

# Geological structure and conditions of formation of Strizhkovskoe barite-polymetallic deposit (Ore Altai)

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**Abstract** Strizhkovskoe barite-polymetallic deposit is a typical medium-low-temperature hydrothermal-metasomatic deposit.

It's located within north-west part of Zmeinogorsk-Bystrushinskiy downfold; host rocks are volcano-terrigenous Devonian rocks. Ore bodies are related to sublatitudinal and submeridional faults intercrossing.

Wallrock quartz-chlorite-sericite metasomatites formed prior to ores formation. Ore mineralization process began in Middle Devonian. Main ore minerals are sphalerite, galena, and chalcopyrite. Also there are gold and silver occurring as electrum, acanthite; silver is present in fahlores as an isomorphous admixture. Formation of the deposit subdivides into two main stages and five phases; according to obtained results of isotope study of the sulfides, it's possible to conclude that there was a mixed source of ore matter (mantle source replacing with crust source). The temperature of main ore formation stage varied from 230 to 180 degrees. Solutions salinity varied from 9 to 15 % wt of NaCl equiv. According to fluid inclusions study results, the solutions consisted of water and following compounds CO<sub>2</sub>, NH<sub>3</sub>, SO<sub>2</sub>, HCO<sub>3</sub>.

## 1. Introduction

Strizhkovskoe deposit is one of in Karamyshevsk group of deposits, which includes Karamyshevskoe I and II deposits and a number of ore occurrences, and is located at northern and eastern periphery of Karamyshevo village of Zmeinogorsky area located in the northwest part of Ore Altai (figure 1). The deposit was discovered in 1781, but its exploration was going interruptedly [1]. At the present moment it's considered as a partly explored one. There are multiple-dislocated lower Paleozoic metamorphic rocks and lower and middle Devonian volcanogenic-sedimentary rocks. Devonian rocks have subhorizontal attitude [2]. The thickness of the ore-bearing part of Devonian rocks (overlying the Korbalkhinskaya series rocks) is quite regular and is about 65 – 70 m [3].

