity the geostatistical modelling, using Geovariance software ISATIS was performed. The density shows stable increasing of the values in the depth. Variogram exponential model anisotropy was discovered in the horizontal plan. The largest range (336 m) is oriented in direction 105° and it is parallel of the largest fold in the region - Chelopech syncline and most important group of faults that controlled the Senonian volcanic activity. The anisotropy ratio is about 4.2. Thus, possibility for physical properties anisotropy discovering with geostatistical methods, could be a very powerful tool for tectonophysic reconstruction. The data regularisation in this case by simple migrations is performed. This helps a lot not just for construction of better experimental Variogram, but also for proper model fitting. Performing cross-validation analysis proves it. The experimental Variogram along every borehole are constructed for the regular grid line data. In very impressive and obvious way they show very different and contrast Variogram for the both variables - density and effective porosity. Obviously they reflect very different phenomenon. So geostatistics can be used for heterogeneity discovering of geological blocks and from other hands it leads to new hidden ruptures tracing.

Keywords: Chelopech; Gold-copper ore deposit; Petrophysical; Geostatistical; Modelling

1. INTRODUCTION

The paleotectonic conditions of hydrothermal ore systems functioning defined significant extend of spatial distribution and the scale of ore deposits. From other hand they are determine from physical parameters of oreforming environment and the paleotectonic stresses. The methods of petrophysic and geodinamic characteristics reconstructions of the compound multistage process of hydrothermal deposits forming make it possible to approach in a new way to prognosing payable ores in different scale.

The ore bodies in monotonous volcanic rocks localised without obvious relationship with any traditional geological structures create a number of problems for exploration. It is obvious that the using of other non-traditional methods is necessary in these cases. Presented with this paper research, including geostatistical modeling, aims to involve new petrophysical and geodynamical premises for ore body exploration.

2. GEOLOGICAL SETTING

The Chelopech gold-copper ore deposit is situated on the boundary between Srednogorie and Stara Planina structural zones in Alps-Himalayas orogenic belt 60 km. to the east of Sofia - capital of Bulgaria, Balkan Peninsula, SE Europe [Vladimirov, 1983, Popov et al., 1983]. It is tied to an area constructed of four complexes. The first consists of Precambrian metamorphites (gneisses, Ms-schists, amphybolites, etc.) that is thrustfolded upon second complex of Palaeozoic metamorphites (argillaceous schists, phyllites, quartzites, etc.) in the time of Austrian phase of orogenesis. The third consists of sedimentary, subvolcanic and effusive trachyandesit-dacite and trachyandesite Upper Cretaceous aged rocks. The last one includes the Quaternary sediments.

The ore bodies are with irregular, lens-like or sometimes tube-like form [Popov et al., 1983 and 1989]. The borders are gradual and mineralization contains 59 minerals and many trace elements such as Au, Ag, Ge, Ga, Sn, Bi, Se, Te, V, Ti, Co, Cr, etc. The mine ore minerals are pyrite, tennantite, chalcopyrite, luzonite, enargite, bornite and a bit of galenite and sphalerite. The ore bodies are localized in monotonous volcanic rocks without obvious relationship with any traditional geological structures.

3. METHODS AND MATERIALS

The Structural petrophysical analysis [Starostin, 1984] was applied with two main research methods: 1) Free water saturation method - consist seven fixed in the time specimens weightings in the process of water saturation; 2) Ultrasonic waves velocities (P- and S-waves) determinations.

By computer processing the following parameters was obtained: effective porosity (Pef, the % of the total volume of rock that consists of interconnecting voids), conditional momentary saturation (A, reflects the saturation in the first few minutes (20) and in fact corresponds to liquid permeability); quantity of large ($P1>10^{-2}$mm), medium ($P2=10^{-2}$ - 10^{-4} mm), small ($P3<10^{-4}$ mm) pores, saturation constant (B, corresponds to exponential part of the saturation and it is independent of total porosity); density(ρ); Poisson's ratio(μ, the ratio of the lateral strain to the longitudinal strain, in a body that has been stressed longitudinally within its elastic limit); Young's modulus(E, the ratio of applied stress of cross section to increased length, N/m^2 = Pa); Shear modulus(G, the ratio of applied tangential stress to angular deformation), Debye temperature(θ, reflects substance structure stability, strength of connections between its separate elements, defects presence and their frequency, K) etc. [Starostin, 1984; Vladimirov, 1990].