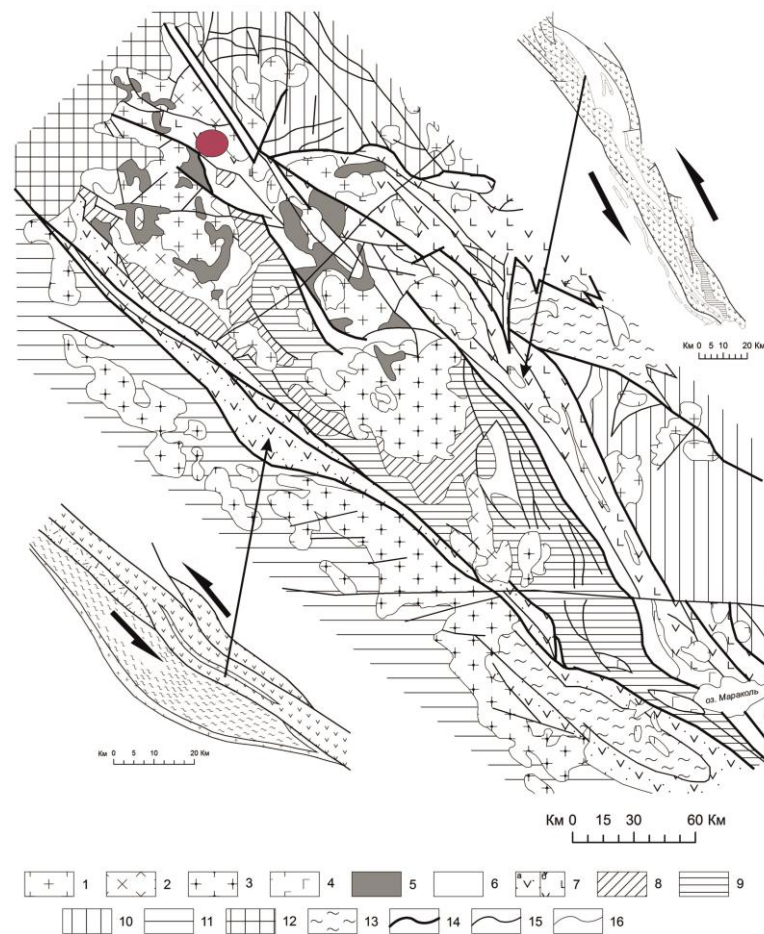
## 2. Object and methods of research

Data on ore and barren minerals composition and pictures of mineral associations and individuals interrelations in back-scattered electrons (BSE) mode was obtained by carrying out the electron microprobe analysis with use of scanning electron microscope Tescan Vega II LMU, which is equipped with energy-dispersive spectrometer (with Si(Li) Standart detector) INCA Energy 350, operated at an accelerating voltage of 20 kV, a beam current of 5 nA, a beam size of 1–2 μm and 120s count time. The operation conditions were the same for all minerals. The results were checked against natural minerals and synthetic phases used as standards (MAC 55 Standard Universal Block Layout+F/Cup, Micro-Analysis Consultants Ltd, UK) for calibration.



Microelement composition was studied by inductively coupled plasma mass spectrometry (ICP–MS) with use of Agilent 7500 x spectrometer. These analyses were carried out at the collective use center «Analytic Center of Natural Systems Geochemistry» of Tomsk State University (Russia). Au and Ag contents determination was carried out by atomic absorption spectroscopy. Thermo- and cryometry of fluid inclusions were conducted with use of Linkam equipment. This analysis was carried out at the Analytical Center of multielement and isotopic research of Sobolev’s Institute of Geology and Mineralogy SB RAS (Russia).

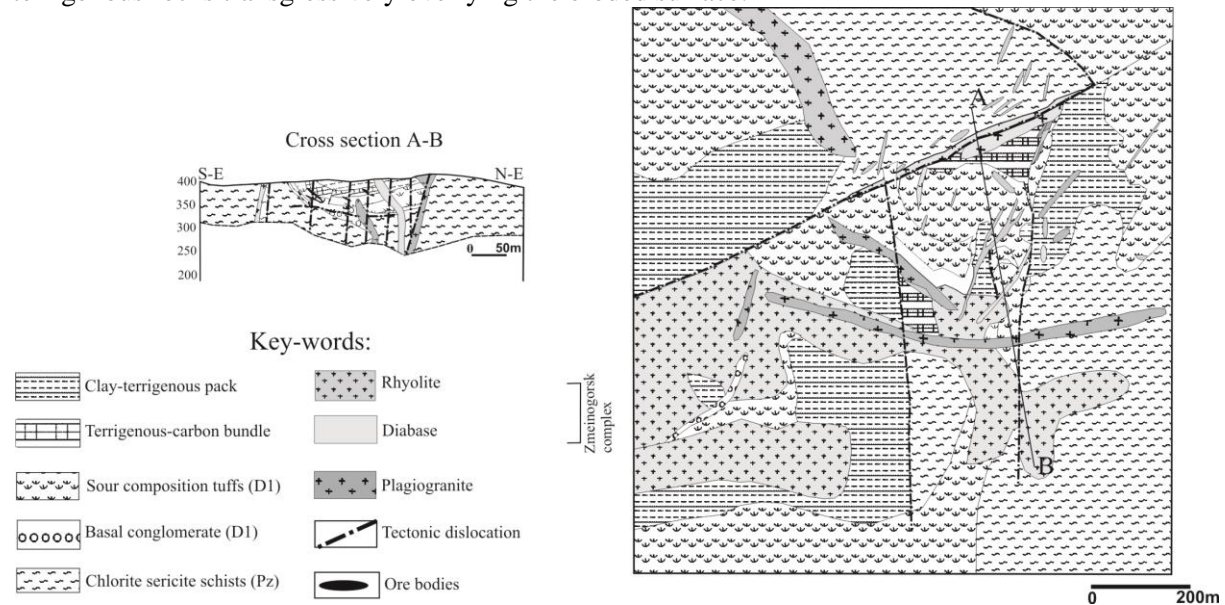
Variations of stable sulfur isotopes contents were studied at the stable isotopes laboratory of Far East Geological Institute of FEB RAS.