For easier interpretation of so many physical characteristics, an integral Complex petrophysical coefficient was involved [Starostin, 1984]. The calculation type and set of properties used depend of the geologic process will be discussed. The Complex petrophysical coefficient (Cpc) introduced in this study reflects the behavior of the investigated materials (rocks) in potential hydrothermal process. Its positive and big values define these rocks as a favorable for hydrotherms flowing media and negative - stops them.

Computer data processing includes statistical methods and cluster analysis, once only for petrophysical data, second time only for geochemical data and finally together for both types of data.

About a hundred different rock and ore samples (some of them space oriented) from Chelopech ore deposit was investigated.

Geostatistical analysis and modelling was performed according to Journel and Huijbregts, [1978].

4. RESULTS AND DISCUSSION

Thus in the different cases are received 7 or 8 groups of rocks united in two ore petrophysical-geochemical complexes (Table 1, 2, Figure 3).

Table 1. Minimal, maximal and mean values of physical properties in ore petrophysical-geochemical complexes of Chelopech ore deposit.

	Cpc	Pef	A	ρ	E	HB
	-	%	%	t/m^3	10GPa	kg/mm^2
Mean for the first complex	0.3	3.21	1.05	2.61	4.48	101
Mean for the second complex	-0.25	1.17	0.53	2.87	6.25	154
Minimal value	-0.65	0.29	0.3	2.58	3.67	45
Maximal value	0.76	5.09	1.93	3.03	7.62	205

Table 2. Minimal, maximal and mean values of element concentration in ore petrophysical-geochemical complexes of Chelopech ore deposit.

	Cu	Ag	Zn	Pb	Ba	Sr
	ppm	ppm	ppm	ppm	ppm	ppm
Mean for the first complex	280	0.47	607	194	228	60
Mean for the second complex	4451	11.75	941	817	1807	400
Minimal value	167	0.3	50	119	170	42
Maximal value	5780	22.8	2140	2067	3250	810

The first of them includes rocks with good filtration properties and low metal contents. In this complex the hydrotherms flowed intensively and there weren't conditions for deposition of ore components at time of ore formation. If they were in it, were extracted and carried away.

The second complex includes rocks with bad filtration capabilities, high values for elastic-density properties and high contents of ore and other trace elements. At the time of ore formation the rocks of this complex were barriers-concentrators for ore substance. They build blocks with wedge-shaped form. The ore bodies are located in their peripheral areas at the places of their wedging.

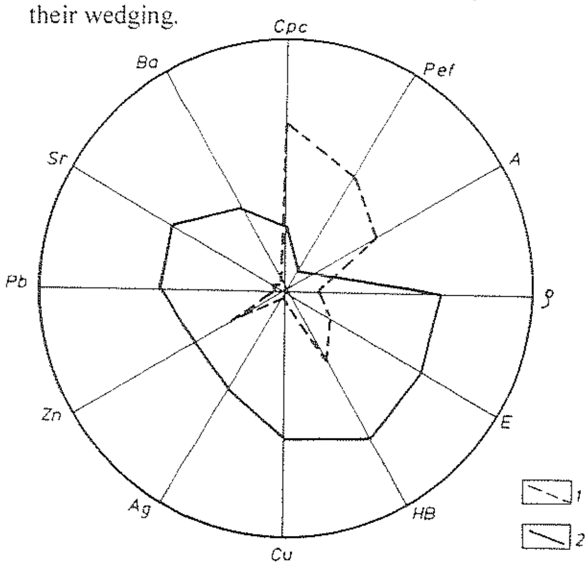

Figure 1. Diagram of mean values of physic - mechanical properties and element concentration in orepetrophysical - geochemical complexes of Chelopech ore deposit (see Table 1, 2) 1 - First complex; 2 - Second complex.

There are two stages of formation of structures and ore bodies of the deposit. The first, sin-volcanic was reconstructed by measuring of velocities of ultrasonic waves in different directions in oriented samples - ultrasonic structural petrophysical analysis and second post-volcanic by tectonophysic analysis. The sin-volcanic stage includes two substages - early and late. At the early substage compressive forces of paleotectonic stress fields were oriented in a NW direction and the stretch forces in a NE direction. The main part of the ore was deposited then.

At the late substage an inversion of the paleotectonic regime occurred. Compressive forces acted in a NE direction and stretch forces in a NW direction. Then the typical process was remobilization of ore components accompanying the formation of little ore bodies and final formation of main ore bodies, with insignificant addition of a new ore substance.

Keeping in the mind volcanic nature of the ore field [Starostin and Vladimirov, 1986] the blocks with vertical or steep orientation of compressive forces were outlined. Those blocks were areas where the hydrotherms flowed there and ore bodies are localised around them.

At the time of post-volcanic stage five paleotectonic regimes were reconstructed [Gzovski, 1975]. The compressive forces were oriented in horizontal direction and stretch forces in a vertical direction.

Just for two, density and effective porosity the geostatistical modeling, using Geovariance software ISATIS, was performed [Vladimirov and La Loch, 1996]. The density shows stable increasing of the values in the depth. In the time of Variogram fitting the exponential model anisotropy was discovered in the horizontal plan (Figure 2). The largest range (336 m) is oriented in direction 105° and it is parallel of the largest fold in the region - Chelopech syncline and most important group of faults, which controlled the Senonian volcanic activity. The anisotropy ratio is about 4.2. Such rock physical properties discovering are very complicated process in geology. Usually for this reason is necessary to collect and study large amount of oriented samples. Their investigation is complicated and long lasting technology. Thus, possibility for physical properties anisotropy discovering with geostatistical methods, could be a very powerful tool for tectonophysic reconstruction. It will reduce in some extend necessity of oriented samples and will increase geodynamical investigations.

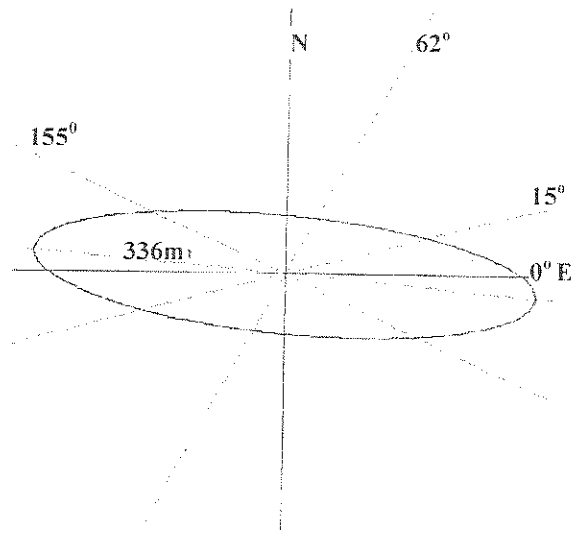

Figure 2. Horizontal Variogram anisotropy scheme

The data regularisation in this case by simple migrations is performed. This help a lot not just for construction of better experimental Variogram, but also for proper model fitting. Performing cross-validation analysis proves it. The experimental Variogram along every boreholes are constructed for the regular grid line data (Figure 3, 4, 5, 6). In very impressive and obvious way they show very different and contrast Variogram for the both variables - effective porosity and density (Table 3, 4). Obviously they reflect very different phenomenon. So geostatistics, in this case Variogram analysis can be used for heterogeneity discovering of geological blocks and from other hands it leads to new hidden ruptures tracing.