**Figure. 1.** Ore Altai megatrough. 1 – Devonian and predevonian (?) zmeinogorsky complex granitoids, 2 – Carboniferous aleysky complex granitoids, 3 – early Permian kalbinsky complex granitoids, 4 – unsubdivided mafic intrusions (D, C, P), 5 – metamorphic complexes (O-S?), 6 – unsubdivided strata, 7 – boundary depression zones strata a) middle and upper Devonian and b) lower, middle and upper Devonian, 8 – middle and upper Devonian bystrushinsky and beloubinsky synclinorium strata, 9 – upper Devonian and lower Carboniferous Kalba-Narym zone strata, 10 – Altai Baikhalides and Caledonides, 11 – Kalba-Narym zone, 12 – Barnaul sag, 13 – dynamometamorphic rocks of basement highs (R-C<sub>1</sub>), 14 – first-order suture zones, 15 – disjunctive faults, 16 – structural-compositional complexes boundaries.

### 3. Geological position of deposits

Main features of Strizhkovskoe deposit constitution are determined by three main structural elements: horst-like dome-shaped block of dislocated greenschists of pre-Devonian basement (figure 2), which compose northern peripheric part of West Strizhkovskoe part of the deposit; a system of sublatitudinal (older ones) and submeridional faults and blocks of Middle Devonian (Eifelian) volcanogenic-terrigenous rocks transgressively overlying the eroded surface.



**Figure 2.** The scheme of geological structure Strizhkovskoe barite-polymetallic deposit.

There are two groups of ore bodies: ore bodies of subvertical shear zones that associate with the largest submeridional faults and disjunctive structures; vein type stockwork ore zones related to systems of small joined cracks (with no considerable rocks displacement).

Mostly ore mineralization belongs to stockwork type and has lead-zinc composition. There is irregular distribution of main components and low copper content in the ores. Cu:Pb:Zn ratio is about 1:3:6.

Altered rocks of the deposit are widely spread: these are wallrock metasomatites having a quartz – chlorite – sericite, quartz – sericite or chlorite – quartz composition [4]. Rare earth elements minerals presence is peculiar for these metasomatites.

According to their mineral and chemical composition Strizhkovskoe deposit ores either belong to polymetallic type (copper-lead-zinc ores with barite) or copper type. Polymetallic ores are located among Devonian rocks while copper ores are located among Lower Paleozoic rocks of the bottom of the ore-bearing section.

### 4. Results discussion and conclusion

Polymetallic ores of Strizhkovskoe deposit are distributed within lower structural level of Lower Devonian rocks mostly. There is a quite distinct vertical zonality expressing in predominance of considerably polymetallic ores within lower parts mostly and polymetallic and barite-polymetallic ores within upper parts. As a rule, so called considerably polymetallic ores are significantly predominant within lower argillo-terrigenous member of Lower Devonian, while polymetallic and barite-polymetallic ones are predominant in overlying rocks. In such a way, there is a gradual replacement of considerably copperish ores with polymetallic ores with lower copper contents and higher lead and zinc contents from bottom to top.

Polymetallic ores contain ore minerals of lead, zinc and copper; there are more of lead and zinc in polymetallic ores. According to V. D. Veligzhanina, following average contents are typical for such ores of Strizhkovskoe deposit: lead – 2,85%; copper – 0,73%; zinc – 7,14%. Considerably copper ores

have increased copper content and very low lead and zinc contents, what makes them almost monomineral (chalcopyrite). Such ores contain 0,00-0,17% of lead, 0,51-5,1% of copper and 0,00-2,32% of zinc.

Besides these main components there also are (according to ICP-MS results, g/t): Sc (0,06-0,7), Ti (3,0-205,0), V (0,5-10,0), Cr (0,1-4,5), Co (1,2-22,0), Ni (0,3-4,7), Ga (0,5-6,0), Rb (0,5-14,0), Sr (0,1-5,0), Y (0,03-1,5), Zr (0,2-9,0), Nb (0,02-0,9), Cs (0,03-0,1) in polymetallic ores; Sc (0,01-0,3), Ti (5,0-41,0), V (4,5-8,0), Cr (0,1-1,8), Co (9,7-36,0), Ni (0,3-10,0), Ga (2,0-10,0), Rb (3,0 -8,0), Sr (2,0-192,0), Y (0,2-1,0), Zr (0,5-3,0), Nb (0,03-0,25), Cs (0,03-0,1) in barite-polymetallic ores; Sc (3,5-9,0), Ti (400,0-2100,0), V (8,0-60,0), Cr (10,0-43,0), Co (3,0-25,0), Ni (11,0-32,0), Ga (2,5-12,0), Rb (0,1-0,7), Sr (5,0-11,0), Y (1,5-8,5), Zr (15,0-70,0), Nb (1,5-5,0), Cs (0,01-0,15) in copper ores from Lower Paleozoic members. Some researchers in the ores of the Zmeinogorsky ore region celebrate indium [5].

Altered quartz-chlorite-sericite and quartz-sericite wallrocks are pre-ore formations of the deposit. Their thickness varies from 3 to 25 m. Main minerals are quartz, sericite, chlorite, secondary ones are rutile (leucosene), zircon, apatite, accessory ones are monazite and xenotime [6].

Ores may have hypidiomorphic, fine-medium-grained, emulsion, crush, replacement, reticulate textures and massive, impregnated, streaky, breccia-like structures.

Strizhkovskoe barite-polymetallic deposit ores are composed by the following ore minerals: pyrite, sphalerite, galena, chalcopyrite. Fahlores are secondary. Also there are such rare minerals as acanthite, hessite, electrum. Gangue minerals are quartz, barite, less often – calcite.

Chemical composition of main sulfide minerals of Strizhkovskoe barite-polymetallic deposit was studied by means of X-ray spectral microanalysis results. Average chemical composition of the main sulfide minerals is given in Table 1.

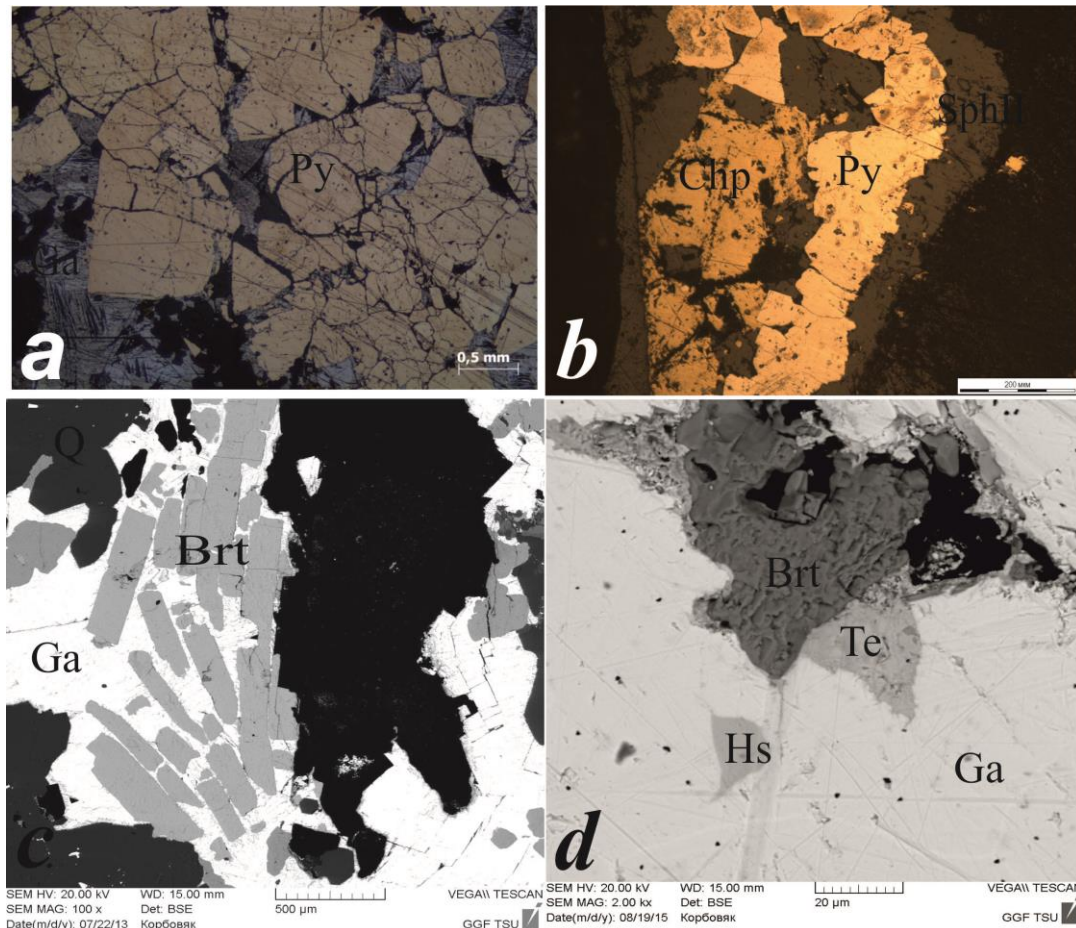
**Table 1.** Average chemical and isotopic composition of major sulfides of distinguished complexes.