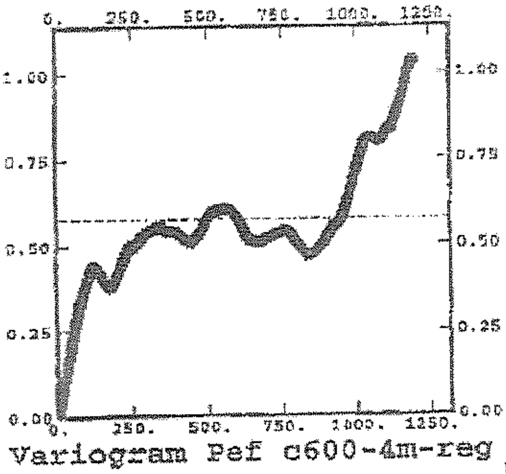

Figure 3. Effective porosity experimental Variogram for borehole c600.

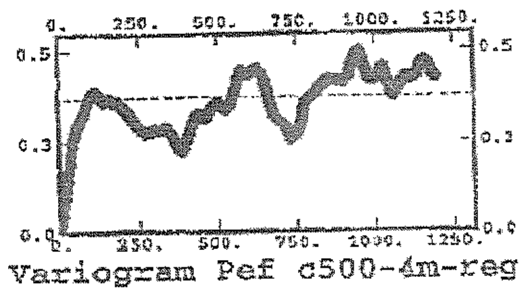

Figure 4. Effective porosity experimental Variogram for borehole c500.

Table 3. Effective porosity experimental Variogram parameters along regularised boreholes.

Borehole #	Range	Sill
500	115 m	0.4
600	760 m	0.6

Table 4. Density experimental Variogram parameters along regularised boreholes.

Borehole #	Range	Sill
500	245 m	0.0055
600	750 m	0.0286

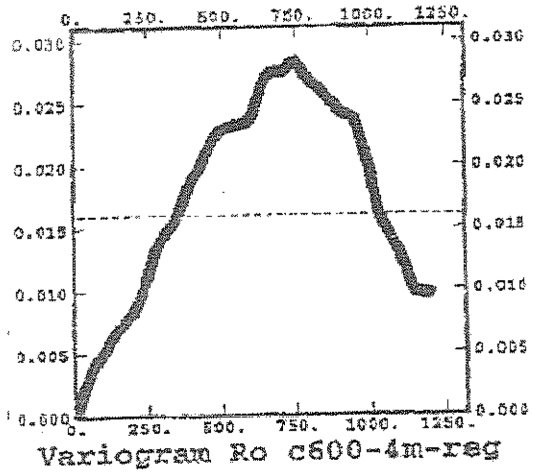

Figure 5. Density experimental Variogram for borehole c600.

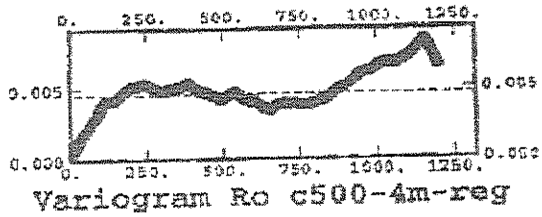

Figure 6. Density experimental Variogram for borehole c500.

5. CONCLUSIONS

The Structural petrophysical analysis (SPA) is based on theoretically established and experimentally verified conformity to natural laws and correlation between physical properties and structures of solid.

First of all SPA has practical significance as a study method for structures of ore fields and deposits. In fact, this is an optimum system, allowing with minimum efforts to obtain structural information, by quality and quantity corresponding to other directions of ore formations and structures study. It is very useful to include new structural petrophysical premises in the metallogenesis.

Moreover, petrophysical properties of rocks and ores may have inestimable significance for environmental protection, mining and constructive activity, for biotechnological extraction of metals directly from rock massif in the future, etc. This method is very simple, productive, cheap and sufficiently precise.

Possibility for physical properties anisotropy discovering with geostatistical methods, could be a very powerful tool for tectonophysic reconstruction. It will reduce in some extend necessity of oriented samples and will increase geodynamical investigations.

Variogram analysis of geostatistics can be used for heterogeneity discovering of geological blocks and from other hands it leads to new hidden ruptures tracing.

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