Minerals	Element, wt. %											Central cases of $\delta^{34}\text{CDT}$ , ‰	
	S	Fe	Cu	Zn	As	Se	Ag	Cd	Sb	Pb	sum		
Pyrite I	Sulfides of the pre ore stage											-0.3‰	
	53.0	46.1	-	-	-	-	-	-	-	-	-		99.4
Pyrite II	Sulfides of the first (I) complex											1.3‰	
	53.2	46.15	-	-	0.20	-	-	-	-	-	-		99.5
Chalcopyrite	34.78	30.34	34.66	-	-	-	-	-	-	-	-	99.78	1.9‰
Sphalerite I	32.50	-	0.50	66.80	-	-	-	-	-	-	-	99.70	2.3‰
Galena	Sulfides of the second (II) complex											3.5‰	
	13.24	-	-	-	-	0.34	-	-	-	-	86.13		99.71
Sphalerite II	31.10	5.20	-	63.53	-	-	0.4	-	-	-	-	99.83	4.3‰
Tetrahedrite	27.60	1.70	33.30	6.70	4.60	-	6.35	-	19.85	-	-	100.1	6.4‰
Galena	13.24	-	-	-	-	0.34	-	-	-	-	86.13	99.71	3.8‰

There is 20-25% of pyrite in the ores. Its' chemical composition is: S – 53,20%, Fe – 46,15%, As – 0,20%. Pyrite grains have cuboid shape (figure 3 a); their sizes vary from 1 to 3 mm. There two pyrite generations in the ore. Pyrite of I generation occurs as separate grains within wallrock metasomatites. Pyrite of II generation was formed within the ores. Pyrite of copper-zinc and barite-polymetallic ores is hypidiomorphic and xenomorphic. Interstices between pyrite grains are filled with xenomorphic fine-grained galena aggregate. Grain boundaries are distinct and sharp. Crush texture is observed;

sometimes there is galena substituting pyrite in the cracks. Replacement structure when pyrite grains are replaced by hypidiomorphic chalcopyrite grains is observed in some polished sections.

Galena mostly fills the interstices between hypidiomorphic and idiomorphic pyrite and sphalerite grains (figure 3 a, d). This is the evidence that galena formed later than pyrite and sphalerite did. Galena aggregates replace hypidiomorphic grains of pyrite making a replacement texture. Also there are sphalerite relics within holocrystalline galena aggregate. Boundaries between different minerals are indistinct, corroded.



**Figure 3.** The basic ore structures. a - Granulated pyrite grains in polymetallic ore.

Note. Py - pyrite, Ga – galena; b - pyrite and chalcopyrite aggregates, replaced by a later sphalerite aggregate c- short columnar barite grains in the galena aggregate; d - segregation of native tellurium, hessite, in galena.

There is 20-30 % of sphalerite in barite-polymetallic ores and 50% of it in copper-lead ores. There are two generations of sphalerite (figure 3 b). The first generation consists of colorless hypidiomorphic grains, sizes of which vary from 0,1 to 5 mm. Chemical composition of first generation sphalerite is: S – 31,50%, Cu – 0,50%, Zn – 66,80%. Brown colored grains from 0,2 to 3-4 mm in size belong to the second generation. Its' chemical composition is: S – 31,10%, Fe – 5,50%, Zn – 63,53%. Second generation sphalerite is more ferriferous than first generation sphalerite. There is emulsion texture observed in massive ores formed by sphalerite and chalcopyrite that indicates that both minerals formed almost simultaneously. It's important to notice that such texture is typical for polymetallic ores of Ore Altai deposits in general [7,8]. Boundaries between sphalerite and galena grains are indistinct and corroded; it's possible to conclude that sphalerite formed earlier while galena formed after it,

sometimes replacing sphalerite grains. Second generation sphalerite aggregates contain cracks that are filled with lately formed calcite.

There is about 50% of chalcopyrite in copper-zinc ores, and about 15-20% of chalcopyrite in barite-polymetallic ores. Chemical composition of chalcopyrite is: S – 34,78%, Fe – 30,34%, Cu – 34,66%. Chalcopyrite is observed in close intergrowth with sphalerite and galena as a part of massive aggregates. Chalcopyrite grains are hypidiomorphic; their sizes vary from 0,01 to 0,2 mm. It forms emulsion texture together with sphalerite. In some polished sections chalcopyrite is observed to form replacement and reticulate textures with lately formed chalcocite.

Quartz is a gangue mineral present in barite-polymetallic ores. Its' content is about 10-20 %. It forms massive aggregates within veinlets. Grains from 0,1 to 5 mm in size have milky white color. Quartz is intergrowing with barite. They both fill the veinlets among sulfide aggregates, sometimes within them being cracked due to tectonics.

Barite makes up 5-10 % of copper-lead ores and 30-40% of polymetallic ores (figure 3 c). Barite grains have platy and tabular shape. Barite is present in almost all of the ores excluding considerably polymetallic (copper-lead) ones. Tabular barite grains have sizes from 1 to 10 mm. Barite fills the interstices between sulfides along with third generation quartz.

According to X-ray spectral microanalysis results there also are following minerals: tetrahedrite (S – 27,60%, Fe – 1,70%, Cu – 33,30%, Zn – 6,70%, As – 4,60%, Ag – 6,35%, Sb – 19,85%), acanthite (S – 12,2%, Cu – 0,75%, Ag – 86,92%), hessite (Ag – 62,0%, Te – 37,73), native tellurium (S – 0,20%, Te – 99,93%). Usually their sizes don't exceed 20-30  $\mu\text{m}$ . Boundaries with previously formed minerals (such as galena, pyrite and sphalerite) are quite distinct.

According to study of interrelations between minerals composing ores and wallrocks two stages of mineral formation – magmatic and hydrothermal – were indicated. Host rocks (tuffs) formed during the magmatic stage. Minerals such as first generation quartz, zircon, apatite, monazite, xenotime, titanite (which leucogene formed upon during the hydrothermal stage) formed during the magmatic stage. After volcano-sedimentary host rock forming they underwent metasomatism that corresponds to hydrothermal stage of mineral formation. It subdivides to pre-ore stage, I ore formation stage, II ore formation stage and post-ore stage.

Such minerals as calcite and barite are forming during the post-ore stage. They form a net of small cracks upon previously formed sphalerite II and quartz III.

In addition, in order to estimate the temperature of ore and wallrock formation following minerals were studied: wallrock quartz, sphalerite of first and second generations, barite and calcite.

Conclusions: host rock alternation (pre-ore stage) took place the following way: rocks were silicified, alkalis and alumina were released. Second generation quartz, chlorite, sericite, leucogene (upon titanite) and first generation pyrite formed as a result of these processes. After that hydrothermal fluids became metal-bearing. The bulk of sulfide minerals and third generation (I and II ore stages) quartz formed as a result. The sulfides include second generation pyrite, first and second generations sphalerite, chalcopyrite, galena, tetrahedrite, hessite, acanthite, electrum. I and II ore stages distinction was made according to I and II sphalerite formation since sphalerite of different generations has differences in crystal structure characteristics and chemical composition.

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